SOCIAL TOUCH TECHNOLOGY

EXTENDING THE REACH OF SOCIAL TOUCH
THROUGH HAPTIC TECHNOLOGY

GIJS HUISMAN

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EXTENDING THE REACH OF SOCIAL TOUCH THROUGH HAPTIC TECHNOLOGY

DISSERTATION

to obtain
the degree of doctor at the University of Twente,
on the authority of the rector magnificus
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on account of the decision of the graduation committee,
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by

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Born April 4th, 1985
in Den Helder, the Netherlands

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Almost but not quite entirely unlike tea

DOUGLAS ADAMS

ENGLISH SUMMARY

The skin not only protects the body from harm but, through receptors found in the skin, also enables the sense of touch. The sense of touch is used to obtain information about the world outside the body, for example, the shape and weight of a book or the texture of its cover. However, the sense of touch also has an important *affective* function that becomes clearly apparent in social touch interactions such as hugging someone or stroking someone's back.

Social touch plays a vital role in the physical, cognitive, and emotional development of infants, can have positive effects on a person's well-being, can affect attitudes and behaviors towards the toucher, and is important in the communication of affect and emotions. Despite its importance in interpersonal communication social touch capabilities are lacking in current communication technology. Therefore, here, through a thorough discussion of a large body of literature, and several studies, a broad perspective on haptic technology for social touch interactions, referred to here as *Social Touch Technology*, is provided.

The Tactile Sleeve for Social Touch (TaSST) was developed to enable research into mediated social touch by allowing two individuals to engage in social touch at a distance by touching their own forearm. In an iterative design process several versions of the TaSST were developed, all featuring a fabric touch-sensitive input layer and an output layer consisting of vibration motors. In a first explorative study it was found that participants mainly touched the TaSST by poking or press-

ing its surface. The second TaSST featured a redesigned input and output layer and was used in a study into emotional expression through touch. It was found that while participants did use socially relevant touches to express emotions, sensor data did not show clear patterns in the expressions. The final version of the TaSST was developed in collaboration with caregivers of people with congenital deafblindness to explore possibilities for extending their clients' communication capabilities.

Work on the type of vibrotactile feedback produced by the TaSST was extended by investigating a vibrotactile apparent motion illusion. This apparent motion illusion can be described as 'vibrotactile stroking'. It was found that pleasantness judgments of vibrotactile stroking sensations followed a velocity-dependent inverted u-curve similar to that found for pleasantness judgments of actual stroking touches. Further investigation focussed on observed stroking touches at different velocities and applied by a human hand or by objects with varying levels of human likeness. It was found that stroking velocity was the most important determinant of pleasantness judgements and that these judgements again followed a velocity-dependent inverted u-curve similar to that found for felt stroking touches.

Visuo-tactile social touch was implemented in a touching virtual agent system. In the first design participants wore a vibrotactile display on their forearm and observed their arm through an augmented reality display. Participants could thus see and feel touches from a virtual agent whose upper body was visible on a computer monitor. The touching virtual agent setup inspired a study in which participants wore vibrotactile displays on their arms and used a hand-held augmented reality display to look around the room in which two virtual agents were present. One virtual agent applied casual social touches to the participant's upper arm during a collaborative or competitive game. It was found that, independent of the type of game, touches by the virtual agent enhanced feelings of social presence and made the virtual agent seem to have a warmer personality.

The work presented here offers insights into the design of devices for mediated social touch, stresses the importance of multimodal cues in touch perception, and provides suggestions for the implementation of social touch capabilities in augmented reality virtual agent systems.

NEDERLANDSE SAMENVATTING

De huid beschermt niet alleen het lichaam, maar ligt ook, middels verschillende receptoren in de huid, aan de basis van het tastzintuig. De tast wordt gebruikt voor het verwerven van informatie over de wereld buiten het lichaam, bijvoorbeeld de vorm en het gewicht van een boek, of de textuur van de kaft. Echter, het tastzintuig vervult ook een belangrijke *affektieve* functie die vooral een rol speelt bij sociale aanrakingen tussen mensen.

Sociale aanrakingen spelen een cruciale rol in de fysieke, cognitieve en emotionele ontwikkeling van kinderen, kunnen positieve effecten hebben op iemands welzijn, kunnen de houding en het gedrag van iemand ten opzichte van de aanraker beïnvloeden en zijn belangrijk voor het uitdrukken van affect en emoties. Ondanks de belangrijke rol van sociale aanrakingen in interpersoonlijke communicatie biedt huidige communicatietechnologie geen mogelijkheden voor sociale aanraking. Om deze reden wordt hier, door middel van uitgebreid onderzoek naar literatuur en verschillende studies, een breed perspectief gegeven op haptische technologie voor sociale aanraking. Dit wordt hier *Social Touch Technology*, oftewel sociale aanrakingstechnologie, genoemd.

De *Tactile Sleeve for Social Touch* (TaSST) werd ontwikkeld om onderzoek naar aanraking op afstand mogelijk te maken. Twee mensen werden daarbij in staat gesteld elkaar op afstand aan te raken door hun eigen onderarm aan te raken. In een iteratief ontwerpproces zijn verschillende versies van de TaSST ontwikkeld, elk met een stof-

fen aanrakingsgevoelige inputlaag en een outputlaag bestaande uit vibratiemotoren. Uit een eerste exploratief onderzoek bleek dat proefpersonen de TaSST vooral aanraakten door te prikken en te drukken. Bij de tweede versie van de TaSST werden de input- en outputlaag verbeterd. De tweede TaSST werd gebruikt bij een onderzoek naar de uitdrukking van emoties door middel van aanraking. Hieruit bleek dat proefpersonen wel sociaal relevante aanrakingen gebruikten om emoties uit te drukken, maar dat in de sensordata geen duidelijke patronen te herkennen waren. De laatste versie van de TaSST werd ontwikkeld in samenwerking met verzorgers van mensen met doofblindheid om uitbreiding van de communicatiemogelijkheden voor hun cliënten te exploreren.

Een uitbreiding van het werk omtrent de vibrotactiele feedback van de TaSST richtte zich op een vibrotactiele bewegingsillusie. Deze illusie kan omschreven worden als ‘vibrotactiel aaien’. Uit onderzoek bleek dat hoe aangenaam een vibrotactiele aaibeweging voelt afhankelijk was van de snelheid van de beweging. Net als bij echte aanraking volgden de beoordelingen een omgekeerde u-curve afhankelijk van de aaisnelheid. De focus van vervolgonderzoek lag op het observeren van aaien met verschillende snelheden. De aaibewegingen werden toegediend door een mens of door objecten met verschillende menselijke kenmerken. Uit het onderzoek werd duidelijk dat de snelheid van aaien het belangrijkste was voor de mate waarin de geobserveerde aai aangenaam werd bevonden. De beoordelingen volgden opnieuw een omgekeerde u-curve afhankelijk van de aaisnelheid.

Visueel-tactiele sociale aanraking werd geïmplementeerd in een systeem met een virtueel personage. In een eerste ontwerp droegen proefpersonen een vibrotactiel display om hun onderarm en observeerden zij hun arm door een augmented reality scherm. Proefpersonen konden aanrakingen van het virtuele personage dat zichtbaar was op een computerscherm dus zowel voelen als zien. Dit systeem lag aan de basis van een studie waarin proefpersonen vibrotactiele displays om hun armen droegen en een augmented reality scherm vasthielden. Door het scherm konden zij twee virtuele personages in de ruimte waarnemen. Één van de personages diende tijdens een spel, dat of collaboratief of

competitief was, een aanraking toe aan de arm van de proefpersonen. In beide speltypen leidde aanraking tot sterkere gevoelens van sociale aanwezigheid van het virtuele personage en werd de persoonlijkheid van dit personage als ‘warmer’ omschreven.

Het hier beschreven werk biedt inzichten in het ontwerp van apparaten voor aanraking op afstand, onderschrijft het belang van multimodale signalen in de perceptie van aanraking en biedt suggesties voor het implementeren van sociale aanraking in augmented reality systemen met virtuele personages.

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There probably are not many people who are able to claim that they brought their professor to a first date. Still fewer, provided that they would be able to make this claim, would be inclined to make this fact known to the world. Nevertheless, I can quite confidently make this claim and proudly admit to it here.

It is safe to say, then, that Dirk has been more than just my promotor, and mentor in the academic sense. I am enormously grateful to have been given the chance to pursue a PhD under Dirk's supervision, but I am even more grateful to have gained a friend. Especially one that does not shy away from sharing stories of his punk past, talking about must-read books of obscure authors, and share his interests in gastronomy.

The early stages of my PhD were particularly challenging, to say the least - coming up with a suitable topic of study is much harder than you may think. Dirk once described it as "letting you walk around in the meadow, smell some flowers, and look at the bees and butterflies floating by, only to get your sweater caught in a barbed wire fence." Luckily, Betsy was on hand to aid Dirk in rescuing me from said fence. I am very thankful to Betsy for her guidance in the early stages of my PhD and for her helping me to write my first papers.

Since academic papers typically have to be about *something*, at least if your aim is to have them accepted at some conference, I must give thanks to my good friend Aduén. His work on the technical develop-

ment of the TaSST and, indeed, many of the technical aspects of the work described here, was incredibly important. Without Aduén I might have had much less to write about. In fact, if it were not for Aduén I would probably still be locked in the bathroom of a small bar somewhere in Barcelona.

When it comes to traveling few trips were as memorable as Lisbon, not in the least because this is where I got to know Jan a whole lot better. Still a Master's student at the time Jan's skill and jump-in-head-first-attitude have always been a great source of motivation and have been instrumental in setting up both touching virtual agent setups and running the studies. I am also quite certain I will never meet another person who will, without the slightest hesitation, devour an andouillette and contemplate ordering seconds.

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HMI has been, and still is, an amazing place to work and it is thanks to all the people that I have shared lunches, Monday-drinks, conferences, and many other events with, that it is so. This goes double for

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While I know it is not really necessary, as they are fully aware of how much I rely upon them and appreciate all of their love and support, just to formalize it here, I must also express my gratitude to my family.

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CHAPTER ONE

THE FIRST DAY OF SCHOOL

I was not a happy boy, on my first day of school. My father, donning a crisp, smart looking suit, ready to go to work, kindly but urgently pushed me in the back to direct me towards the front door of our split-level house. I was reluctant, and walked on slowly through the hallway, quietly considering a tantrum. Just before I stepped over the threshold I was intercepted by my mother who pulled me close, hugged me, and kissed my forehead. 'You'll do great today! Have fun!', she spoke as she gently stroked my upper arm. What fun she meant I could not possibly fathom as I had just left a nearly finished Lego spaceship in my room upstairs, which I would not be able to put the final touches to now.

I did not have much time to contemplate the fate of the crew that was now left with an 'under-construction' spaceship as my father, running slightly late for work, steered me out of the house and into the backseat of our metallic green Toyota Carina E station wagon parked in the driveway. As my father buckled me in I could not help feel a sense of impending doom, such as I had up until that point never experienced. The fact that I was now buckled into the backseat, the car door gently slammed shut, and the car slowly reversing off of the drive way did not calm my anxious state of mind in the slightest.

As a child I had been no stranger to long drives for family visits or holidays, but the drive we took that morning lasted an eternity in my

four-year-old mind. Though I know now that in reality the distance could be covered by a brisk five minute walk.

After a drive that felt like we must have surely left the country and by now should at any time be able to see the first mountain ranges, my father pulled up in front of a low, stretched out building that was surrounded by a friendly looking fence that seemed designed to invite rather than protect. Lush green bushes curved their way around a small square, clutched by the low, curving building that featured a play house, climbing apparatuses, and a sandbox. I had heard of such a place before. It was called 'school'. The little square, firmly in the grip of the to me imposing building, was filled with parents, and children my age looking not quite as anxious as I felt I did.

Still very vigilant, I was guided by my father through a small gate in the friendly fence and onto the square, where we stood for a while, my father speaking encouraging words which I barely registered as I carefully scanned these alien, and to me obviously hostile, surroundings. We waited a while and just as some of my worst nerves started to recede, a short, plump woman with short blond hair walked up to us. She greeted my father heartedly and then turned her attention to me.

'This must be Gijs! I am very happy to have you in my class' she exclaimed merrily.

I clutched the neatly pressed leg of my father's trousers with both hands and moved behind him a bit.

'A first day is always a bit scary' the plump woman spoke kindly 'but I'm sure that you will have a great time once you get settled in'.

Her kind words did nothing to put my mind at ease, as I looked up to my father, wondering if I could somehow convince him to take me back home to my Lego spaceship, or at least convince him that, if my space crew had given up on their mission of interstellar exploration, surely my toy cars needed proper parking? My father exchanged a few words with the woman whom I now understood held some position of authority at this school, before a sound like fog horn (I had lived near the sea, and was familiar with the sound), cruelly pulled me out of my thoughts of returning home. All around me I could see parents kissing and hugging their children, waving goodbye to them, and walking out of

the front gate of the school. I was still holding onto my father's trouser leg for dear life, but he easily wriggled free from my grip, and kissed me on the cheek.

'I have to go to work now. You can go with Mrs. Sugarheart¹ here, and she will make sure you have a great first day of school' he informed me encouragingly.

He then waved a short goodbye and with long strides walked out of the school gate. I did not even see him get into the car, which somehow sparked the thought in my mind that this was all some kind of joke parents played on their children. Everyone must be in on it. Surely all the parents were just around the corner out of sight, sniggering, waiting for the opportune moment to take their perplexed children home again. I was mulling these thoughts over as Mrs. Sugarheart and I remained for a little while longer on the rapidly emptying square; parents out the front gate, children into the building.

'Come on Gijs, I'll show you the classroom' Mrs. Sugarheart spoke as she gently took my hand, gave it a gentle pat with her other hand, and started walking me towards the front door of the school building. We entered through two large, swinging front doors that she pushed open easily, into a hallway that smelled of a mix of household cleaner, as it was close to several small toilet cubicles, and plastic toys. Finally, we passed some coatracks on which Mrs. Sugarheart helped me hang my coat, only to take my hand again and direct me to an open door of what was, I guessed, the classroom.

About fifteen children scurried around playing with a variety of toys I had never seen before, and talking to each other loudly, some giggling as they jumped and ran around in the pandemonium that was the classroom. Mrs. Sugarheart let go of my hand, and walked in to address the class and start the day, leaving me to stand, surveying the spectacle, just past the entrance to the classroom.

Suddenly I remembered. I did not see my father get into his car! Joke or no joke, there might still be a chance he was just outside the front gate! The thought formed itself into a more solid idea in my head,

¹This is, in all honesty, a fairly accurate English translation from Dutch of my very first teacher's actual family name.

and then expanded. Even if he was not standing outside the gate anymore, how long would it take me to walk home? In my mind I started retracing the route our car had taken earlier that morning, and came to the conclusion that, while a serious journey, it would be something I could probably manage. I had to manage.

Noises from the classroom slowly subsided as the children were beckoned by Mrs. Sugarheart towards a number of small wooden chairs arranged in a circle in the middle of the classroom. With my half-formed plan still crystalizing in my head, I mustered all the courage I had, turned my back on the classroom, and ran for it.

My Nike sneakers squeaked on the terra linoleum floor of the hallway as I gathered speed. Passing and ignoring the coatrack, I ran farther down the corridor I had just a moment ago walked through hand-in-hand with my ex-teacher. As I ran past the toilet cubicles I could hear a startled, subdued yelp coming from the classroom. The doors of the toilet cubicles flashed passed, and I was spurred on by the thought that this somewhat corpulent teacher would never be able to run as fast as I could, and besides, I had built up a decent head start!

My confidence rising, I reached the two large, swinging front doors, and halted. I put my shoulder up against the rightmost door and with my full weight, pushed through and stumbled out onto the little square. I quickly looked around and almost immediately I spotted the gate through which my father had walked towards the direction of where he had parked his car. I picked up pace again and started towards the gate at a full run, already checking to see if I could spot a glimpse of the metallic green shine of my father's car, but, just in case, also considered which direction I should run to reach home.

But then, as these thoughts were racing through my mind as I raced through the school's gate, I felt a firm hand on my shoulder and was promptly halted. I had gravely misjudged the speed and agility of my pursuer, who swiftly picked me up, pressed me against her and walked me back to the classroom.

1.1 THE IMPORTANCE OF SOCIAL TOUCH

I spent a considerable part of my first day of school on my teacher's lap as she hugged me, and stroked my back to calm me down. And one might say that this caring, comforting touch by my teacher has had the desired effect. After all, I went on through roughly 20 more years of education, not to mention to pursue a doctorate!

While the actions of my teacher may seem like the obvious thing to do, it is not often that we pause to think about the role that touch plays in our social interactions. Actually the uses of social touch in everyday life are abundant: a gentle nudge in the back out the door, a hug and kiss to show affection, a child clinging to his father's leg, or a teacher hugging a distressed pupil. In general, we use social touch for a great variety of things, including to communicate support, appreciation, inclusion, sexual interest, affection, playfulness, to gain someone's compliance, to get someone's attention, to announce a response, and during greetings and departures [272]. Touch is the primary sense through which we express intimate emotions [21]. It is vitally important for the proper development of infants [81], and is a social adhesive that binds together those in a romantic relationship [170]. Touch has played a central role in history [101] and between different cultures its role is diverse [363]. The sense of touch is evolutionarily one of the oldest senses and it is the first sense to develop in the womb [363], thus it offers us our very first contact with the world outside of ourselves [240]. Though to date much less thoroughly studied than for example the visual sense [246, 363], the sense of touch is a fascinating and complex sense capable of discriminating many different sensations [282].

Despite the fact that the sense of touch plays a dominant role in the earliest stages of life, and that use of social touch in later life is important in the way we form relationships, the role of the sense of touch in social interactions has only really been structurally investigated since the early 1960's [178, 491]. Not only that, but the use of touch in social interactions, for example when raising children, has received some strong criticism [see 363, p. 149] and is now in, for example, the North American education system, strictly regulated, if not forbidden [159].

Recently however, there has been an upsurge in research into touch

and especially in research on social and affective aspects of touch, as is attested to by recently published books [178, 314] and inaugural conferences [1] about the topic. This upsurge follows the relatively recent discovery of a specific type of receptor in the human skin that is implicated as a receptor for social and affective touch [267, 385]. This discovery and subsequent research efforts were important in that they legitimized social and affective aspects of touch as important components of the human sense of touch.

However it is not just this new line of research that has sparked a renewed interest in the sense of touch. Technological developments, from advanced prosthetics that restore the sense of touch to an amputee, to video game controllers that render in-game events as vibrations, are continuously making possible new ways through which technology can address our sense of touch. Here, we are particularly interested in how such technologies can support our everyday social interactions.

1.2 SOCIAL TOUCH TECHNOLOGY

We are all too familiar with sliding our fingers over the glass panel of a touch screen, and haptic feedback (‘haptic’ originating from the Greek *haptikos* ‘to be able to touch or grasp’) [234, 474], computer-generated feedback that you can feel, is in nearly every mobile device, notifying you of incoming text messages, and in nearly every video game controller making you experience in-game explosions. Such technology offers us new ways to interact using our sense of touch. Yet these technologies do not fully do justice to the capabilities and functions of the human sense of touch.

It is now fairly common for a large portion of our day-to-day communication to take place mediated through any number of digital devices [288, 467]. We have been making phone calls since the late 19th century, and with a mobile phone in every pocket making a phone call is second nature to us. We feel comfortable sharing intimate feelings through text messages, and do not shy away from letting others in on our daily lives through a diverse and ever growing number of social media platforms. And if we feel a need to communicate ‘face-to-face’ we can use video chat applications, or perhaps in the most extreme cases a

remote-controlled tele-presence robot, early versions of which are best described as ‘Skype on wheels’ [486]. However, what all of these efforts in mediated communication lack is proper use of the sense of touch and all that it affords in social communication. Researchers as well as some companies are beginning to fill in the gaps by studying and designing technology that allows for social touch between two or more people to take place mediated through haptic technology [219, 509]. Thus, the ability to shake hands, for example, is no longer limited to the reach of a person’s arm, but can be extended to anywhere on the globe, and perhaps even beyond [154].

Such efforts are gaining momentum with advances in Internet, micro-electronic, and haptic technology, not to mention a better understanding of the neurophysiology of the sense of touch and the psychological consequences of social touch. What is more, digital devices with some form of social intelligence, from fully embodied social robots [64] to voice assistants not entirely unlike HAL from Arthur C. Clarke’s *2001 A Space Odyssey*, are finding their way into our lives at a rapid pace. Think, for example, of voice assistants such as Apple’s Siri, Amazon’s Alexa, and Microsoft’s Cortana. The fact that such services carry human names and voices suggests that their creators envision that we approach them as social entities. Actually, we may not know any better but to treat any piece of technology we perceive as intelligent in an inherently human, and thus social, way [416]. With technological developments it is likely that our social communication will be extended to artificial social entities, such as voice assistants, which may in the not too distant future be fully embodied, walking and talking social robots [347]. We may encounter such social robots in our hospitals, schools, and indeed our own homes [65, 120].

Not only that, but the virtual worlds that we currently on occasion, and in the near future with increasing frequency, inhabit, feature virtual social agents. Enabled by Virtual Reality (VR) and Augmented Reality (AR) technology we will share our virtual space with virtual agents, which are currently predominantly found in entertainment or training settings [548], but which may very well be used for anything from therapy, to companionship.

It is likely that in the near future we will encounter physically or virtually embodied agents more often than we do now. The fact that we will share our physical and virtual spaces with them makes it almost inevitable that our actual or virtual bodies will come into contact with them [22]. Where a social robot has a physical form and can directly touch and be touched by us, the use of specific haptic technology is necessary to allow virtual agents to apply and receive touches [474]. With this in mind, investigating the role of social touch in interactions with such artificial social entities will become of paramount importance in the near future.

Here we have arrived at the central premise of this book, namely that haptic technology can be used for social touch interactions. I have reserved the term *social touch technology* for all instances in which a person engages in social touch with another human or artificial social entity through haptic technology. This can refer to interactions in which two or more people engage in social touch at a distance, mediated through haptic technology, which is referred to as *mediated social touch* [219], and interactions where a person engages in social touch with a humanlike artificial social entity, such as a virtual agent or social robot. This is referred to here as *simulated social touch*.

The general question to which this book contributes part of an answer is: what is necessary for haptic technology to be successfully used in social touch interactions? Inherent to the developing nature of social touch technology research the approach taken here is broad and explorative. This means that, rather than focussing on one specific element, this book contains several explorations that cover the design of a haptic device for mediated social touch, investigations into the perception of haptic and visual social touch cues, the design of a touching virtual agent system and investigations into the capabilities of such a system. The aim here, then, is not to tease out either the exact way a vibration motor can produce a sensation that is like an actual touch, or a definitive list of factors that are required to design a proper touching virtual agent (though suggestions for both are provided), but rather to sketch the boundaries of a fledgling field of research through design explorations and explorative studies.

1.3 CONTENTS OF THIS BOOK

I have attempted to write this book to reflect the most up-to-date state of affairs of the research field that I call social touch technology. The contributions that I have made to this field are described in detail, and contain all the relevant information to satisfy academic readers. The aim in this sense is to provide a basis for others in academia, working on social touch technology, to build on.

On the other hand, I have also attempted to write this book in such a fashion that, while from an academic point of view it should be complete and accurate, it is also accessible to the reader who is less, or not at all versed in the academic discipline. While certain sections may be less interesting to the average reader, for example, the detailed description of study setups, my hope is that, nevertheless, this book contains enough insights for the layperson to find it interesting, dare I say, enjoyable to read.

I took this dualistic approach not only because I wanted people outside the academic world, especially those people outside of academia that are dear to me, to be able to get a grasp on the work that I have been doing in the past few years, but also because of a more ideological reason. I firmly believe that as scientists we have a moral obligation to share the knowledge that we acquire (often through public funding) with the general public. Writing research papers is an ineffective way of doing this, not in the least because such papers are generally inaccessible to those outside of academia, but also because page limits and writing for a specialized audience forces one to resort to writing condensed texts in jargon. For these reasons this book contains personal anecdotes, examples, and explanations that are aimed at explaining central topics relevant to the field of social touch technology to a more general audience. My hope is that these anecdotes, examples, and explanations are enjoyable to the academic reader as well.

To those pressed for time, or to those mainly interested in a specific topic, I would like to extend a hand by providing suggestions on how best to read this book. In Part I a cultural and historical background for the use of the sense of touch in social interactions is provided (Chapter 2). This is followed by a neurophysiological account of the human

sense of touch (Chapter 3), and an outline of research on the ways in which social touch can affect people (Chapter 4). Part I concludes with reflections on the complexity of social touch, and links social touch and social touch technology (Chapter 5). Readers well versed in touch and social touch research may skip Part I, with the exception of Section 5.1 that links social touch, and social touch technology.

In Part II the focus is on the concept of mediated social touch, and the hardware necessary to achieve it (Chapter 6). This part continues with an overview of research on the way mediated social touch can affect people (Chapter 7), and presents the design process of a research prototype for mediated social touch (Chapter 8). Part II concludes with reflections on the link between social touch and mediated social touch, as well as on the design of devices for mediated social touch. Readers knowledgeable about haptic technology, and mediated social touch may skip Chapters 6 and 7, but would do well to read Chapter 8.

In Part III ways in which the sense of touch can be tricked into registering things that are not really there are discussed (Chapter 9). This is followed by the description of a study on tactile apparent motion (Chapter 10), and a study on the visual perception of social touch (Chapter 11). Those who know all about haptic perceptual illusions can skip Chapter 9, but it is recommended that they read Chapters 10 and 11.

In Part IV research on simulated social touch by social robots and virtual agents is discussed (Chapter 12). The following chapter outlines the design of two touching virtual agent setups, and accompanying studies (Chapter 13). The first chapter of this Part may be skipped by those knowledgeable about (tactile) human-robot interaction and virtual agents. Chapter 13, however, should not be skipped.

Part V contains a discussion of ethical issues pertaining to social touch technology, as well as an outline of potential future applications, and the conclusions regarding the contributions of the work described in all previous parts. Part V is therefore best not skipped.

PART I

WHAT IS SOCIAL ABOUT TOUCH?

CHAPTER TWO

TACTUAL TOWER OF BABEL: SOCIAL TOUCH HISTORY, SOCIAL TOUCH CULTURE

Imagine for a moment a society in which all forms of interpersonal communication are carefully monitored. Cameras on every street corner, in every building, in every home constantly track your every move. In each tree stump, waste bin, and lamppost microphones are hidden that record all utterances you make. Living in such a society, how could you possibly communicate privately? How would you express your intimate feelings to a person that you care about? Let me help you. Take a look at the following passage:

“It was almost time for Winston and the girl to part. But at the last moment, while the crowd still hemmed them in, her hand felt for his and gave it a fleeting squeeze. It could not have been ten seconds, and yet it seemed a long time that their hands were clasped together. He had time to learn every detail of her hand. He explored the long fingers, the shapely nails, the work-hardened palm with its row of callouses, the smooth flesh under the wrist. Merely from feeling it he would have known it by sight.”

This passage from the novel *1984* by Eric Arthur Blair, better known under his pseudonym George Orwell, shows that our sense of touch is a highly personal and intimate communication channel. One can beam a smile, or rather, a piercing stare in the case of Big Brother, at an

audience of thousands, but a touch is private. And this is exactly why being touched can move us unlike any other sensation can. A touch is intimately shared between toucher and receiver as every touch is reciprocal: touching is to be touched (although as we shall see later on technology might circumvent some of the aspects inherent in actual touch). Even something as simple as a squeeze of the hand, as Julia and Winston experienced, can be a signal sometimes more powerful than words spoken. Especially when any word spoken could lead to you becoming an ‘unperson’.

Of course, one does not need to live in a dystopian society to appreciate the sense of touch as a means for social communication. Think, for example, of how often we shake another person’s hand to introduce ourselves, or how intensely happy a hug from a loved one can make us feel. Indeed social touch is one of the primary means through which we communicate intimate emotions [21].

That is, in our day and age. Social touch has not always been regarded with the same positivity as you would perhaps think from reading the first sections of this book. The cultural history of social touch is a checkered one to say the least. In this checkered history lies a possible explanation for why social touch even today remains an understudied phenomenon in comparison to the other senses, especially vision and audition [183, 246, 363]. Not only that, but social touch is also used differently in different cultures. What is considered appropriate social touch in one culture, can be considered unbelievably rude in another.

While it goes beyond the scope of this book to give a full historical and cultural account of the use of the sense of touch in social interactions, it is nevertheless useful to provide ourselves with a little bit of perspective. The view that we may have of social touch now, and the view that is at the centre of this book is not one that has been around for a very long time. Therefore, in this chapter we will take a brief look at how social touch has been regarded throughout history from ancient to modern times, and we will be introduced to a number of clear cultural differences in the use of social touch around the globe.

2.1 DEVIOUS OR DIVINE? SOCIAL TOUCH AS REPRESENTED THROUGHOUT HISTORY

Slightly uncomfortable, creaking seats, an audience attempting absolute silence as they watch with rapt attention as the composer walks onto the stage. Every cough, snuffle, and sigh is suppressed as the first tones of Bach's *Matthäus Passion* reverberate through the concert hall. Among the most magnificent pieces of music ever composed, Bach's *St. Matthew Passion* describes the events leading up to the crucifixion of Christ and his subsequent resurrection. The story also happens to include history's perhaps most infamous use of social touch: Judas' kiss. Featured in the Passion as "Welchen ich küssen werde, der ists, den greifet!", Judas kissed Jesus to identify him to the Roman soldiers who would promptly go on to arrest him (Figure 2.1). The way the sense of touch, and its use in interpersonal interactions especially, is portrayed throughout history is diverse, and ranges from devious, even sinful, to divine.

In the ancient Indian texts of the Ayurveda, for which the first written records date back to the 6th century BCE [230], the sense of touch was linked to the element of wind, one of the five natural elements in ancient Indian philosophy [280]. In a similar fashion, Chinese medical-philosophical writings from the 3rd century BCE, describe tactile perception in relation to the five elements [254].

In Greek philosophy, the sense of touch takes on a mixed role. Empedocles, in the 3rd century BCE, associated all sensory perception with the sense of touch [475], while Plato attributed no specific organ to the sense of touch, but described tactile sensations such as pleasure, pain, and warmth as affecting the body in a general way [280]. Aristotle, providing one of the most complete first accounts of the senses, which went largely undisputed until well into the Middle Ages [101, 280] [see also 314, p.33], relates the sense of touch to the heart and flesh, not so much the skin [280]. Though both Plato and Aristotle considered the sense of touch inferior to sight because of the palpable nature of the sense of touch, Aristotle argued that touch is the sense most closely related to the four basic elements, and therefore had a special status in man [280, 314]. Later, this special status

Figure 2.1: An engraving depicting Judas betraying Jesus by means of a kiss. *De Gevanneming*, Albrecht Dürer, 1508. Rijksmuseum.

of the sense of touch was further underlined by Thomas Aquinas in the 13th century, who stated that all other senses are rooted in the sense of touch, and that without the sense of touch there would be no other senses [280].

Gradually, starting in the 13th century, the sense of touch falls increasingly into disrepute [101, 280]. This can be ascribed to a re-interpretation of the works of Aristotle, and connecting this re-interpretation to passages from the Bible, resulting in touch being more

strongly related to sinful behavior [101, 280]. In addition, changes in the way society was organized, such as the increased reliance on the written word instead of interpersonal face-to-face interactions, the fortification of class differences, and an overall more individualized society, contributed to a further decline of the regard for and use of social touch [101]. All this is not to say that people in the Middle Ages and the Renaissance, did not engage in leisurely touch activities, sexual or otherwise, as is attested to by the proliferation of bathhouses and brothels [101].

The use of touch in the Christian tradition of the Middle Ages is somewhat of a double edged sword. On the one hand social touch was strongly related to sinful behavior, and was discouraged. On the other hand, touch was also the means through which one can gauge the real existence of a thing or phenomenon, indeed the fundamental nature of reality [101, 178, 280]. Moreover, touch has, since the early Middle Ages, been an important part of Christian rituals. Examples include the laying of hands in communion, rites of healing, and the kiss of peace. The kiss especially, was considered a union of body and spirit, and served as a rite of commitment and the ultimate signal of trust, thus making the betrayal of Jesus by Judas through the means of a kiss, all the more relevant [101].

The general view of social touch as being closely related to sinful behavior, a view solidified by medieval Christianity, carried over to later times [101, 363]. Within the increasing individualized society of the 18th century, etiquettes showed growing restrictions on the use of touch in various situations, such as in table manners, and greeting rituals [101, 144]. These etiquettes were further refined in the homes of 19th century middle and upper class Victorians, and their homes too, played a role in the reduction of physical contact. Where in the Middle Ages communal, close-contact living was common, ever larger houses with multiple separate rooms in the 18th and 19th century, underlined physical separation [101].

Though the use of touch in general, and in social interactions in particular, may have been in decline from the 13th century onwards, the knowledge about the sense of touch increased over the ages. This

increase in knowledge was most notable in the 19th century, when the first experimental studies into the physiology of the sensory apparatus underlying the sense of touch were conducted. A pioneer in this field was Ernst Heinrich Weber (1795-1878), whose work on the skin's sensitivity to localization of two touch-points is still relevant today [203, 280].

The study of the sensory aspects of the sense of touch started by Weber, is still ongoing [269, 386], but it was not until the 1940's that researchers started to look into social touch in a structural fashion [491]. The reason that it has taken so long for research on social touch to develop is that social touch was long considered something spontaneous, private and inaccessible, not to mention something that did not happen very often [491]. It is also plausible that negative associations (e.g. 'sinful' behavior) with social touch affected interest in social touch as a topic worthy of study early on. Indeed, who would want to be seen in the public eye as 'that perverted scientist working on social touch'?

The first study to experimentally show the importance of social touch is incidentally also one of the most well-known studies. Harlow [227] and colleagues separated infant rhesus macaques from their mothers and placed them in cages with a wire-frame surrogate mother that dispensed food, and a terry cloth surrogate mother that did not dispense food but was soft to touch. When the baby monkeys were startled as part of the experiment, they consistently ran towards the terry cloth surrogate mother and cling to her [227]. This behavior was considered an unlearned, biological need for touch, similar to the need for food, and one that influenced both immediate and later social, emotional, and cognitive behavior [482, 491]. While this experiment was perhaps ethically questionable, it started a new line of research into the importance of social touch for the development of human infants [491], and contributed in the 1960's to the conviction that touch is an important biological need [280].

From the studies of Harlow [227] onward, a body of research on the importance of social touch, not just important for the development of infants, but also for the forming of lasting adult relationships, has been steadily gathering [159, 363]. In tandem with the increasing sci-

entific work the positive regard for social touch also increased [280]. Still, some argue that in the modern times we live in today many of us are ‘touch deprived’, a situation that should be remedied according to Field [159]. We will see in later chapters how technology could potentially be used to combat some of this touch deprivation.

It should be noted that the historical perspective provided here mainly covers European, and therefore mainly Christian, culture. Though ancient Indian and Chinese writings on the topic of touch have been mentioned briefly the general regard for the sense of touch may have been different in these parts of the world. Indeed, this is what we see when we travel and come into contact with people from other cultures; their norms about social touch can differ quite strongly from our own.

2.2 SOCIAL TOUCH AND CULTURE

For everyone, like me, who is from the Netherlands it will be a familiar experience: you lean in to greet someone with the customary three kisses (though only in male-female or female-female situations. Many social touch interactions differ depending on gender, as we shall see later), only to find that the person you are greeting pulls out after a single kiss, or if you are really lucky after the second one, leaving you in a slightly awkward ‘kissing-limbo’. Introducing ourselves to someone from a different country can be quite tricky sometimes. Do you shake hands or hug someone? Do you kiss someone one, two, three, or even four times¹? Or perhaps you do not touch at all and simply bow. When and how we apply these types of ritualized touches, such as touches during greetings or departures [272], is in part determined by the country and culture that we grew up in.

The social norms and rules regarding touch can differ strongly between different cultures. There are cultures in which any form of touch is taboo, but there are also cultures where touch is used for personal

¹An informal investigations involving 75.000 responses to the question “Combien de bises?” (how many kisses?), shows that in France the number of kisses may even differ between regions. To prevent awkward greetings in France consult an interactive kissing-map here: <http://combiendebises.free.fr>

expression in a host of different situations [8, 15, 16, 352, 361, 363]. Viewed broadly, in Asia, including China, Japan, South Korea, Thailand and Vietnam, touch is used the least in interpersonal interactions, followed by Northern European countries like Germany, the United Kingdom, and Sweden [15, 273]. In contrast, Latin America, and Mediterranean countries such as France, Portugal and Greece, are among the regions in which social touch is used the most often [8, 15, 273, 361]. Other regions in which we find so called 'high contact' cultures are Eastern European countries including Russia, Arab countries including those in Northern Africa, and Indonesia, though in these latter countries public same-sex touch is accepted but public opposite sex-touch is not [15]. Australia and North America are considered regions in which touch is used moderately often for social expression [15].

Why should there be differences in the use of touch in social interactions between these regions? One suggestion is that this has, at least partially, to do with the climate of the regions in question [15, 17]. Most high contact cultures are found around the equator, while most low contact cultures are found farther away from the equator. Colder climates with long and harsh winters typically have more task-oriented cultures, while warmer climates feature cultures that are more oriented towards interpersonal interactions [15, 401].

However the climate-explanation does not hold completely, as countries with colder climates, such as Eastern European countries including Russia, are considered high contact cultures. Indeed, some observational studies have failed to find evidence for the argument that cultures closer to the equator use touch more frequently in interpersonal interactions [352, 418]. What is more, the regions discussed above are very diverse, and contain within them several cultures, each with slightly different norms for social touch [see also 418]. Such differences become readily apparent when we look at the way children are reared in these cultures.

From the earliest onset of life the child in the womb is carefully cradled in the embryonic fluid and gets to know its limited surroundings through the sense of touch first, as it is the first sense to develop in the

womb [363]. From the moment the child is born, however, it is subject to influences from the culture in which it is born. Though the intuition of many a new parent is to stroke, cuddle and kiss their child, there are very clear differences between cultures in the amount and type of touch that an infant will receive.

A general observation from anthropological studies conducted mainly in the 1960's and 70's in indigenous cultures in Africa and the Americas, compared to Western societies, such as those found in North America and Europe, is that in the former societies infants and children receive much more physical contact [363]. In many indigenous cultures, such as the Tasaday, the Ganda, and the Arapesh the infant is carried on the back or side of the mother, making direct skin-to-skin contact. Observations describe less crying on the part of the infant, the mother paying very close attention to the infant's needs, and addressing these needs directly by breast feeding or washing. Interestingly, and perhaps another nail in the coffin of the climate-explanation, is that Netsilik Eskimo² cultures feature very high levels of mother-infant contact, and such frequent social touch is carried on in later social interactions [363]. Overall, indigenous cultures meet the infant's biological need for close bodily contact to a great extent. For many of these cultures close contact practices that are common in infancy and childhood endure in adulthood as well [363].

The observations in indigenous cultures are in rather stark contrast to the way infants are raised in many Western cultures, where feeding with a bottle and putting an infant in a stroller or crib are common practice. In the United Kingdom it is not uncommon for relatively young children to be sent away to a boarding school. Some argue that aids such as security blankets are a poor substitute for actual skin-to-skin touch, such as when breast-feeding or carrying infants, and that, combined with practices such as sending children to a boarding

²Note that "Eskimo" is used here as a broad term, and includes Inuit (residents of Northern Canada), Kalaallit (inhabitants of Greenland), and Yupik people. In Northern Alaska 'Eskimo' is commonly used to refer to both Inuit and Yupik people. Contrary to popular belief the name 'Eskimo' does not mean "eater of raw flesh", but in accordance with the latest linguistic research is thought to derive from 'to net snow shoes'. <https://www.uaf.edu/anlc/resources/inuit-eskimo/> (Last accessed 03-10-2016).

school, leads Western children to suffer from ‘touch hunger’ [159]; a lack of the types of touch that they crave early on in their lives [363].

It is tempting to explain the differences between indigenous cultures and Western cultures in terms of economic development. It is possible that in indigenous cultures infants, and later on adults as well, are directly dependent on each other for their survival, with increased effort necessary for the gathering of food and maintenance of shelter [340, 363]. This is in contrast to Western cultures in which basic needs are abundant and children are raised to be independent, mobile, and competitive [340, 363]. Even within Western cultures there are differences in touch behavior depending on social economic status (SES), though not always in the sense that those of a lower SES apply more touches [237, 363]. Differences in SES or the social class that one belongs to can also affect touch interactions between people from different classes. Typically, those of higher status can touch those of lower status, but not vice versa. Such strict touch-rules can be observed in the Indian culture, which knows a strict caste system [237, 363].

Still, SES is not a full explanation for the different uses and frequencies of social touch in different cultures. In a comparison between the United States and Japan, both strongly economically developed countries, there are clear differences in the rearing of infants and the use of touch. The Japanese mother is known to be in constant very close contact with her infant, and mainly uses touch to pacify and sooth the infant. In contrast, the American mother uses touch less frequently, but when it is used it serves to stimulate the infant. It is argued that this differential use of touch in upbringing partially explains why Japanese children grow up more passive and quiet compared to their active and vocal American counterparts [83, 363].

The use of social touch in different cultures is much more complex than would be expected based on geographical observations. We should also not forget that these observations are a strongly aggregated view, and that many differences exist within a culture, in the form of subcultures. As an example, Jewish culture is characterized by frequent use of touch independent of the geographical location of the Jewish community [363]. Moreover, subcultures within a low contact

culture may actually touch quite a lot in certain situations. A prime example is the frequent use of touch in sports teams [298, 461].

It is also worthwhile to mention that many of the studies reported here are correlational. That is, regarding the use of touch in the upbringing of infants, there is no way to say if certain child rearing practices have a tendency to result in a culture that favors touch interactions later on in life, or if a culture that favors touch interactions in general, produces child rearing practices that involve frequent physical contact. To complicate matters further, there are those cultures that feature frequent contact in the earlier years of an infant's life, but that in general, in later adult life, are considered low contact cultures. Such a change in touch behavior from infancy to adulthood is found in Japanese culture [83, 363].

Finally, many of the studies reported here were conducted in the 1960's and 70's. It is quite likely that cultural changes have happened in the observed regions since the studies were conducted so that the observations may not be fully representative of current cultural social touch practices. For example, more recent studies have called into question some of the observations relating to high and low contact cultures and proximity to the equator [352, 418].

To conclude, culture, as defined by geographical location and country borders is a convenient way to frame social touch practices. However, we should also be mindful that the explanatory power of culture on social touch behavior of an individual is limited. For one, there are many differences in social touch practices within a culture, some that can be characteristic of a certain sub-culture. We should also be aware of the fact that correlational studies on culture and touch do not explain exactly how these touch practices are formed. Nevertheless, the culture in which one finds oneself can have specific norms for interpersonal touch, especially for ritualized touches [272], such as kissing someone as a greeting.

CHAPTER THREE

THE HUMAN SENSE OF TOUCH

The human skin is a wholly remarkable organ. Weighing in at about 3.6 kilograms, and covering about 1.7 square meters in the average human male, the skin is by far the largest of our sense organs [159, 363, 491]. The human skin serves a dual function. Firstly, it protects our internal organs, muscles, ligaments and bones from outside dangers, be they mechanical, thermal, chemical, or microbial dangers [178]. Second, it is the organ that enables our sense of touch. In this respect it is a unique sense organ as it is the only sense organ that is distributed all over the body, instead of being localized like our eyes, nose, ears and tongue. Montagu states that “In the evolution of the senses the sense of touch was undoubtedly the first to come into being” [363, p.4]. Indeed, the function of the sense of touch to set the boundaries of self or to determine what is part of an organism and what should be considered the external world, might have very well been the first to develop in the animal kingdom [178, 368].

When only six weeks old, a human fetus, still completely blind and deaf, can respond to tactile stimulation [23, 199, 240, 363] [See also 178]. The sense of touch is the first sense to develop in the womb [159, 240, 363], and thus offers us the very first contact with the, albeit for a fetus limited, external world and our own bodies. From these very early moments of life onwards we continuously feel, as the sense of touch is always active [491]. We can shut our eyes, close our mouths, pinch our

noses shut, and cover our ears, but we cannot shut down our sense of touch (though note that there are certain medical conditions that are characterized by a partial or complete loss of the sense of touch, often with devastating consequences for the affected individuals [106]).

The sense of touch enables us to pick up a pencil, feel the texture of a piece of paper and write a poem by applying just the right amount of pressure to the pencil for the tip not to break. We can feel the warmth of sun rays on our skin, and can judge the weight of a cup by holding it in our hands. Our sense of touch enables many actions we perform automatically such as walking or driving a car. It requires detection and processing of a remarkably diverse range of sensations to allow all of these actions to be executed. Indeed, the sense of touch is actually not one single unitary sense, but can be divided into two functionally distinct senses, namely the cutaneous sense and the kinesthetic sense [178, 326]. The cutaneous sense allows us to be aware of stimulation of the outer surface of the body through a host of different receptors found in the skin. The kinesthetic sense on the other hand, provides us with awareness of the relative position of our body in time and space. This is made possible by receptors in the skin, muscles, and joints, and motor-commands executed by the brain [326, 517].

The way that we perceive with through sense of touch can be thought of in terms of five modes of touch perception. The term *tactual perception* is typically used to refer to all sensations that have to do with the sense of touch [326]. A further distinction that can be made is between *tactile perception* and *kinesthetic perception*. The former comprises all touch sensations mediated by variations of sensations on the skin's surface (i.e. cutaneous sense) occurring in a static posture. The latter refers to kinesthetic sensing in situations where the cutaneous sense does not contribute any information other than static contact, such as in the case of measuring the length of a match held between thumb and index finger [326]. In truth though, most sensations that we encounter day-to-day consist of a combination of tactile and kinesthetic perception. For these combined sensations the term *haptic perception* is reserved.

To complete the classification of modes of touch we have to consider

the amount of control one can exert. In other words: are you touching or being touched [190]? We can distinguish between active touch (i.e. touching) and passive touch (i.e. being touched) [190, 326], as well as a combination of both (i.e. touching oneself, also called intra-active touch [54]).

A nice example of intra-active touch is when you try to tickle yourself [51, 453, 526] [see also 314, p.198]. While trying to tickle yourself, you are both touching and being touched at the same time. Three types of information are relevant here: first, the motor command that 'instructs' you to move your arm; second, sensory feedback from the movement of your arm; third, the sensation at the location of the tickling [526]. When you are being tickled by someone else, only the latter type of information is available, producing a strong sensation of ticklishness. However, when you try to tickle yourself, your brain, particularly the cerebellum, integrates information about your arm moving and the sensory feedback from the location of the tickle, which reduces the ticklish sensation when you try to tickle yourself compared to being tickled by someone else [51, 526] (though see [49] for a situation in which self-tickling might produce a stronger sensation). Recent research has found that even rats enjoy being tickled, positively squeaking with laughter - at a pitch inaudible to humans - at the touch of an experimenter [260, 391]. It is suggested that tickling leads to positive affective responses, and that it serves to facilitate social play behavior in order to strengthen social bonds [260, 391]. If tickling is indeed meant to stimulate interactions between conspecifics it makes sense that tickling oneself, which would not match with the evolutionary function of tickling, produces a less strong sensation.

Apart from tickling, differences between active, passive, and intra-active touch arise in, for example, the identification of the size or shape of an object [54, 236]. Active exploration of an object makes it much more easily identifiable compared to having the object touch the skin (i.e. passive touch) [236] [see also 54]. To conclude we can distinguish five modes of touch that make up our sense of touch: passive kinesthetic perception, active kinesthetic perception, passive haptic percep-

tion, active haptic perception, and tactile perception, which can only be passive [326].

The question that should be considered at this point is: how do we use our cutaneous and kinesthetic senses, and the different modes of touch, in social touch interactions? The sense of touch, as thus far described, is used in much the same way in social touch interactions as it is in interactions with objects. When a loved one caresses our hand, the perception of the caress occurs through our cutaneous sense as passive touch perception (i.e. tactile perception). The application of the caress, applied with a certain amount of force and at a certain velocity (which is important as we shall see in a bit) is made possible by the kinesthetic sense and is an example of active touch (i.e. active kinesthetic perception). Such sensations are perceived through the same methods of touch perception as those in other, non-social, touch interactions, for example, when a fabric is brushed over our skin or when we stroke the upholstery of a new couch.

In these latter examples the sense of touch is clearly used as an exteroceptive sense; a sense to detect, discriminate, and identify stimuli in the world outside the body [355, 356]. Using the sensory qualities of the sense of touch in this way, is called *discriminative touch*, and is used to make rapid decisions and initiate behavior [355, 356]. Discriminative touch enables a sculptor to feel the texture of the marble, his grip on his chisel and hammer, and allows him to adjust his tools in a way as to eventually produce *Apollo and Daphne* (Bernini, 1622-1625). Though a significant amount of skill and practice is also necessary in this particular case.

Besides the discriminative function of touch, the sense of touch also serves an interoceptive function, having to do with motivational-affective aspects of touch [24, 366], and giving feedback about the well-being of the body [355, 356, 366]. This function of the sense of touch is referred to as *affective touch* [355, 356, 366]. Affective touch is most easily understood when we think about how we use our sense of touch to determine whether something is pleasant or unpleasant. For example, moving smooth, soft silk over the skin subjectively feels much more pleasant than if burlap were to be used. In more extreme cases we can

think of the way our sense of touch can produce pleasant erogenous sensations, or unpleasant painful sensations [24, 246, 499]. Such pleasant or unpleasant tactual sensations are very relevant in social touch interactions.

To fully understand the distinction between discriminative touch and affective touch and to understand the role of discriminative and especially affective touch in social touch interactions, we need to consider the neurophysiology of the sense of touch. While a comprehensive account is beyond the scope of this book (for that, the reader is referred to [282]), it is important to get a feeling for how certain sensations that we encounter in the real world, while interacting with objects or with other people, are the result of an integration of information from different receptors.

3.1 THE NEUROPHYSIOLOGY OF DISCRIMINATIVE TOUCH

In a similar vein as the sense of touch has been described throughout history by the likes of Aristotle, Plato, and Thomas Aquinas, Bertrand Russell noted in regard to the sense of touch: “Not only our geometry and our physics, but our whole conception of what exists outside us is based upon the sense of touch.” [433, p.10] Here Bertrand Russell describes the sense of touch as a method to determine what is real, as an exteroceptive sense that is used to determine the nature of things outside the body. Though note that, according to Russell, our everyday tactual sensations as experienced by humans on earth can be misleading to the astronomer coming to grips with the concept of relativity [433, p.15].

Unfortunately, we must leave the poor astronomer to struggle with relativity on his or her own and consider the neurophysiology of discriminative touch and how receptors in the skin make it possible for us to detect and process a wide variety of everyday tactual sensations. Our perception of touch, that is tactual perception encompassing tactile, kinesthetic and haptic perception, is actually the result of the integration of multiple distinct forms of sensory information pertaining to touch, pressure, temperature, pain, itch, joint position, muscle sense, and movement [39, 178, 253, 328, 354]. The total of these sensory

modalities and their respective receptors and nerve fibers is also referred to as the *somatosensory system* [282]. Each of the submodalities of touch draws information from a combination of specific receptors that are found in the human skin. Many tactile sensations, such as wetness, pressure, vibration, and tickle are not detected by single receptors, but are actually a result of activation of a specific combination of receptors and are therefore regarded as “sensory blends” [178, 453]. What is more, sensations that are coded by a single receptor type can still be influenced by qualities of a stimulus that are coded by a different type of receptor [178], producing a kind of sensory interaction effect. Such effects are at the basis of many haptic illusions [233], for example one where of two identical objects the one that is colder will also feel heavier [70]. We shall revisit this topic in more detail in Chapter 9. For now it is useful to consider where these receptors are located in the skin and what type of specific information each receptor contributes to different tactile sensations.

Tactile receptors are found in the human skin as well as in the skin of other mammals [119, 246] all over the body, in both glabrous (i.e. hairless) and hairy skin [178, 224]. Glabrous skin (Figure 3.1) is only found on the palms of the hands and fingers, the soles of the feet and toes, the lips, the nipples and certain parts of the genitalia. Sometimes the glabrous skin surrounding mucous membranes is referred to as mucocutaneous skin, and includes skin surrounding the urethra, anus, eyes and eyelids (i.e. conjunctiva), and lips, among other regions [314, 538]. Though this may not be something that people getting ready for bathing suit season and working on their bikini lines want to hear, but the rest of our skin is hairy. Even the parts that appear smooth are actually covered with very fine so-called vellus hairs. The exact amount and distribution of hair over the body differs between body locations, genders, and from person to person [397].

The general structure of both the glabrous and hairy skin is very similar, with the obvious difference that the hairy skin contains hairs. The glabrous skin is also thicker than the hairy skin [84, 178], and, to the dismay of many a careless burglar, the top layers of the glabrous skin feature papillary ridges (which manifest themselves in the fingers

as fingerprints), that are more pronounced than in the hairy skin [84]. The distribution density of receptors found in both skin types can differ strongly between different locations on the body. For example the fingers contain an especially high density of receptors [224], while the receptors found in the skin on the back are less densely distributed [48, 282, 472]. Such differences in distribution densities of receptors become apparent in, for example, the detection of edges of an object, a task for which the skin on the fingers is considerably more accurate than the skin on the back [282, 472] [see also 307]. Receptors are found in the layers of skin below the top layer (i.e. the stratum corneum) called the epidermis, dermis, and subcutis or hypodermis [224, 328](Figure 3.1).

So what are these receptors exactly? And what do they do? We can distinguish between them in terms of their conduction velocity; the speed with which they send signals through the central nervous system to the brain. Nerve fibers that carry information to the central nervous system are called *afferent* fibers. Receptors can be connected to the central nervous system via afferent nerve fibers of different diameters. Thicker nerve fibers that are coated in a protein/phospholipid layer called myelin (and thus are called myelinated nerve fibers), can conduct impulses much faster than thinly myelinated, or unmyelinated nerve fibers. Impulses from unmyelinated fibers can move as slowly as 0.4 meters per second, meaning that an impulse from the tip of your big toe can take seconds to reach the brain. In contrast, thickly myelinated nerve fibers can send impulses at up to 120 meters per second [282]. This fast transportation of information is useful for discriminative touch. When we manipulate tools, let's say while eating with chopsticks, the time it takes for information from our touch receptors to be available for processing in the brain is important for us to be able to adjust our behavior accordingly. The fast transfer of information about the force on the chopsticks, their texture and their positioning between our fingers, allows us to get even the smallest slivers of udon from a nice bowl of ramen.

Another way to distinguish between cutaneous receptors is to look at their function, in other words the type of information they con-

Figure 3.1: Abstract representation of a cross section of the glabrous (i.e. hairless) skin. The four main mechanoreceptors are indicated as well as the relevant nerve endings and features of the skin.

vey. Broadly speaking cutaneous receptors provide the central nervous system with information regarding temperature, skin deformations, pain, and itch [282, 328, 356]. The latter two of these functions are related to interoceptive aspects of touch [282] and will be discussed in the next section. Here we are interested in how discriminative touch is made possible by thermoreceptors that sense temper-

ature and mechanoreceptors that detect skin deformations, or what is generally called ‘touch’ [282, 328].

Several specialized thermoreceptors are found at the ends of thinly myelinated (A-Delta) and unmyelinated (C) nerve fibers in the epidermis and dermis of both glabrous and hairy skin, and each receptor is sensitive to a different temperature range. Subjectively we experience these temperatures as cold, cool, warm, and hot, determined by the difference in temperature of the skin (i.e. about 32°C) and the temperature of the air or of the object touching the skin [282, 328, 329] [See also 314]. Because of the characteristics of specific warm and cold receptors we are more sensitive to sudden cooling sensations than to warming sensations [282]. Interestingly, thermoreceptors also respond to chemical stimulation as those who rubbed their eyes after having sliced chili peppers for a pot of hot chili con carne and having felt a subsequent burning sensation, can attest to. Capsaicin in chili peppers and menthol in mint can activate thermoreceptors and thereby produce hot or cold sensations [282, 314].

The general structure of both glabrous and hairy skin may be quite similar, but we already know that the density of receptors differs between body locations [48, 282, 472] [see also 307]. What is more, the types of mechanoreceptors found in the glabrous and hairy skin, also differ [282, 328]. Mechanoreceptors can sense physical deformation of the tissue in which they reside [282] and thus respond to mechanical stimuli. There are four types of mechanoreceptors in the glabrous skin: Meissner corpuscles, Merkel cells, Pacinian corpuscles, and Ruffini endings. These receptors are either slowly adapting and respond to static touch, or they are rapidly adapting and respond to movement over the skin’s surface and vibrations [268, 282, 354](Figure 3.1).

Let’s take the most common form of personal transport in the Netherlands as an example: riding a bicycle. And let us, to keep things simple, focus on our hands on the handlebars. Merkel cells allow us to feel the textured material of the grips, while Ruffini endings enable us to feel the general rounded shape of the handlebars as we grip tightly and kick off. As we start cycling over cobblestoned streets Meissner corpuscles allow us to feel the low frequency vibrations of the wheels

bouncing on the cobblestones and enable us to feel our hands slipping over the grips of the handlebars due to the rough ride. Luckily, the road smoothens out and now Pacinian corpuscles enable us to sense the much higher frequency vibrations produced by the tires rolling over the road's much smoother tarmac surface.

In contrast to the glabrous skin, the hairy skin does not contain Meissner corpuscles. However, the small sacks from which vellus hairs and larger hairs grow are sensitive to movement of these hairs and provide much the same information as do Meissner corpuscles [282, 328]. All other mechanoreceptors found in the glabrous skin are also found in the hairy skin. To boot, the hairy skin also contains field receptors that are particularly sensitive to skin stretch. Finally, the hairy skin, and only the hair skin, contains low-threshold mechanoreceptors innervated by unmyelinated thus slow conducting C fibers that respond particularly strongly to slow stroking of the skin [282]. And it is especially the relatively recent discovery of these specific types of C fibers in the human hairy skin [267, 503] that has sparked interest in research into affective touch.

3.2 AFFECTIVE TOUCH: THE MYSTERY OF THE HAIRY SKIN AND THE CARESS

Close to where I live there is a popular shopping street. It is the territory of people who in the '90's would have been referred to as 'young urban professionals', or yuppies [216], shopping for exquisite and exclusive food at trendy delicatessen, butchers with locally sourced 'animal friendly' meat, buying daily groceries at organic supermarkets, and purchasing fine wine at one of many wine stores where most bottles on offer can be sampled on the spot. While in light of recent developments in popular culture it may be more accurate to classify these shoppers as 'hipsters' [447], there is one thing in particular that has always surprised me, and that is the remarkably high number of hair removal and waxing salons in this particular shopping street. Surprising, not just because the average male hipster sports a full beard, but more so because the abundance of these salons seems to signal an unfavorable attitude towards hair and the hairy skin in general despite the fact that

the hairy skin has some unique properties not found in the glabrous skin.

We have already seen that compared to the glabrous skin, the hairy skin lacks Meissner corpuscles [282, 328], and has an overall less dense distribution of fast conducting receptors [282, 472]. Why then, when the hairy skin can be considered inferior to the glabrous skin for discriminative touch purposes due to a lower density of fast conducting receptors, should we be concerned with the hairy skin at all? First, we should obviously be concerned with it for the fact that most of our body is covered with hairy skin. And second, we should be concerned with the hairy skin (as well as the glabrous) because apart from discriminative functions, touch also serves affective-motivational functions that are not necessarily served by a high density of fast conducting receptors [24, 282, 366].

Affective-motivational aspects of touch might be best understood by first briefly considering two sensations that we are all familiar with: pain and itch. Both pain and itch have less to do with detecting, discriminating and identifying stimuli outside of the body (i.e. discriminative touch) but they have more to do with communicating about the well-being of the body [24, 282, 355, 356, 366]. This interoceptive aspect of touch is related to affective valence (e.g. pleasantness and unpleasantness of a tactual sensation) and the way stimuli are qualified can signal attraction or aversion towards a given stimulus [366, 355]. For example, if something is painful to touch you will most likely not want to touch it again.

Pain is an inherently unpleasant (i.e. negatively valenced) sensation that serves to signal damage to tissue (remove your hand from the hot stove!), and to signal continuously to warn about damaged tissue (your hand has been burned, protect it!) [282]. Pain is the result of stimulation of moderately fast A-delta nociceptors (from Latin *nocere* 'to harm or hurt') that result in sharp, prickling pain sensations, and slow conducting C fibers that produce longer lasting burning pain sensations that can be hard to localize exactly [282]. Nociceptors can be stimulated directly by thermal and mechanical stimuli and indirectly

by signals from other receptors. Pain is a highly subjective, affective experience and it is the product of a variety of neural signals [282].

Like pain, itch is an inherently unpleasant sensation that we immediately try to relieve by scratching, going even so far as to scratch to the point of pain [265, 282]. Receptors that signal itch sensations can be activated by both tactile stimuli (e.g. think of an ant walking on your skin) and chemical stimuli (e.g. such as histamine which is found in stinging hairs of the *urtica dioica* or common nettle) [265, 449]. Though it was long thought that itch was a result of infrequently firing impulses from pain receptors, recent findings suggest itch results from activation of a specific class of slow conducting C fibers [265, 449].

It is beyond the scope of this book to discuss the sensations of pain and itch in detail (pain especially has been studied in tremendous detail, as pain alleviation and pain management are of great interest to medicine [103, 359] [see also 282]). The important point to take home from this is that there are sensations such as pain and itch that provide signals about the well-being of the body rather than about aspects of the external world (i.e. discriminative touch), and that are inherently negatively valenced, or are, in other words, unpleasant.

The fact that there are inherently unpleasant tactual sensations begs the question whether there are also inherently pleasant tactual sensations. It is not too hard to come up with a positive answer and examples to this question: the feeling of a smooth piece of soft fabric, slipping into a hot bath, and indeed stimulation of erogenous zones [187, 499]. A less obvious answer, and one that is of particular interest here, takes us back to the hairy skin and a specific type of nerve fiber found only in the hairy skin.

3.2.1 The pleasure of stroking

In the early 20th century it was thought that slow conducting fibers that lacked myelination (a layer around the nerve that helps conduction of signals), so-called C fibers, only signaled temperature, pain, itch, and tickling sensations in mammals (including humans) [547] [see also 41, 134, 382, 503]. As we have seen, there are indeed several

classes of C fibers that are important in signaling, for example, lasting pain sensations [282], and itch sensations [449]. However, it was Bishop [46] who first considered that perhaps C fibers could also signal other sensations. And indeed, with advances in methods to record electrical signals from specific nerve fibers, he was proven right a few years later [41, 134, 266, 301].

In a rather invasive procedure, where nerves in the hind leg of a cat were surgically exposed and electrodes were placed on two different sites, it was discovered that a specific class of C fiber did not signal temperature, pain, or itch sensations, but instead, signaled gentle touch sensations [134]. The experimenters describe how gently stroking the skin on the cat's leg with cotton gauze produced the most clear signals from this specific class of C fibers. The existence of such a specialized 'stroking' nerve fiber in cats (as well as in other mammals such as primates [301]) is perhaps not surprising considering that cats generally love being stroked. It was not until roughly thirty years later that the same C tactile receptors were first found, somewhat by accident, in humans [267]. And since the average human is not as partial to being stroked as the average cat, this was somewhat of a puzzling finding.

It was first posited that these so-called tactile C afferents [504], or C-tactile afferents, CT afferents for short [385], were an evolutionary relic, and were slowly being eliminated during evolutionary processes predating man [301] [see also 382, 503]. This turned out not to be the case however, because an abundance of CT afferents was found in the hairy skin of the human arm [503]. The researchers who found CT afferents in the forearm doubted that these nerve fibers had much to do with cognitive aspects of touch (i.e. discriminative touch), because of CT afferent's poor capacity to discriminate details of touch and because of their slow conduction velocity [503]. A number of studies followed that showed that CT afferents were found all over the hairy skin of the human body, but interestingly enough not in the glabrous skin [281, 317, 385, 504]. With this, the mystery of the light stroking touch receptors slowly started to unravel.

3.2.2 The social touch hypothesis

A breakthrough in research into CT afferents came in the form of a patient who suffered from an affliction that resulted in a loss of myelinated nerve fibers, those important for discriminative touch [168, 385]. Because of the loss of these myelinated fibers this patient reported not being able to feel any kind of touch sensations below the nose, except for temperature, pain, and itch sensations, sensations which are signaled by unmyelinated C fibers [168]. With this particular patient it was now possible to isolate signals from CT afferents without interference from signals of myelinated nerve fibers [385].

In a controlled study, responses of the patient were compared to responses of people whose sense of touch was fully intact. The patient could only detect vague pressure in the glabrous skin of her hand, and could not feel vibration stimuli on the lower arm, sensations generally detected by myelinated fibers in healthy people. In contrast, the patient could detect stroking touches on the forearm, which she clearly described as pleasant [385]. She could not, however, detect the direction of these stroking touches while healthy subjects could. In addition to gathering the patient's subjective responses to different tactile stimuli, functional Magnetic Resonance Imaging (fMRI in short, which is used to measure changes of blood flow in specific areas of the brain as an indication of neural activity) showed that while people with a fully intact sense of touch showed activation of the somatosensory cortices, as well as the insular cortex, the patient showed specific activation in the insular cortex but not the somatosensory cortices [385]. This was an important finding because the insular cortex is involved in the processing of affective stimuli, whereas the somatosensory cortices are involved in the processing of sensory-discriminative stimuli [385]. The findings from their study lead the researchers to suggest that the CT afferent system plays a role in the processing of affective aspects of touch and may be important for emotional, hormonal, and behavioral responses to tactile stimuli [385].

By now, many studies have been conducted that corroborate these early findings. CT afferents have thus far only been found in the hairy skin and seem to be lacking entirely in the glabrous skin [353, 366,

504]. They respond particularly strongly to slow stroking touches and are highly sensitive to the speed with which these stroking touches are applied. Several studies have found that stroking the hairy skin with a velocity of 3 cm/s shows the strongest activation of CT afferents. What is more, when people were asked to rate how pleasant stroking touches of different velocities felt, they rated 3 cm/s as the most pleasant [48, 151, 152, 317, 321, 367]. Overall, CT afferent firing rates and subjective pleasantness ratings for different velocities show a remarkably similar ‘inverted U-curve’ pattern [321, 367]. CT afferents are also more sensitive to stroking stimuli that are applied at the temperature of the outer layer of the human skin (i.e. 32 degrees centigrade) [3]. And finally, the pathways to the brain are separate for myelinated fibers and CT afferents, with CT afferents projecting mainly to the insular cortex and orbitofrontal cortex, both areas of the brain that are involved in affective processes [353, 355, 356, 366, 386]. In addition to affect-related brain areas such as the insula, an fMRI study found that a network of brain areas was activated by CT optimal stroking touch that covered areas of the brain involved in social perception and social cognition [198].

The combination of all this research on the properties of CT afferents have lead to an intriguing hypothesis regarding the function of CT afferents. The ‘social touch hypothesis’ states that CT afferents might serve as a “filter” that operates in conjunction with other mechanoreceptors in order to help determine if a certain touch has social relevance or not [366, 385, 386]. In social interactions between people, stroking touches may have particular significance. It could be that this special role of stroking touch in social interactions is solidified early in life, where social touch between mothers and infants often involves stroking touches [155, 159, 176, 241]. The repeated stroking of an infant by its mother may strengthen neural connections in the infant’s brain that relate this stroking sensation to positive feelings, such as a feeling of security while being cradled in the mother’s arms [176]. The positive association between stroking touches and the feeling of security in early childhood may explain part of why CT afferent optimal touches are perceived as pleasant [176]. Stroking touches applied by

a mother to her infant have possibly developed through evolution from licking (think of a mother cat licking her kittens), to tooth-combing (a behavior common among lemurs), to grooming, and handstroking in great ape species and our early human ancestors [343, 363, 375]. Social touch that involves stroking is even found in certain high touch cultures such as the Eskimo who do not shy away from welcoming visitors by touching and stroking them [363].

The social touch hypothesis reserves a central and important role for CT afferents in social touch interactions. However, when we look at some of the details of this research we may begin to wonder how central and important CT afferents and their stimulation through stroking touches really are in social touch interactions. A relevant and quite interesting detail of the studies that inspired the formulation of the social touch hypothesis is that the stroking touches were often applied, not by a human hand, but by a handheld or even robotically controlled soft brush! [152, 320, 365, 402] While CT afferent responses to brush stroking with either a handheld brush or robotically controlled brush do not differ [493], the object which a touch is applied can certainly make a difference. In a study where stroking touches were applied with either a stick covered in velvet or a human hand it was found that stroking with a human hand was rated as more pleasant and showed stronger activation in the insula as well as the primary and secondary somatosensory cortices [300]. Not only the fact that a human hand feels different from a velvet stick, but also the fact that there is an entire human being attached to the hand can alter perceptions of a touch. Seeing either a male or female apply a CT optimal stroking touch can alter how such a stroking touch is perceived in terms of pleasantness. In a study a group of heterosexual men received stroking touches (all actually applied by a female) to their leg which they could see on a video screen. By manipulating the video feedback to show either a male or female applying the stroking touches, researchers could study how the perception of gender could alter the way CT optimal stroking touches were perceived. And indeed, the male participants found the touches more pleasant when they thought they were applied by a female [182]. Thus, while stroking touches may activate CT afferents, it

is not to say that the sensation of every stroking touch will be perceived in the same manner.

What is more, stroking touch applied to the hairy skin is not all there is to the affective-motivational aspects of touch, let alone to social touch interactions. While CT afferents may have a special role in processing social and affective aspects of touch, socially relevant or pleasant touches can also stem from stimulation of myelinated nerve fibers in the glabrous skin [153, 171, 356]. When out shopping for a new couch, for example, you will most likely touch the fabric of the couch with the glabrous skin of your hand to assess how pleasant it feels, rather than use any of your hairy skin. You would surely draw strange looks from the store manager would you use your hairy skin on, say, your forearms, back or abdomen to make such a purchase decision. And any purchase that would follow would likely be sealed with a handshake, a very common social touch that mainly involves contact with glabrous skin. Indeed most social touches, like those for getting someone's attention and even for showing support, like a pat on the back [272] do not involve stroking of any kind. We will see in the next chapters, how many effects of social touch do not require any stroking touches to occur either [see also 176, 246].

So with all this in mind can we really speak of a social touch hypothesis? Perhaps. If we consider stroking touches vital in social interactions, for example, those in mother-child interactions [155, 159, 176, 241]. On the other hand, it may be more accurate to speak of an affective touch hypothesis and consider the CT afferent pathway as a unique way for certain specific affective aspects of touch to be detected and processed [356]. We can posit that stroking touches are an important part of social touch, but are only that, a part. Furthermore, social touch can be seen as a specific case of affective touch, as affective touch can encompass any form of tactual stimulation, including pleasant and unpleasant, as well as social and non-social ones.

Contrary to what you would believe if you were to take the extraordinarily high number of hair removal salons in the shopping street described in the introduction as an indication, the hairy skin does serve an important purpose for our sense of touch. The hairy skin

is well equipped for handling affective-motivational aspects of touch, both in terms of unpleasant (e.g. pain and itch) and pleasant (e.g. CT optimal stroking touches) tactile sensations. If anything, the discovery of the unique pathway for pleasant touch in the hairy skin shows that affective-motivational aspects of touch are just as important as discriminative aspects. Moreover, it underlines the complexity of the sense of touch, a complexity which we are only just beginning to understand for affective touch.

With this in mind let us now turn to the ways in which social touch through brief touches, holding hands, and indeed stroking touches, can affect the way that we feel about ourselves, the environment around us and about other people.

CHAPTER FOUR

HOW SOCIAL TOUCH AFFECTS US

It is all very well and good to invite people into the lab and use rather complex, sophisticated techniques requiring a steady hand, such as microneurography (i.e. using a needle-like probe to take measurements directly from peripheral nerve fibers), as this will seem like a legitimate scientific enquiry to those invited to participate. But how does one go about studying social touch as it occurs in actual interactions between actual people in the real world? We may know intuitively that much of our social touch interactions take place in a private setting, are highly personal, not to mention often intimate. A prototypical researcher wearing a spotless white lab coat and carrying a clipboard would surely stand out as he or she carefully observes a hug between lovers, or a firm handshake during a business meeting.

Kidding aside, this is a real problem faced by researchers studying social touch. Social touch takes place in ecologically valid settings and inviting people to the lab often puts them in a position where they would be disinclined to use social touch, apart from highly ritualized forms of touch, such as shaking hands. What is more, social touch does not occur as frequently as other social signals. Take facial expressions for example. It is relatively easy to observe and code facial expressions by looking at people from a distance [142]. However, when observing touch, a lot of the information that is communicated and received by the ones participating in the touch, is lost to the observer. It is difficult

to assess the amount of force used to shake hands, more difficult still to judge the finer motion of the hand, and virtually impossible to assess the tactile qualities of the hand's surface, such as its roughness, level of moisture and so on.

It is for these reasons that researchers have adopted three different methods to be able to study social touch [491]. One is self-report, in which people are asked about their tactile experiences. Another is observing social touch in the wild and taking for granted that a lot of information is lost. Finally, to answer questions around how touch affects people, researchers have come up with very clever experimental methods that can be used in the lab [491].

During self-report methods, researchers ask participants to recall moments in which they used social touch, or to indicate what they think of certain social touch situations. Using such a method has shown that the relationship with the person that touches you matters. People do not generally like to be touched anywhere on their body by a stranger, but a romantic partner will have access to most areas of the body [273, 483]. Similar approaches ask people to report on their social touch interactions right after they occur. Through these methods we have gained insights into the types of situations in which social touch is used [272, 535]. A downside of these methods is that participants may not always remember when certain social touches occurred, may not want to report all touches, or they may forget to report them when they occur. Let's face it, after the first kiss from someone you have been romantically pursuing for a while, reporting on this kiss will likely be the last thing on your mind. Furthermore, protocols for reporting can never be exhaustive on reporting all aspects of the touch itself, the people between whom it occurred, or the situation in which it occurred.

Observational methods have researchers remove their lab coats and go out into the field to visually observe social touch taking place. Being unobtrusive is important in that when the researcher is unnoticed, the people who are being observed can be observed in their most natural environment. Using such an observational method has shown that people with a lower social status initiate more ritualistic touches such

as handshakes whereas people with a higher status apply more informal affectionate touches [226]. Observational methods have the advantage over self-report methods in that they are not biased by the fact that the observer is also the reporter and it allows for touches to be observed without disturbing the interaction [246]. Some of the downsides of this method have already been discussed, but additional downsides are that it is a time-consuming method and that the researcher has no control over the variables of interest.

What both self-report and observational methods as described above have in common is that it is difficult to show causal relations (i.e. showing that, for example, touch A leads to behavior B). For this reason researchers have come up with clever experimental paradigms to study effects of social touch, either in the wild or in the lab, and to be able to infer causal relations from the results. One example is a study where participants were invited to fill out a fake personality questionnaire. The request to fill out the questionnaire was accompanied by a touch or not, and it was found that participants who received a touch filled out significantly more items on the very long questionnaire [395]. One not immediately obvious drawback of such an approach, however, is that it is difficult for the confederate, an accomplice (not unlikely an undergraduate student) of the researcher who is instructed to apply the relevant experimental manipulation, to remain consistent in his or her behavior [311]. It is quite likely that a confederate will show slightly different behavior depending on whether or not a touch is applied, and such slight variations in behavior can alter experimental results.

When reading about social touch research, or in fact any type of social science research, it is good to keep in mind the benefits and drawbacks of each method. In the next sections we will look at how these methods have been applied in research into social touch, and what results have been obtained from social touch research to date.

4.1 PHYSICAL AND EMOTIONAL WELL-BEING

Have you ever had the pleasure of watching a mother cat rear her kittens? Unfortunately, I have not, but luckily Youtube offers many such examples. Try any of the search terms ‘mother cat’ in combination with

'kitten' and you will be presented with a variety of examples. Assuming you are looking at some of the same videos as I am, you will see that there is an enormous amount of physical contact going on between the mother cat and her kittens, and especially licking predominates. This licking is not just a way for a mother cat to keep her kittens clean. The amount of licking actually far exceeds the amount that would be necessary for hygiene [363]. Although, if you are a cat owner like me, you too might have serious doubts about licking serving any hygienic purpose at all, what with a cat not shunning a good 'cleaning' after having just devoured a nice and smelly tin of tuna (See also [363] and [427] on self-licking behavior in mammals).

Importantly, licking is a form of social touch between mother cats and their kittens and licking occurs in almost all mammalian species [363]. Licking serves to stimulate all kinds of processes in both the mother and the infant, one such process, quite the opposite of hygiene one might say, is to help infant mammals to urinate and defecate [350, 363]. Since the 1940's numerous studies have been conducted that show that contact behaviors like licking, grooming, and general contact between mothers and infants are an absolute necessity for survival and proper development of infant mammals [363]. The coding of licking or stroking touches likely occurs through CT afferent nerve fibers found in the hairy skin of mammals [41, 134, 266, 301] and constitutes a unique pathway for this kind of positively valenced social touch (see Section 3.2). Without such positively valenced contact the infant's immune system will suffer, the digestive system will largely fail, behavioral patterns of the infant will be more anxious, and survival rates in later life will drop [40, 97, 348, 363, 524]. The most well-known study to illustrate this point was conducted by Harlow and colleagues [227], who separated infant rhesus macaques from their mother and found that the infant monkeys, when startled, would favor the contact of a soft surrogate mother to a wire-frame surrogate mother that provided food [227]. This behavior was taken as an indication of the biological need for touch.

While many such studies have been conducted with mammals, particularly in the early 20th century (See also Section 2.1), con-

ducting similar research with human infants has, luckily, never been attempted. However, historical accounts of orphanages in Romania in the late '80's and early '90's paint a remarkably similar picture [77, 98, 332].

As part of Decree 770 Nicolai Ceausescu, whose brutal Stalinist regime ran from 1965 until he was deposed and executed during the Romanian revolution in 1989, sought to increase the industrial output of the country and for this he needed a large workforce. Special measures were taken to increase birthrates in the country and these measures were so 'successful' that families could not take care of the many children they had birthed. This resulted in tens of thousands of children from birth to age 3, being institutionalized in so-called *leagăne* (meaning 'cradle' in Romanian), orphanages which turned out to be understaffed and unable to provide the sensory and social stimulation needed by children of such a young age [77, 294].

The negative consequences of this type of sensory and social deprivation were severe. Observations of deprived children revealed reduced cognitive, emotional, and social development [77, 98, 332, 374], the consequences of which may still show years later [35]. While it is difficult to say with certainty which factors contributed most strongly to the developmental issues experienced by these children [176], some argue that the lack of touch specifically accounts for the developmental issues of these deprived children [77, 159, 363]. Given the importance of touch in the early stages of life in mammals, the lack of touch (i.e. tactile deprivation) may indeed have had a profound negative impact on the development of these institutionalized children [See also 81].

Experimental evidence supports the notion that touch is important for the development of infants. Studies show that caring maternal touch can positively affect the infant, as well as the mother [157]. For example, caring maternal touch has a positive impact on neurological development of infants whose weight at birth is too low. Low birthweight infants of mothers who applied more stimulating touches showed greater visual-motor skill development a year later [528].

Maternal touch stimulates developmental processes in the human infant much like the way touch is important for the proper develop-

ment of other mammals [e.g. 348, 363]. Maternal touch can, however, also have direct effects on the infant's well-being. A method called sensorial saturation in which a multitude of sensory stimuli including taste, smell, voice, sight, touch and massage are used to compete with pain signals in an attempt to alleviate pain, has been successfully used to mitigate pain produced by certain medical procedures conducted on young children [37]. However, in such a multi-sensory approach it is difficult to assess the role of touch specifically. Another study has shown that when an infant is held with skin-to-skin contact by its mother, physical discomfort and pain during a medical procedure is reduced, more so than when the infant is placed in a crib instead [201]. With this study, however, it is still not possible to completely rule out the influence of other senses. For example, the mother's scent (which the infant would have been able to perceive when it was held but not when it was placed in a crib) might help the infant identify the mother [331], especially in the presence of pleasant tactile contact (i.e. stroking) [480], this identification of the mother in turn could alleviate the infant's discomfort.

An important drive for a mother to pick up, caress, hug or otherwise affectively touch her child is to improve the child's well-being by showing support or providing comfort [158]. Still, demonstrating the effects of maternal touch experimentally can be quite challenging due to the difficulty of isolating the effects of touch from the effects of other senses. One viable approach to study the influence of touch specifically is to use a so-called still-face paradigm [264]. In the still-face paradigm the mother interacts with the infant but then suddenly stops the interaction and shows a neutral facial expression. The infant's response will at first be to reestablish social contact, but when the mother remains unresponsive the infant will typically show disinterest and look away [4].

The still-face paradigm, as a simulation of 'maternal deprivation', was used in a study to see if maternal touch could reduce an infant's stress responses and recovery from stress in absence of other cues such as facial expressions or vocal utterances by the mother. The researchers found that maternal touch in combination with a still-

face reduced the magnitude of the infant's immediate stress response, measured as cardiac vagal tone responses (a physiological indicator of stress [407]), and facilitated a quicker recovery from stress in the infant, measured as changes in cortisol (a stress hormone) levels [157]. This type of contact between mother and child may be beneficial for the mother too, as cortisol levels of the mother and child tend to move closer together when mother and child are in contact with one another [377]. Moreover, the use of touch may be a beneficial tool for depressed mothers who are less expressive in their facial and vocal expression, in order to still provide proper socio-emotional stimulation to their child in absence of other social signals [399].

Maternal touch then, may indeed help to improve a child's well-being by lowering stress responses and facilitating recovery from stressful events. How then, could a mother best touch her child to maximize such effects? One study compared the effects of tickling, poking, and stroking touches on a child's affective and social responses [398]. When a female experimenter was interacting with a child and while making eye-contact also applied a touch, it was found that stroking touches resulted in the child making eye-contact more often, vocalizing more, smiling more, and crying and protesting less [398] [see also 400]. Conversely, in another study, when a mother touched her infant more roughly, in this particular case by clenching her hands around the child's abdomen, the child responded with more negative emotional expressions and less confident behavior [243]. Another type of touch that may be particularly beneficial in mother-child interactions is massaging touch. In an extensive review where multiple randomized controlled trials with massage as an intervention were analyzed, it was found that massage improved sleep and relaxation, reduced crying and had a beneficial impact on a number of physiological processes including responses to stress in infants [500]. The authors of the review remarked however, that the results were not convincing enough to make massages a universal recommendation for mother-infant interactions.

It could, however, be that massage therapy has additional benefits for children suffering from afflictions in the autism spectrum disorder (ASD) [150, 161], who are typically averse to being touched [107,

159, 518]. Recent studies with mice even suggest that a deficiency in the neurological organization of the sense of touch is linked to certain symptoms of autism disorders [387], thus the role of the sense of touch in autism may be quite profound.

4.1.1 A touch of romance to calm the nerves

Examples of maternal touch should be familiar to those who enjoyed growing up in a loving family. Though perhaps at the time, being stroked, squeezed, hugged, and kissed by your parents, especially in the presence of school friends, was an incredibly embarrassing affair, social touch, touch can positively affect a child's development (see Chapter 1 for some examples of social touch in the early school career of a young boy). The amount of touch we receive steadily declines as we grow older [159], yet social touch can still have positive effects on our well-being even at a later age and especially for those in a romantic relationship.

Many a line of poetry and prose have been written about the power of a lover's touch. Expressions of sheer ecstasy and rapture fill the screen in movies featuring the likes of Tom Cruise and Nicole Kidman when a lover caresses. While these images seem a bit exaggerated they do actually hold some truth. Studies have shown that physical contact with one's romantic partner can reduce stress and pain responses. Actors can make it seem easy, but for most people delivering a public speech can be a stressful event. A study has found that partner contact in the form of hand holding and hugging can have a measurable positive effect on physiological stress parameters such as blood pressure and heart rate during and after delivery of a speech [202]. Being massaged by one's partner, more so than receiving verbal support, can also lower stress responses, measured as heart rate responses and cortisol levels, during and after a public speaking task [127]. Such an attenuating effect of touch on stress responses is typically stronger when the touch is applied by one's partner than when it is applied by a stranger [102], and partner contact, rather than contact with a stranger has a stronger positive effect on pain reduction [345].

Interestingly, one study found that people who reported having a higher quality marriage showed enhanced effects of neural responses indicative of stress reduction when they held their spouse's hand [102]. It could of course be that people in a high quality marriage touch each other more, indeed research suggests that short-term positive effects of partner contact on stress may be stronger for those individuals who receive more frequent hugs from their partner in general [313].

Higher levels of oxytocin (sometimes called the "social bonding" hormone), which can be the result of more frequent physical contact with one's partner [156, 501, 502]), potentially mediates short-term positive effects of being touched by one's partner [313]. Frequent partner contact over longer periods of time is also related to general positive affect and psychological well-being [121], and is related to a lower risk of infection with the common cold virus [105].

If we were to provide some health advice based on these studies it would seem to boil down to: touch more to stay healthy! That, and make sure you have a happy marriage [102]. While such a one-sided advice would be taking it too far [193], as there are many factors that influence effects of social touch, think of the frequency and type of touch [528], not to mention who is doing the touching [102, 345], social touch does seem to benefit people's physical and emotional well-being under the right circumstances. A potentially useful way to capitalize on these beneficial effects is to apply social touch in health care settings.

Intuitively it makes sense that being touched in a loving way by your spouse can reduce stress. Nonetheless, at least in a lab setting, being touched by a stranger such as an experimenter, can also lower a person's heart rate [135]. Such an effect is more pronounced when the person's heart rate prior to the touch is higher [135], for example in the moments before a patient enters surgery. Such an effect is promising for the use of touch in health care as doctors and nurses could apply social touch to benefit a patient's well-being. Indeed, a study found that when a female nurse touched a female patient, this patient reported more positive affect towards hospitalization and surgery. Note, though, that touch by a female nurse had a negative effect on male patient's affective responses. The researchers hypothesized that this

has to do with the idea that males are socialized to be more uncomfortable with being dependent, and suggest that the touch by the nurse signaled that the patient was dependent on the nurse [529]. This last study already indicates that the use of touch by nurses can be less than straightforward and can also have negative effects for certain patients. The overall effects of touch as an intervention used in nursing are mixed, so an overall policy to adopt touch as a standard nursing practice is not to be recommended, and is even discouraged by some [193].

In the previous study the nurses used touch in an unobtrusive, communicative way but touch can also be used as a form of therapy and it is possible that such a more focussed therapeutic use of touch can be beneficial [537]. Using slow, circular stroking touches during multiple therapy sessions, researchers found that the anxiety levels and blood pressure of patients in an intensive care unit were lowered by such a therapy [239]. Both simple touch and more intense massage therapy can improve the mood and pain experience of cancer patients, though the beneficial effects of massage therapy are stronger than those of simple touch [302] [See also 160].

Touch has also been found to have therapeutic uses in mental health care [252, 537]. Social touch signals a therapist's care of and involvement with his or her patient, which can help patients to open up. That being said, the use of touch in mental health can be tricky and requires openness and sincerity, not to mention proper judgements from the therapist [252]. Touch can be used inappropriately and can be detrimental to the treatment if, for example, the intention of the touch is misinterpreted by the patient [12, 252].

How should we view the effects of touch on physical and emotional well-being? Is there such a thing as a healing touch? From the work discussed above, it would seem touch serves an important function in the development of young children. This is in line with the extensive body of research on the effects of touch in the development of other mammals. The use of touch between those in a romantic relationship also seems to have beneficial effects, especially for reducing stress.

However, the benefits of touch in health-care settings is debatable, and, until further research shows more consistent benefits of touch as a form of therapy, cannot be recommended as a form of treatment.

4.2 ATTACHMENT AND BONDING

When I was younger I used to have a small terry cloth blanket to which I clung for dear life, especially when it was time for me to go to bed. Alone, in a semi-dark room, while my parents went back downstairs to watch some well-deserved television after a hard day's work, I stroked and fondled the blanket while I fell asleep. Even long after I had given up the pacifier, I would still take my little terry cloth blanket with me when I went to bed (note: I have now given up on this habit). Terry cloth just so happens to be the same material that covered the surrogate mother that the baby macaques in Harlow and colleagues' study [227] clung to when they were startled. Coincidence? Or is there something more fundamental to the soft feel of a piece of terry cloth that comforts mammalian infants?

In a first description of what was then called 'transitional objects' [539], it was observed that young children can become attached to certain objects, typically a blanket, piece of cloth, or even part of the bedsheet. A child can form an emotional dependency on the object and can be soothed by it in times of anxiety and when going to bed [73, 394, 539]. Crucial for the use of the object and its soothing effect is the tactile quality of the object, which can even be washed as long as the feel of it does not change [73](though see [525] for the importance of familiarity rather than material qualities).

Having a security blanket is a rather common thing in many cultures, and does not seem to be harmful for a child's development [394]. The question remains however, why children become attached to an inanimate object. One suggestion is given by the baby monkey study, namely: the absence of the mother [227]. A popular hypothesis is that child-rearing practices in which there is less social and physical contact between mother and child leads to the child becoming attached to an inanimate object as a kind of substitute for motherly contact [169, 316, 363] [See also 394]. There is even some evidence that

in cultures where children are in constant contact with their mother, attachment to inanimate objects occurs less frequently (see also Section 2.2) [363] [See also 394]. In addition, children who spend more time in day care, away from their parents, are more likely to become dependent on a non-social object for a sense of security than children who spend less time in day care [169].

Of course I do not mean to imply that my having had a terry cloth blanket means my parents were negligent in any way. However, social contact and specifically social touch plays an important role in the way a child develops a secure attachment to its mother [7, 59, 60, 469]. Attachment refers to the affectional tie that one person forms with another [7], in this specific case a mother and child [59, 60]. The attachment relation is formed in an interplay between a child engaging in attachment behaviors, such as smiling, crying, moving closer and stretching out its arms, which are aimed at seeking proximity and contact with the mother, and the way in which a mother responds to these behaviors [7, 195, 469]. Attachment behaviors are especially relevant in situations where the child experiences distress [18, 66, 195, 333, 527], and physical contact with the mother serves as an important signal for safety and security to the child [527]. According to attachment theory a child will see a responsive and available mother as a secure, steady, and dependable base. This allows the child to become securely attached to its mother and the child will use her as a base from which to explore, and in the long run will be a confident and independent adolescent [7, 59, 66]. Conversely, a mother who does not respond in such a manner might run the risk of having a child that is anxiously (i.e. insecurely), or ambivalently attached, which can lead to the child having difficulty in dealing with certain social situations [7, 59, 66]. One study found that children who are less frequently touched by their parents, score higher on reports of current depression and show less secure attachment styles in later adolescent life [487]. Nevertheless, it is also important *how* the mother responds to the child's behavior's. In a study into the role of social touch in the forming of attachments it was found that nurturing touch rather than

the frequency of touch per se, was important for the forming of secure attachments for low-birthweight infants [527].

Physical proximity and physical contact are at the basis of an infant's attachment behaviors [333], and the frequency with, and the way in which a mother engages in social touch can affect the attachment relationship. Conversely, a person's attachment style can also predict this person's general feelings towards social touch, in both romantic, and parent-child relationships [95]. People with a less secure attachment style have been found to have more negative feelings towards cuddling in both types of relationships [95]. So a parent's own attachment style may carry over through the generations; a parent with an insecure attachment style will likely have children who are insecurely attached [95, 166] [see also 66]. An insecure attachment style may have an impact on how a person deals with romantic relationships, and the role of touch in such relationships. A study was carried out in which college students had to view images of a man and a woman engaged in touch of different intimacy levels [360]. The students were asked to imagine that either the man or woman in the images was their partner and had to rate how they felt towards the situation in the image. More intimate types of touch (i.e. touch to the torso) resulted in stronger feelings of jealousy overall. This was especially the case for female participants, and for participants with an insecure attachment style [360].

The concept of attachment is closely related to other concepts related to interpersonal relationships such as love and intimacy [80], and attachment theory has for quite some time now been recognized as a framework for explaining adult romantic attachment [170] [see also 7]. It should not be surprising that social touch in such relationships, such as a comforting hug from your partner, or being greeted with a kiss, that is to say non-sexual physical affection, is positively correlated with how satisfied a person is with his or her relationship and partner [213, 214]. And when you get into a fight over whose turn it is to do the dishes, do not fret! Affectionate physical contact has been found to help with conflict resolution for couples in a romantic relationship [214].

What then, makes social touch into a bonding agent for people in a romantic relationship? A part of the answer may be that the bonding aspect of social touch for couples is mediated by the release of oxytocin as a result of being touched [156, 501, 502]. Oxytocin is a hormone that has been implicated in bonding behavior of mammals [130], and is released during physical contact, such as grooming [259]. A study showed that being hugged frequently by one's partner can have health benefits in the form of lowered blood pressure [313] (see also Section 4.1.1). More frequent hugs from one's partner, were also found to be related to increased levels of oxytocin in the women that participated in the study [313]. This suggests that social touch, for example in the form of a hug, can result in the release of oxytocin which in turn could be a factor that aids people in forming a lasting social (romantic) relationship [213]. Nevertheless others caution against the overinterpretation of the effects of oxytocin on social behavior, due to methodological issues with a number of studies [522].

For most of us it may seem like a bit of an open door that responsive and caring parenting is good for a child's development, but since its conception there has been considerable critique on attachment theory [see also 7, 469]. Quite the opposite of what attachment theory suggests, behaviorists posited that coddling a child would lead to reinforcement of unwanted behaviors (e.g. if you respond to a crying child the child will cry again next time to elicit the wanted response in the mother), and would lead to an emotionally dependent child [363]. A mama's boy or girl, if you will. These claims have largely been refuted, and attachment theory in its general form is a widely accepted framework for the study of interpersonal relationships [34, 170], and is even used in the context of psychotherapy [310].

To summarize, a child will actually seek out physical contact, and appropriate responses from the mother to such contact, are an important signal of security to the infant. Such a feeling of security is important for the child to feel safe and be comfortable with independently exploring the world, and impacts how the child approaches social situations in later life. Considering modern life where it is not uncommon for both parents to work, a security blanket, while by no means a sub-

stitute for a mother's loving embrace, can serve as a stopgap to provide a sense of physical security for times when a mother is not immediately available.

4.3 ATTITUDE AND BEHAVIOR CHANGE

One of my favorite James Bond movies is *Goldfinger*. Not in the last place because Sean Connery, as we all know the best Bond ever, plays Bond, but also because the movie features one of the most interesting villains of all Bond movies: Auric Goldfinger. Goldfinger gets his name from his penchant for gold, not to mention the way in which he orchestrates the early demise of Jill Masterson, namely by painting her skin gold, causing "skin suffocation"¹, as Bond puts it. Indeed, as Shirley Bassey sang: "Goldfinger, he's the man, the man with the Midas touch". Goldfinger's predilection for turning anything and anyone to gold follows the legend of King Midas, a figure from Greek mythology for whom everything he touched turned to gold.

Where King Midas's situation was both a blessing (infinite riches) and a curse (not being able to be physically intimate with others), in social touch research the Midas touch effect is mainly regarded positively. The Midas touch effect describes an effect where people will be more likely to show pro-social behavior as a result of being briefly touched by another person [114]. Social touch can positively influence a person's attitude towards the toucher [71, 146, 163], and towards the environment in which the touch takes place [163, 251]. Not only has it been found that a person's attitude can be positively affected, behavior can be influenced as well. Have you ever found yourself leaving a restaurant wondering why on earth you were so generous with the tip?

¹007 Might have been better off consulting with Q or another scientist on this one. There have never been reported cases of 'skin suffocation', though complete blocking of the skin's pores, and thus preventing the body from cooling through the release of sweat could cause problems, one will not suffocate from having one's skin painted over. This was not fully known at the time of filming. As the story would have it, the filmmakers were so concerned about skin suffocation that a patch of skin was left open on the stomach of actress Shirley Eaton playing Jill Masterson. The idea of skin suffocation was so compelling, that there was even a stubborn myth that Eaton would have died from skin suffocation on set!

Well the answer might be that the waiter briefly touched your shoulder, without you noticing, when he handed you the bill. In a series of studies it has been found that being touched by a waiter in a restaurant can increase chances of giving a higher tip [114, 207, 251], and can increase the likelihood that restaurant guests follow menu-item suggestions by the waiter [208]. Some of these effects have been found to occur whether the restaurant guest was aware of being touched or not [204].

The Midas touch effect does not only occur in restaurants, but has been found to affect people in a number of other settings as well. One often used experimental paradigm is asking people for help or making another type of request, while either touching them briefly or not touching them. It has been found that a brief touch can make people more likely, when asked, to help pick up dropped items [206], help answer a lot of bogus personality item questions [395], give their opinion on difficult social issues [373], and return lost money [292].

While the Midas touch effect may seem like a ‘super power’ suitable for a Goldfinger-like Bond villain, studies have shown that the Midas touch effect can be used for good as well. Some studies have found that when a doctor or nurse briefly touches a patient’s shoulder the patient will be more likely to adhere to his or her prescribed medicine intake [209]. In a study in a retirement home it was found that a touch by a caregiver can even positively affect calorie intake by elderly residents, which in turn positively impacts their overall health [137].

If right now you’re thinking that it would be a good idea to accompany any request that you make of every person you meet with a touch, think again. Both characteristics of the toucher and the type of request that is being made can influence what effect a touch might have. Studies have shown that touch applied by more physically attractive people has a stronger positive effect on the person being touched [71, 251]. In general, positive effects of touch on pro-social behavior are stronger for females than for males [251, 536]. Others have found that when a female touches a male pro-social behavior is most strongly affected [396]. Moreover, touch may especially affect compliance for requests that require moderate effort, such as filling out a survey [536], but may have

little effect for requests that require little effort, such as signing a petition [536], or requests that require a lot of effort from a person, such as signing up to become a blood donor [205].

It is also worth noting that the situations in which the Midas touch effect has been studied are limited. It could very well be that touching a person when the timing is off, touch is not really appropriate in the situation, or a touch is made to an inappropriate body part, social touch can have a negative effect as well. Besides, it is currently not entirely clear why touch can affect a person's attitude or behavior positively. One possible explanation is that the touch is interpreted by the receiver as a signal that the toucher likes and trusts him or her, which is reciprocated by the receiver in the form of pro-social behavior [426]. Another explanation is that touch serves as a signal for power, dominance and status differences, resulting in the recipient of a touch being more compliant [76, 395].

These explanations however, involve a conscious process in which the toucher and the touch are evaluated by the person being touched and thus do not account for positive effects when people are not aware that they are being touched. It is possible that the release of oxytocin as a result of being touched, positively influences pro-social behavior of the person being touched [364]. Oxytocin is a hormone that plays a role in the forming of social bonds [130], so in case of the Midas touch, the release of oxytocin may trigger processes that are related to pro-social behavior.

A final suggestion for why touch can positively influence pro-social behavior might have to do with positive experiences with touch in infancy. As we have seen, when an infant is stressed or otherwise uncomfortable, a soothing touch by the mother can lower the infant's stress levels. Repeated exposure to positive maternal touch, may solidify the neural link between touch and positive feelings. This association between touch and positive affect, such as stress reduction, solidified during infancy, may result in positive responses to being touched in later life [176].

The positive effects that a Midas touch can have are quite remarkable and might actually be useful in situations where people require

to be convinced, such as in the case of a hospital patient that needs to stick to his or her medication. However, the nature of the studies into the Midas touch effect have raised some concerns. Think back for a moment to you tipping a waiter in a restaurant an exorbitant amount without your really knowing why. Perhaps the waiter smiled or smelled nice, and this, in combination with a touch, resulted in you giving a higher tip? This is to say, factors other than touch may influence pro-social behavior. Such other factors may be especially abundantly present in studies that are ecologically valid. These are studies that take place ‘in the wild’ and represent the noisiness and messiness of real-life situations. Such studies are different from lab studies in which there is greater control over external factors that may be of influence. A number of studies have found that the Midas touch effect is possibly confounded by a confederate bias effect [217, 292, 311]. This means that the confederate, the person who has been instructed by the experimenters to apply touch in a consistent manner, also, unwillingly, adjusts other social cues such as his or her gaze and facial expressions, which may impact pro-social behavior. As we shall see later, social touch technology can play an important role in uncovering such potential biases in Midas touch studies [217].

4.4 AFFECT AND MEANING

A phenomenon that is of interest to researchers in linguistics and anthropology alike, as well as is a favored topic in popular culture, is the phenomenon of so-called ‘untranslatable’ words [322]. An untranslatable word is a word for which there is no single word or sentence in another language that accurately describes the phenomenon the untranslatable word describes, without losing some of its meaning [322]. Most languages have such words, and chances are you can name a few yourself. In Dutch, for example, we have the word *gezellig* which denotes a feeling of cosiness, warmth, and enjoyment [322].

Whether or not you think of the Dutch when you hear the words ‘cosy’, ‘warm’, and ‘enjoyable’ is another matter entirely, but interestingly, there are many untranslatable words that describe aspects of

touch. What is more, these words often translate into affective phenomena. For example in Tagalog (Philippines), the word *gigil* refers to “the irresistible urge to pinch or squeeze someone because they are loved or cherished” [322, p.5]. In Portuguese, *cafune* refers to “tenderly running one’s fingers through a loved one’s hair” [322, p.6]. Even for the most culturally distinct words there seems to be a relation between touch and affective phenomena.

In the English language, as well as many other languages, from Basque to Chinese [314], there are actually plenty of words and expressions that use tactile descriptions to denote affective phenomena [363, p. 313]. A person can be described as emotionally ‘hot’ or ‘cold’, something can be a ‘touchy’ subject, you can feel ‘touched’ by piece of art, and a person can ‘rub you the wrong way’. Someone who is emotionally clumsy is sometimes referred to as ‘tactless’, literally lacking touch [314]. And why is it that we call feelings ‘feelings’, and not ‘smellings’, ‘hearings’, or ‘sightings’ [314, p.3]?

There is a clear connection between the metaphoric use of touch in language and affect. This is perhaps not surprising when we look at the importance of touch in signaling comfort to an infant, how a touch by a romantic partner can reduce stress, or when we look at how being touched can make someone judge a person more favorably. However, the most direct way in which a touch can elicit an affective response in the recipient, is through stimulation of specific receptors found in the skin. We have already seen in the previous sections that nociceptors provide the brain with information regarding painful, inherently unpleasant, tactual stimuli, stimulation of CT afferents signals the brain about pleasant stroking sensations, while stimulation of receptors in erogenous zones can produce pleasant erotic feelings [499].

Still, this is somewhat of an oversimplification. Think, for example about the meaning of the Tagalog word *gigil*: a (slightly) painful touch (e.g. pinching) from the right person can actually signal positive affect. At this point, it is necessary to consider the concepts of equifinality and equipotentiality with relation to social touch [246]. Equifinality refers to the fact that the same message can be communicated in different ways. For example, it is possible to show support to someone in dis-

tress by hugging them or putting an arm around their shoulder, both different types of touch that communicate the same message. Equipotentiality on the other hand, refers to the notion that the same type of touch can have very different meanings. When you push someone, it could either be a signal of playfulness, or it could be that you are looking for a fight. The same type of touch has a very different meaning. This is from the perspective of the person applying a touch, but the recipient of a touch can also interpret different touches to have the same meaning (i.e. equifinality), or the same touch to have different meanings (i.e. equipotentiality). For example, when someone puts an arm around your shoulder you might interpret this as either a sign of support, or a sign of dominance [246].

Both equifinality and equipotentiality are important concepts for interpersonal communication in general and social touch in particular, especially where the meaning and affective qualities of a touch are concerned. Factors such as the relationships between the toucher and the person being touched, their gender, and the body location which is touched can influence the interpretation of the meaning of a touch.

Researchers interested in how the meaning of touch is influenced by these factors, asked male and female unmarried college students to indicate how they would interpret touches to eleven different body locations, including the head, arm, and groin, when they were applied by a person of the opposite sex who is close to them [380]. For each touch (i.e. pat, squeeze, brush and stroke) participants were asked to indicate to what extent it communicated pleasantness, playfulness, warmth/love, friendship/fellowship, and sexual desire. The researchers found that the playfulness and warmth/lovingness of a touch depends more on the type of touch, but that the sexuality and friendliness of a touch depends more on the body location to which it is applied [380]. Interestingly, stroking was rated most loving, sexual, and pleasant overall, which is in line with the social touch hypothesis [366, 385, 386]. However, for female participants, the more a touch was associated with sexual desire the less it was considered to be playful, warm/loving, or to indicate friendship/fellowship, while this was exactly the opposite for male participants [380]. What is more, female participants primar-

ily interpreted the meaning of a touch based on the body location to which it was applied, whereas male participants interpreted the meaning of a touch mainly based on the type of touch that was applied [380].

The interpretation of the meaning of a touch then, seems to differ between men and women, at least when the touch is applied by someone familiar to the recipient [380]. The same researchers wondered how the interpretation of a touch would differ if it were to come from a complete stranger [247]. Again, they asked a sample of college students, both male and female, to indicate how they felt towards different types of touch to different body locations, but now they were also instructed to imagine the touch coming from either a person close to them or from a stranger of the same or opposite gender. In this study it was found that overall it mattered who applied the touch: touch from someone close and of the opposite gender was rated more pleasant and less of an invasion of privacy, than touch from a same gender person, whether friend or stranger. Stroking touches specifically, were rated as the most pleasant touches overall when applied by a close opposite-gender person to sexual body areas. However, female participants rated touch from an opposite-gender stranger as unpleasant, while male participants rated it as pleasant. In fact, male participants rated touch, even sexual touch, from a female stranger equally pleasant as from a female friend [247].

It is not yet exactly clear why there are such differences between men and women in the interpretation of touch. One suggestion is that, in general, women are more vulnerable to sexual assault than men and are thus more protective of their body. Another explanation has to do with stereotypical gender roles in courtship behavior [247, 380]. What is more, men are overall less comfortable being touched by other men than women are comfortable being touched by other women, though again the type of touch that is applied matters here [248]. Some researchers suggest that this difference exists because men are more afraid of being perceived as homosexual than are women [131, 248], though this may also depend on culture [534].

4.4.1 The expression of emotions through touch

Words can communicate, in some detail, an emotion or feeling a person wants to express, and the language used to do so can also impact the experience of emotions [403, 531]. Untranslatable words in different languages especially can describe rather complex affective phenomena [322]. In speech, both nonlinguistic vocalizations (e.g. laughing, sighing) and vocal expressions (e.g. acoustic parameters of speech) can make a vocal utterance emotionally expressive [434]. Facial expressions too, are a clear way through which we express emotions. There is evidence that prototypical facial expressions are related to certain emotions, for example, a smile can indicate happiness, a frown anger, and a pulled-up nose disgust [143, 434]. But what about touch? A touch can signal friendliness, can be interpreted as warm and pleasant, or indicate sexual desire. Exactly how you interpret the meaning of such a touch, though, depends on where it is applied, in what manner, and by whom. But is there perhaps more detailed information that a ‘sender’ of a touch can hope to communicate to a receiver?

In relation to this question, one group of researchers wondered if social touch could be used to communicate specific emotions, not unlike the way emotions are communicated through facial expressions. To investigate this matter they carried out a series of experiments [242, 244, 245]. In a first study that was carried out in Spain and the United States, two participants were invited to the lab, where they were separated from each other by a black curtain so they could not see each other [245]. One participant was then asked to stick his or her arm through a hole in the curtain. The participant on the other side of the curtain then touched the arm of the first participant in order to express one of twelve emotions. The first participant had to select which of the twelve emotions was being communicated.

Results from this study showed that participants in both Spain and the US could recognize the emotions anger, fear, disgust, love, gratitude and sympathy at above chance level [245], that is, better than just guessing at random. What is more, results from a similar US-only study showed that participants used specific types of touch to communicate specific emotions. For example, anger was communicated

by high intensity touches of a moderate duration, and mostly associated with hitting or squeezing. Love, on the other hand, was characterized by moderate-intensity touch of a longer duration, and was mostly associated with stroking touches [245].

Finally, the researchers asked a separate group of participants in the US to watch videos of the emotions being expressed through touch and to indicate for each expression which emotion they thought was being communicated. Results showed that participants could recognize the expression of anger, fear, happiness, disgust, love, and sympathy at above chance level [245]. From these studies it can be gathered that for at least six emotions expressed through touch, the accuracy with which these expressions are recognized is similar to that of the recognition accuracy of facial expressions of emotions [143].

In the first studies by Hertenstein and colleagues [245], emotions were only communicated by touch to another person's forearm. In reality social touch is applied to many different body locations and the location to which such a touch is applied can influence how it is interpreted [380]. So in another study Hertenstein and colleagues set out to investigate how well people would be able to recognize emotions expressed through touch, when these expressions were not limited to the forearm, but could be expressed by touching all over the body [244].

Again, participants were invited to the lab where the decoder (i.e. the person receiving the touches) would be blindfolded. Then the encoder (i.e. the toucher) would be instructed to express eight different emotions using touch to 'appropriate body locations' [244]. Similar to the previous studies the emotions, anger, fear, disgust, love, gratitude, and sympathy were recognized at above chance level. Moreover, unlike in the arm-only studies, the emotions of happiness and sadness were now also recognized at above chance level [244]. While the same types of touch were used to express different emotions (i.e. equipotentiality), for example hugging was used to express both sadness and happiness, the duration and intensity of these specific types of touch did differ for the expression of different emotions.

For this last study, when emotions were expressed through touch, it did not matter for the recognition rates whether a man expressed

emotions to a woman or vice versa, despite the fact that men and women used different types of touch to express the emotions [244]. However, when the researchers took a closer look at the data from their first arm-only study in the US, and especially at the gender of the toucher and recipient of the touch, they found that the recognition of certain emotions was different for men and women [242]. In particular, women overall failed to recognize anger expressed through touch by another woman, while men overall failed to recognize sympathy expressed through touch by another man. Finally, happiness was only accurately recognized when the encoder and decoder were both women [242]. The researchers suggest that gender stereotypes (e.g. men are more aggressive, while women are more caring) on both the side of the encoder and the decoder played a role here.

From these studies it would seem that social touch can be used to communicate emotions with the same level of accuracy as facial or vocal expressions [143, 434]. What is more, touch might actually be the preferred way to express certain emotions [21]. In one study, participants were asked to imagine that a life-sized mannequin represented a person that they felt close to. Then, participants were asked to express eleven different emotions using facial expressions, body postures or touch. Touch was found to be the preferred way of communicating emotions that are related to intimate relationship goals, namely love and sympathy [21]. In a follow-up study the same researchers investigated whether this preference for touch also meant that these emotions would be more accurately recognized when expressed through touch than through facial expressions or body postures. Indeed, the results from this study showed that love and sympathy were best recognized when they were expressed through touch, but note that using a combination of channels resulted in even better recognition of these emotions [21].

To conclude, social touch can be used to communicate quite detailed affective information between two people. As suggested by the use of touch metaphors in language, expressions related to intimacy and interpersonal relationships, especially, are readily communicated through touch. However, the interpretation of meaning from the touch

depends on what part of the body a touch is applied to, whether a touch occurs between people of the same gender or of different genders, and what is being communicated exactly. It is also worth noting that none of the studies reported here feature the use of actual social touch as it occurs in the real world. Studies either asked participants to imagine the touch [380, 247], or to apply a touch in an acted-out fashion [21, 242, 244, 245]. Moreover, in the studies into expressing specific emotions through touch, the expression of an emotion does not mean that the person expressing the emotion also experiences it internally. It is possible that when a person really feels angry, for example, he or she will express this anger quite differently than when acting out anger. Then again, expressing your anger through touch, especially painful touch, should at all times be discouraged.

CHAPTER FIVE

NO TWO TOUCHES ALIKE

One of the most exciting and memorable occurrences in Dutch football history of recent years was the 2014 World Cup. Eccentric coach Louis van Gaal was at the helm of what was first described as a mediocre team by most Dutchmen, but which, after wiping the floor with at that time reigning world champion Spain, soon inspired confidence and hope in a first Dutch world title. Alas, the team stranded in the semi-final, but not before pulling off one of the most fascinating substitutions of any world cup, in the quarter final against Costa Rica.

With the score drawn at 0-0 and extra time coming to a close, thus leaving the outcome of the match to be decided by a penalty shootout, Van Gaal, in his infinite wisdom, decided, during the last seconds of the match, to substitute the goalkeeper that had until then played every second of every match, with another goalkeeper. The idea here was that the substitute was a real 'penalty killer'. And indeed he delivered in rather spectacular fashion.

Not only did he seem well prepared, knowing at which corner each penalty taker would aim, he also went to extraordinary lengths to intimidate the Costa Rican players: jumping around, walking slowly back-and-forth, pointing at the penalty taker to let him know he did not stand a chance. This behavior did not, however, phase Costa Rica's first penalty taker. The Netherlands managed to score their

first penalty too, but then it was the turn of Costa Rica's captain. The Dutch goalkeeper casually walked up to him, and, with his massive goalkeeper glove, gently patted Costa Rica's captain on the shoulder. The team captain promptly missed his penalty and the Netherlands went on to win the shootout and thus the match.

Why, when social touch is so very common in sports [298, 461], did this particular touch disturb Costa Rica's team captain to such an extent as to make him miss his penalty? Surely a friendly pat on the shoulder inspires confidence? The adverse effects of this seemingly friendly touch most likely have to do with the fact that the person who was applying the touch was an opponent [76], rather than a friend or teammate. Moreover, while the type of touch that was used (i.e. patting), is generally associated with showing support [244, 245, 272], the sensory quality of the touch, being applied with a large goalkeeper's glove, was most likely not ideal for expressing support. Finally, the broader context in which the touch took place, namely at a crucial moment in an important football match, likely influenced the interpretation of the touch as well [246], and ultimately made the player miss the penalty.

If there is anything we can gather from all this, as well as from the research on social touch discussed in the first part of this book, it is that no two touches are alike. Looking back at the historical context of touch, we have seen that touch has been equally often related to sinful behavior as it has been described as the sense that makes the world real, can heal, and comforts those in need [101, 280, 433]. Cultural differences in the use of, and responses to touch are plentiful as well, especially for ritualized touches such as a handshake during a greeting [272, 363]. We have been introduced to the complexity of the human sense of touch, such as the fact that what we call 'touch' is actually made up of multiple submodalities, such as pressure and temperature [39, 178, 253, 328, 354]. What is more, there is a neurophysiological distinction between discriminative and affective touch [355, 356], and the latter of the two may be particularly relevant in social touch interactions [385].

Finally, we should also be aware of the fact that people differ in to what extent they use social touch, and that not every person may be equally comfortable with being touched by another person [273, 274]. The most extreme example of this is people who suffer from an affliction in the autism spectrum disorder, who may be very averse to being touched [107, 159, 518]. Apart from these more extreme cases people may differ in their attitudes towards touch [172]. In the literature on social touch, this is sometimes referred to as ‘touch avoidance’ [14, 16, 210, 211], in that someone low in touch avoidance has a relatively positive attitude towards social touch in general. Touch avoidance may be shaped by early childhood interaction, is linked to the development of attachment styles [389], and is related to certain personality traits [16, 123, 133]. Thus it is important to remember that, all other factors being equal, people may differ in how they respond to social touch based on their personality and general attitudes towards social touch.

Returning to that missed penalty, this situation perfectly demonstrates the challenges faced by social touch researchers. The person applying the touch, the sensory qualities of the touch that is applied, the broader context in which the touch takes place, as well as a person’s attitudes towards social touch in general, all influence how the social touch is experienced by the receiver. The answer as to why the player missed the penalty requires insight into all of these factors. However, much like in research into social touch, in this penalty situation it is still difficult to say to what extent exactly the social touch contributed to the miss, as the situation in which the touch occurred featured many other signals that likely influenced the penalty taker (e.g. the facial expression and stare of the goalkeeper, stadium noises, condition of the pitch, etc.) [see also 178].

Those studying social touch, then, are faced with the difficulty of having to take into account all of these factors to be able to say anything about the effects of a touch. As we have seen in the first part of this book research on social touch has utilized many different experimental paradigms, from controlled lab studies to observations in the field. Despite the challenges these research efforts have provided

valuable insights into which factors influence effects of social touch, and how they do so. Such findings are not just highly relevant for future social touch research, they should actually be considered the foundation on which research into social touch technology can build.

5.1 FROM SOCIAL TOUCH TO SOCIAL TOUCH TECHNOLOGY

Anyone who has ever had their mobile phone vibrate and has been notified of a text message through this type of haptic feedback may wonder how, compared to actual human touch, such a sensorially poor sensation could ever hope to achieve anything that even remotely resembles an actual human touch. Considering all the complexities of social touch, from historical and cultural, to the influences of other modalities and attitudes towards touch that have been discussed in the first part of this book, this question seems all the more relevant. How do we go from social touch to social touch technology?

While there are obvious differences between the sensorial qualities of vibrotactile feedback and those of an actual human touch, social touch, as discussed in the previous chapters, is a useful framework for thinking about social interactions through haptic technology. One way to do this is to make direct comparisons between social touch and social touch technology. Based on what we know from research into actual social touch, we might have expectations about what sort of effects might be obtained through social touch technology (e.g. the Midas touch effect [217]). Given that certain requirements are met, something which we shall return to in detail in the following chapters, we might expect people to respond to social touch technology in a way that is similar to the way that they respond to actual social touch. In this sense, we could see social touch as a kind of benchmark against which to test social interactions through haptic technology.

At the beginning of this chapter we have already been made aware of the fact that there are some clear challenges in the study of actual social touch. How do these challenges carry over to social touch technology research? All of the concepts important in social touch research, from historical connotations and cultural norms, through the influence of gender, age, and relationship, may also bear upon social

touch technology. In this sense, the challenges faced by researchers working on social touch technology are similar to those faced by the researchers discussed in the first part of this book.

However, where social touch researchers work with actual human beings applying or receiving actual social touches, researchers working on social touch technology have to make do with approximations of actual human touch by using haptic technology. It is important to consider to what extent such approximations are enough to compare social touch technology to actual social touch.

With the use of haptic technology rather than actual human touch, social touch technology research has not only to deal with all the complexities relevant to actual social touch, but also has to contend with aspects of hardware to apply or detect a touch, network speeds, and the general obtrusiveness of social touch technology devices [see also 495]. We will see in the following parts of this book, however, that these technical challenges can, with some clever use of available technology, to some extent, be overcome.

To boot, social touch technology is unlike actual social touch in several ways and these differences allow for factors that are difficult to control in actual social touch interactions to be controlled in social touch technology interactions. For one, though social touch technology is typically less sensorially rich than actual social touch, it allows for minute control over the physical parameters of a tactual sensation. Perhaps surprising for studies into social-affective aspects of touch, but many studies into CT afferent response characteristics have used a computer controlled tactile stimulator, rather than actual human touch [152, 320, 365, 402, 504]. The idea here is that a computer controlled stimulator can apply stroking touches with much more accuracy and much more consistency than an actual human could. So if we want to know more about the role of specific somatosensory aspects (i.e. the 'feel' of a social touch), it may actually be helpful to apply computer controlled social touch, rather than have a human experimenter, who has little control over his or her perspiration, skin texture, possible injuries such as scratches, et cetera, try their best to apply touches consistently (though note that in some settings re-

sponses between computer controlled and human touch may still be similar [493]).

Nonetheless, there is more to social touch technology than attempting to approximate the sensory qualities of a human touch. Imagine you are wearing a small bracelet with a vibration motor in it. Simply feeling a vibration would not be enough for you to even remotely consider this vibration as a social touch. If you knew that someone else had pressed a button to make you feel this sensation, this would likely make you more inclined to consider the sensation you felt as at least a social signal, though not necessarily as a social touch. What is more, in situations where a social touch is applied through technology it is not necessarily clear who is applying the touch. In other words the sensation that you feel is not attributed to another person *per se*. This has benefits for research (i.e. the perception of who is touching can be altered using additional cues, such as visual feedback), and provides significant challenges. If a haptic sensation is not attributed to another person or an artificial entity that we perceive to be social (e.g. a social robot), can we really speak of social touch through technology?

Unlike in actual social touch where you will likely see the person that touches you and can perceive his or her gender, facial expressions, the way they are dressed, and even the way they smell, such multimodal signals are not a given in social touch technology. The absence of such signals can make it more difficult for someone to attribute a haptic sensation to another person. Therefore, the use of signals from other modalities, such as visualizing that another person is the source of the vibration that you felt on the bracelet, may be very important for social touch technology when we make comparisons to actual social touch.

However, if you think back to the introduction of this chapter and the situation with the penalty taker you may have noticed how the lack of any cues from other modalities (e.g. stadium noises) can also be a benefit for research specifically because such cues are missing. In social touch technology it may be possible to investigate the effects of touch while keeping the influence of other modalities under control. For example, it is possible to manipulate the visual feedback of another

person applying a touch to make them appear either male or female [see also 182], control their facial expressions to be happy or angry while applying the touch, and, provided a fully immersive virtual reality (VR) environment is used, make it seem as if the touch occurs in a busy football stadium or in the comforts of one's own living room. As we have seen in the penalty example being able to rule out the influence of information from other senses might be very important in order to be able to say something about the influence of social touch specifically.

Another challenge that is faced by social touch researchers is obtaining information about how people touch [491]. We discussed how wearing a lab coat and carrying a clipboard to observe people interacting through social touch might not be the best way to go about obtaining data. If we go back for a minute to the imaginary vibrotactile bracelet you are wearing, and add to this image another remotely located person also wearing such a bracelet. Now imagine that you can both apply and receive touches through this bracelet, thus enabling a sort of low fidelity mediated social touch. However, for it to be possible to make you feel a vibration on the bracelet a touch applied by your communication partner has to be detected somehow. This could be done with a simple button press but this would limit the possibility for expressivity on the end of the sender, not to mention it would potentially throw out very useful information pertaining to the touches the sender makes. Current sensor technology makes it possible for specific aspects of a touch, such as the amount of force applied, to be detected and recorded. This information about the qualities of a touch is virtually impossible to obtain in actual social touch research without the use of such sensors. The idea that sensor technology can be integrated into social touch technology and can play a central role in interactions using such technology, is another benefit to research that social touch technology has over actual social touch.

There are some obvious differences between social touch and social touch technology. Some of these differences offer additional challenges to research into social touch technology, while at the same time, they can actually enable new ways of doing research and gathering data.

In the following parts of this book we will look at a number of ways to overcome some of these challenges and we will look at ways to capitalize on the potential benefits of social touch technology.

PART II

MEDIATED SOCIAL TOUCH

CHAPTER SIX

GAMING AND CANING: TECHNOLOGY FOR TOUCH

I have been fortunate enough to have been born in the 1980's. Not only was this a great decade for music, Bon Jovi, Madonna, Prince, Michael Jackson to name a few, it was also the decade in which Nintendo released the original Game Boy. To be completely honest, the Game Boy was much more interesting to me at the time than any kind of '80's music. A device with a display showing no less than four different shades of moss-green, a mono speaker, and a hand full of buttons, wrapped up in a brick-like plastic casing was the pinnacle of entertainment technology. So naturally, when I received a Game Boy as a gift on my fifth birthday, I could not have been happier, and spent many an after school afternoon playing *Tetris* and *Super Mario Land*.

Having been born in the 1980's had the added benefit of having missed the stricter school regime that I had first come to know about through stories told by my grandparents. I cannot help but wonder, had I been born in say, the '50's, how different my first day of school would have been had I undertaken the same escape attempt as described in the introduction to this book. In the past it was not at all uncommon for teachers to punish students quite severely for lesser misdeeds [100, 363]. The method through which such punishments were executed could vary from having to stand in the corner to corporal punishments such as receiving a spanking. Perhaps worst of all though, was being struck with the cane [100, 363, 390]. Now, as

unpleasant, ineffective [390], and even detrimental to a child's development [188], such corporal punishment may be, I want to turn your attention to the function of the cane in this instance. Here, the cane serves as an instrument with which to apply a punishing and painful touch. The cane serves as an example of a crude - and cruel - piece of social touch technology. One could say that the punishing touch is in essence mediated by the cane; the intent of the teacher to punish is effectuated, and perhaps enhanced, by applying such a touch with a cane.

Fortunately, there are other, much more pleasant examples of similar technology. Think, for instance, of hand-held massagers. A hand-held massager is an example of technology for applying a specific type of touch to deliver physical stimulation that is difficult to deliver by hand but that is made easier by the use of a piece of relatively simple technology [see also 283, 520]. Massagers can range from simple hand-held passive devices to vibrating massagers, shiatsu massagers, and even complete robotic installations [283], which can deliver quite rich tactual sensations. Though it is worth noting that such devices are not without risk, as a report of an unfortunate woman being accidentally strangled by her roller-type automatic massager makes evidently clear [124] [see also 149].

The use of technology that can stimulate the sense of touch has also found its way into human-computer interaction (HCI), and such technology is called haptic technology [234, 474]. Sadly, my Game Boy did not deliver any haptic feedback back in the '80's, but the gaming industry has been at the forefront of bringing haptic technology to the mass market. An early example is the Nintendo 64 rumble pack that would provide a rough vibrating (or rumbling) sensation when, for example, an explosion occurred in the game. Similar technology is still found in modern gaming peripherals.

The research field of haptics is concerned with investigating human-machine communication through the sense of touch [234, 474], in interactions where we can not only use our sense of touch for input, such as when using a touch-screen-based smart phone, but also receive computer generated touch output. Research into haptics has

mainly focussed on addressing the discriminative aspects of the human sense of touch. These discriminative aspects relate to the use of the human sense of touch as an exteroceptive sense that can detect, discriminate, and identify stimuli outside the body in order to guide behavior [356]. Haptic interfaces can be used to provide information about the state of a system through the user's sense of touch in order to allow the user to make decisions based on this information [234, 506]. Applications of such interfaces in HCI are found in remote operation, such as remote surgery [215, 336], haptic navigation systems, for example for helicopter pilots [510], and haptic warning systems, such as lane departure warning systems in cars [484].

As we have seen in the previous chapters, besides its discriminative function, the human sense of touch also serves an interoceptive, affective function, that can signal attraction or aversion towards a stimulus [355, 366]. Going back once more to the example of the cane, we can see that the cane serves as a device to deliver social touch that addresses the affective aspects of touch for motivational purposes. The idea here is that a painful stimulus generally motivates a person to withdraw from the stimulus, or from unwanted behavior in this specific example (note that the effectiveness of the cane for this purpose is highly questionable, though [188, 390]). It is, however, also possible to use technology, and technology rather more sophisticated than the cane, mind you, for positive affective touch in social interactions. Researchers have investigated how haptic technology can be used for interpersonal interactions aimed at such positive affective touch.

Research efforts for using haptic technology for social interactions that are not necessarily task-oriented are sometimes referred to as mediated social touch [219]. The general idea of mediated social touch is that one person can touch another person who is in a different physical location, through the use of sensors that can detect a touch, and actuators that can generate a haptic sensation based on the sensor input. In essence, the technology between the sender (i.e. the sensor) and receiver (i.e. the actuator) mediates the social touch interaction.

However, the use of technology to mediate a social touch inevitably means that there are differences between mediated social touch and

actual social touch. First, it should be noted that the term ‘mediated social touch’ is somewhat of an oxymoron as touch by its very nature implies physical proximity. The fact that in mediated social touch a considerable distance can separate the toucher and the receiver means that the receiver may not necessarily attribute a haptic sensation to the sender, especially given that information obtained from other modalities (e.g. facial expressions, vocal expressions, gender, social relationships) is not automatically communicated.

Second, though significant strides are being made in various labs around the globe [e.g. 429], technology cannot, at present, produce a full reproduction of human touch. This applies not only to the sensation felt by the receiver but also to what current sensors can detect on the sender’s end. What is more, in actual social touch, ‘sending’ and receiving a touch are closely intertwined, whereas in mediated social touch, technically speaking, a haptic sensation could be delivered with the press of a button. Thus, the output does not necessarily closely resemble the input. The notion of ‘touching is to be touched’ can be quite different for mediated social touch.

Finally, the computation and networking technology often found in mediated social touch are also a source of clear differences between mediated and actual social touch. Mediated social touch requires a connection between input and output. Such a connection could be wired, limiting the distance between sender and receiver to a few meters, but will most often occur through a network such as the Internet. And with such networking almost inevitably comes a delay between input and output. A touch may be applied, and then with a delay varying from a few milliseconds to several seconds, be received. In addition, hypothetically, touches could also be stored and made available to the receiver at a completely different time. Moreover, where actual social touch is usually one-to-one, or at least limited to the number of people you can hug at once given the reach of your arms, the computation and networking technology used in mediated social touch, also makes it possible for touches to occur not one-to-one, but one-to-many, or many-to-one [99].

An important question is to what extent the differences between ac-

tual and mediated social touch are detrimental to the experience of mediated social touch and its potential to elicit the same responses as to an actual social touch. In the next chapters we will explore this question by first discussing some of the technology that makes mediated social touch possible. We will then look at how researchers have used this technology to create various devices for mediated social touch interactions. Then, as for actual social touch, we will take a look at how mediated social touch can affect humans. All this serves to introduce the core of this part of the book: the iterative design process of a device for mediated social touch called the TaSST: Tactile Sleeve for Social Touch.

6.1 PRODUCING TOUCH

The dream of every social touch technology researcher thinking about what sort of method to use to apply haptic stimulation with, can be found in a creation of American cartoonist Charles Addams: The Addams Family. I am not referring to stoically servile Lurch serving as an ideal experiment aid, or uncle Fester as the perfect test subject for whom no experimental task would be too outlandish or indeed too dangerous or harmful. I am referring here to Thing. Thing, first hinted at in a cartoon in a 1945 issue of *The New Yorker* in which the Addams's mansion was depicted with a sign reading "Beware of the Thing" [5], and later, in a 1954 cartoon [6], first shown as a pair of hands changing a phonograph. The subsequent 1964 television show reserved a larger role for Thing, where he often popped up out of one of the many containers strewn around the Addams's mansion. It was not until the later 1991 movie adaption, however, that Thing was envisioned as a completely disembodied human hand.

Such a dexterous hand would be a marvelous tool to have for social touch technology researchers in order to apply haptic stimulation to various parts of the human body, but without the need for a complete human being to be present. Perhaps not surprising then, that companies and researchers have been investing time in creating Thing-like mechanical hands for various purposes, such as robotic manipulation [429] and prosthetics [122]. However, such robotic hands are com-

plicated devices requiring a lot of control hardware and software, are not as dextrous (yet) as an actual human hand, and are very costly. If only we had a perfectly obedient disembodied human hand. Alas, since Thing has remained the brainchild of a cartoonist, researchers have had to look elsewhere for available methods of applying haptic stimulation to the human body.

One of the aims of mediated social touch is to reproduce actual human touch at a distance. This is no easy task given the dexterity of the human hand, and the use of various types of actuators - devices that can stimulate the sense of touch - as a substitute for actual human touch almost inevitably means that the sensation that is produced is to a more or lesser degree a degradation of actual human touch. Nevertheless, proper use of actuators can produce sensations that reproduce at least part of a human touch, such as the pressure applied during a grasp, or the warmth of a human body. Such actuators can stimulate receptors in the human skin in a way similar to actual human touch.

We can divide haptic devices, which may include several actuators, into two broad categories: those that address the kinesthetic sense and thus exert forces on the limbs, muscles, and joints, and those that address the cutaneous sense and thus produce sensations on the skin's surface [45, 225, 263]. An example of the former are so-called force feedback devices [45, 234, 235], while examples in the latter category are so-called tactile or tactual displays [96, 263, 271, 488].

Examples of force feedback devices, like many mainstream applications of haptic technology, can be found in the world of video games, specifically in arcade machines and peripherals for racing simulations. In both the elaborate arcade cabinets that are made to look like the interior of a racing car, as well as in steering wheels that you can buy to be used at home, force feedback is used to provide the player with a feel for what the in-game car is doing, the conditions of the road, and collisions with opponents. Such devices typically use a DC motor, and some type of sensor (such as a rotary encoder), to measure the position of the steering wheel. The steering wheel can now apply forces based on what is happening in the game by turning the motor in a certain direction. This process is referred to as impedance control [235]. When the

impedance is zero the player will only feel the natural resistance of the steering wheel. However, when the impedance is increased, turning the steering wheel will require more effort. With very high impedance, which requires a powerful motor, it would be very hard to move the steering wheel at all.

Steering wheel peripherals for gaming are one example of the commercial application of force feedback. The same principal found in these steering wheels (usually using impedance control, though other methods are available [235]), is applied in much more complex systems. Traditionally, force feedback was used for teleoperation purposes [234, 474], which can in essence be seen as a form of touch at a distance, but for discriminative touch purposes. The ultimate test for discriminative touch at a distance is perhaps remote surgery [215, 336], where a surgeon uses haptic technology to operate on an actual patient in a different physical location. The first remote surgery on a human took place in 2001 when a surgeon in the United States remotely controlled two robotic arms that were located in France, allowing him to operate on a patient remotely. The system communicated everything that the robotic arms felt to the surgeon which enabled him to make accurate incisions, and eventually conduct a successful laparoscopic cholecystectomy (gall-bladder removal) [336]. This incredible feat was made possible by fast computer networks, and the same basic principles of haptic feedback found in the gaming steering wheel.

A motor is the most common way of generating force feedback [235], but there are other possibilities that have been explored. One Thing-like robotic hand, for example, can move thanks to compressed air that moves artificial muscles [429]. Another approach that has been explored is to apply an electrical current directly to someone's muscles using electrodes, thus making the muscles contract involuntarily and giving the person a sense of a force being applied to his or her arm [327]. Incidentally, this last method is also what Bruce Lee used for building up muscle, and can be found in workout devices that stimulate the abdominal muscles, for example.

Unlike force feedback devices tactile displays do not address the

kinesthetic sense. They do not exert forces on the limbs, but instead, stimulate different receptors found in the skin. For example, a Peltier element can, when a voltage is applied, transfer heat from one side of its surface to the other resulting in one side becoming cool and the other side becoming hot. Such temperature differences can be detected by thermoreceptors in the skin, and, when care is taken not to overdo things and cause a burn, warming sensations especially can feel quite pleasant to the recipient [440, 441].

While thermal sensations are interesting and could be used to emulate the warmth of a human body [533], actuators and devices that mechanically stimulate the skin are far more common in haptic interfaces. Such mechanical stimulation is detected by the various mechanoreceptors found in the human skin, though which specific receptors are involved in the detection of a mechanical stimulus depends on the type of stimulation provided. For example, we have already seen that CT afferents may play a prominent role in the detection of stroking touches [356].

There is a large variety of actuators available to provide a mechanical stimulation to the skin. For example, there have been some efforts in recent years to use compressed air to directly stimulate the skin; a so-called ‘air jet’ system [463, 496]. The idea is that when air is pushed through a specially designed nozzle, a vortex of concentrated air is created that can be felt on the skin. By manipulating the angle of the nozzle the location of the sensation can be changed and it is even possible to create a moving sensation over the skin. Additionally, the temperature of the air can also be altered, thus this approach has the potential to also deliberately stimulate thermoreceptors.

One benefit of this technology is that it does not require a person to wear any kind of hardware on his or her body and thus allows one to move around relatively freely within the reach of the nozzle, unencumbered by wires and the like. Applications of this type of technology have been suggested for, here we go again, gaming. What is more, research suggests that certain aspects of an air jet stimulus, such as the velocity of movement, and the intensity and warmth of the air flow, can be used to communicate affect [496]. Thus, there may be a potential ap-

plication for social touch technology. However, we should be mindful that these types of systems are not as unobtrusive as sometimes suggested [495], as they require a relatively large, noisy, and stationary compressor to push the air through the nozzle.

Air jet systems do not require any hardware to be worn on the body, however there are several approaches in which a person wears a device on the arm, wrist, or hand, and through this device can feel different tactile sensations. Different types of motors, such as servomotors or stepper motors, can be attached to the body and can be used to create sensations such as tapping, stroking, squeezing, and twisting [471]. Still, the most common approach to delivering stimulation to the skin is through the use of vibrotactile feedback [96, 271, 506].

6.1.1 Vibrotactile feedback

The type of feedback that is most often used in haptic devices and that virtually everyone who has ever owned a mobile phone or modern game console will be familiar with, is vibrotactile feedback. The prolific use of vibrotactile feedback in the design of prototype devices as well as in studies into haptic perception [96, 271, 506], warrants a closer examination of this type of feedback. Not in the least because vibrotactile feedback will play a prominent role in later parts of this book.

The detection of vibrotactile stimulation occurs through rapidly adapting mechanoreceptors (i.e. those that do not continuously respond to static pressure, but rather to motion over the skin), specifically Meissner corpuscles and Pacinian corpuscles. Meissner corpuscles lie close to the surface of the skin and are sensitive to low frequency vibrations of between 0-100 Hz. Pacinian corpuscles are found in the deeper layers of the dermis and respond to a much wider frequency range from 5-1000 Hz [282].

Vibrotactile stimuli are consciously perceived when the amplitude (i.e. the intensity) of vibration is above a certain threshold. This threshold is dependent on a number of factors including the number of actuators grouped together, the duration of vibration, the body location to which it is applied, as well as at what frequency the vibration is applied [271, 506]. Overall, vibrotactile stimuli with a frequency between

150-300 Hz will be most easily detected all over the body as long as the detection threshold is reached in terms of vibration amplitude [271]. The finger tips are the most sensitive to vibrotactile feedback, and can detect vibrations that have a relatively low amplitude [271, 506].

There are three varieties of vibrotactile actuators that are commonly used: eccentric mass vibration motors, voice coil actuators, and piezo actuators. Eccentric mass vibration motors are small motors that have a weight attached at an offset to the axle of the motor. When the motor spins it basically hurls this weight around its axle, causing the entire motor to shake around (think of a brick in a washing machine), and as long as the entire motor is not rigidly affixed to something solid, will produce a vibration [235]. A downside of using these motors is that the frequency of vibration cannot be controlled separately from its amplitude [235]. If you want a stronger vibration the only option available is to make the motor spin faster, which also increases the frequency of vibration. The general appeal of vibration motors is that they can be very small, energy efficient, and affordable and thus lend themselves well for experimentation in wearable prototypes.

Vibrotactile actuators for which frequency and amplitude can be controlled separately have the benefit of allowing for their vibration to be tuned to an optimal frequency of between 150-300 Hz. Both voice coil actuators and piezo actuators can be used in this way, though the way they produce vibrations differs. Voice coil actuators use magnetic coils to drive a tactor, a solid piece that makes contact with the skin, into the surface of the skin. The design is basically that of a loudspeaker with the speaker conus being replaced by a tactor. Thus, unlike an eccentric mass vibration motor which relies on the entire casing to be able to move around, a voice coil actuator with a tactor will stimulate a relatively small area of the skin. Piezo actuators consist of different layers of piezoceramic materials that, when an electrical current is applied, can bend and deform [409]. When this deformation happens quickly enough, the piezo actuator will produce a vibration.

One downside of all vibrotactile actuators is that they produce audible sound. This is especially the case for eccentric mass vibration motors, as all those who have left their phone lying on the table with

the vibration function on will recognize. Another possible downside is that the stimulation they produce can feel quite mechanical and artificial. While this is generally not an issue for applications where vibrotactile feedback is used to present information [179, 506], it may make vibrotactile feedback less suitable for affective or social communication. Nevertheless, there is evidence that vibrotactile feedback can be used for interpersonal communication [478], for example using specifically designed vibration patterns as a kind of ‘haptic icons’ [68, 431]. Such messages could be used for affective communication using mobile devices, by varying the rhythm and frequency of vibrations [414, 451, 452]. As we will see in later chapters there are other methods that might make vibrotactile feedback useful for social touch interactions.

None of the methods to provide haptic feedback discussed in this section really come close to the sensation of an actual human touch, or a touch by the Addams family’s Thing for that matter. Nevertheless, considering the variety of methods discussed here it is possible to reproduce parts of a human touch sensation by careful use of specific types of actuators. For example, a servomotor can be used to deliver a squeezing sensation that perhaps lacks the warmth, texture, and exact form of a human squeeze, but can nevertheless reproduce the kind of force that is typical of a squeezing sensation [471]. Furthermore, recipients of haptic feedback, even relatively crude vibrotactile feedback, can attribute affective qualities to the sensation that they feel [e.g. 452]. Although this does not mean that people respond in a similar fashion to these types of stimulation as they do to actual human touch *per se*, it does show that haptic stimulation can have qualities beyond task-related information transfer [219].

With this we now have some more insight into which technology can be used in mediated social touch on the side of the recipient. However, mediated social touch, in the sense that an actual social touch occurs mediated through technology, also requires insights into technologies that are available to the sender. In other words, sensor technology that can detect aspects of a human touch. This sensor technology will be discussed in the next section.

6.2 SENSING TOUCH

As humans we have, quite literally, a highly sensitive sensor apparatus at the tips of our fingers. The fingertips contain a very high density of mechanoreceptors [224], and this makes our fingers exceptional touch detectors. We are, however, not unique in this sense. Many other mammals, especially primates, have a similarly high concentration of receptors in their fingertips [513]. Think, for example, of a chimpanzee carefully plucking ticks and fleas from a family member's back, or using a thin stick to scoop termites out of their nests [52]. Other animals have developed even more specialized sensor apparatuses. The star-nosed mole, for example, has tentacle-like appendages on its nose that contain an especially high density of receptors, making this tentacle cluster one of the most sensitive mammalian touch-apparatuses, and allowing the star-nosed mole to detect even the slightest movements of unsuspecting prey [314]. Perhaps most remarkable of all though, are the fingers of the aye-aye [2], all of which have evolved for a specific function, like the tools in a Swiss army knife, and all of which can be controlled independently [464]. The middle finger in particular is rather special in that it is needle-thin and much longer than the other fingers [464]. The aye-aye uses this finger to carefully tap the trunk of a tree to locate larvae, and it is suggested that the aye-aye's sense of touch plays an important role in locating its meal [147].

The specialization of the aye-aye's fingers forms a nice analogy for the currently available touch sensor technology. This sensor technology too, is specialized in detecting certain features of touch, and can thus be used for a specific purpose. Like the haptic feedback technology discussed in the previous section we can also globally divide touch sensors into sensors that measure kinesthetic aspects of touch and those that measure touches on a skin-like surface. This division parallels the human's sense of touch which can also be functionally divided in a kinesthetic sense, dealing with sensing limb movement in time and space, and a cutaneous sense which detects stimuli on the skin's surface [326].

From reading the previous section you will have noticed that we have already briefly mentioned sensor technology in relation to force

feedback devices. For example, for a racing game steering wheel to be able to provide force feedback, it needs to know the orientation of the wheel. This is similar to more complex force feedback devices, such as devices that allow for manipulation of objects in 3D virtual spaces [45, 344, 454]. Such devices can take the form of a stylus that is connected to a number of rods and joints and thus have more degrees of freedom than a racing wheel. This also means that these devices need to be able to measure the position of several joints all at once. The positions of the joints are used to provide an accurate representation of the position and orientation of the device in the virtual space and to be able to provide appropriate force feedback through motors in each joint. Most common is the use of sensors such as rotary encoders, or Hall effect sensors to measure the position of a joint in force feedback devices [235].

It may be possible to derive the general position of a person's arm and hand from the position of a stylus that is attached to a force feedback device. This would in essence give a person a way to reach into a virtual world [474]. Other approaches to derive the position of a person's limbs include attaching sensors, such as bend sensors, directly to a person's body [192], or using vision based sensor technology, such as a Kinect to detect the position and movement of a person's body and limbs [406].

The detection of touches on skin-like surfaces, which is analogous to the way the cutaneous sense works, has been of particular interest to the field of robotics and human-robot interaction where efforts have been made to give robots a touch sensitive skin [115]. This makes the parallels with the human cutaneous sense all the more apparent. We will revisit tactile human-robot interaction in Chapter 12. For now, let us consider the sensor technology used in such robots, as this technology can be equally useful for mediated social touch applications.

There are relatively simple over-the-counter sensor technologies that have been successfully used to detect touches [542]. One example is the force-sensitive resistor (FSR). An FSR is basically a resistor that changes its electrical resistance when a force is applied that compresses the layers that make up the resistor, thus allowing it to detect

touches of differing force. FSRs are relatively cheap and can be placed on flat as well as curved surfaces [542]. Downsides of FSRs are that they need to be affixed to a rigid surface to function properly, and have a relatively high detection threshold and will therefore not detect very subtle touches. What is more, because of the fact that FSRs are discrete sensor units, their use in the detection of the location of a touch is limited unless a number of them is placed in a grid.

Sensors such as capacitive sensors, like those found in laptop trackpads and touchscreens, on the other hand, require only contact with a conductive material for a touch to be detected. This makes them more sensitive to touch than an FSR, but capacitive sensors lack the ability to detect differences in forces being applied. They do, however, allow for multiple touches to be detected on a continuous surface making them ideal for detecting the location of a touch. There are several implementations of techniques that are similar to capacitive sensing in that they can detect contact and location, but not force. Such techniques have been used to detect multi-touch gestures on a flat [417], or curved [445, 459] surface, and they can even be integrated into textiles [408].

Finally, there are technologies that combine the qualities of resistive and capacitive sensing, making it possible to detect both the force as well as the location of a touch [540, 279]. These technologies are similar to an FSR in that they consist of strips of conductive materials (e.g. piezo-resistive materials) and isolating material stacked on top of each other perpendicularly, forming a grid structure [540, 279]. With such a design it becomes possible to not only detect the force of a touch through compression of the layers of conductive and resistive materials, but also to get an idea of the location of the touch on the grid.

One particular benefit of this sensor design is that more data regarding the touches applied to the sensor can be gathered. The gathering of such data opens up ways to use machine learning in order to derive features of social touch [277, 278]. Such features can then be used for automatic touch detection, such as detecting whether someone is applying a stroking touch or is hitting the sensor with the palm of their

hand [277]. It should be noted, though, that the accuracy of such classifications may strongly depend on the method used to derive features from the data [11, 181, 255, 485]. A step beyond the classification of the type of touch would be to be able to derive the meaning of a touch from recorded sensor data. Such efforts are already being undertaken for the detection of affect in touch gestures [540].

The use of sensor technology for the automatic classification of touches could be very useful for the study of social touch in general. This approach would enable researchers to gather data, such as the force of a touch, that is difficult to obtain otherwise. For mediated social touch too, being able to analyze a touch applied to a sensor makes it possible to optimize the output at the end of the receiver. If, for example, a sender wants to apply a smooth, continuous stroking touch to a receiver, he or she could apply a stroking touch to a skin-like sensor. The data obtained by the sensor is analyzed, and classified as a stroking touch with a certain velocity, and certain force. The classified touch could then be coupled to a pre-designed and optimized stroking touch that is applied at the end of the receiver. A benefit of this approach is that it will remove any unwanted noise that would be present when sensor and actuator are connected in a direct fashion. A downside is that there will likely be an increased delay between sending and receiving a touch.

The coupling of touch input, enabled by various sensor technologies, to haptic output can be seen as a rough outline of a system that could detect a touch on the end of the sender and produce a touch on the end of the receiver. This is the basic premise of mediated social touch [219]. In the next section we will see how touch producing technology and touch sensing technology can come together in prototypes for mediated social touch.

6.3 DEVICES FOR MEDIATED SOCIAL TOUCH

The political climate in the 1980's was one that can be characterized by a slow winding down of the Cold War. Instrumental in bringing an end to this large-scale international conflict were the efforts of American president Ronald Reagan and Soviet leader Mikhail Gorbachov, which

led to growing rapprochement by both superpowers [421]. The end of the Cold War is perhaps most clearly symbolized by the fall of the Berlin Wall in 1989, and made definitive by the dissolution of the Soviet Union in 1991.

Three years before the Berlin wall came down, however, two artist joined forces with the aim of improving US-Soviet relations, by using a device that they had developed. In 1986 Norman White and Doug Back presented their Telephonic arm wrestling¹ installation at an arts symposium in Italy [530]. The idea was that the device would allow two people to arm wrestle while being at opposite ends of the world. This was made possible by two connected force feedback devices that could communicate the position of, and force applied by, a user's arm. Two identical devices were connected over the telephone line and the forces and movements of one device were, with some inevitable delay caused by the limited bandwidth, transferred to the second device. White and Back envisioned one half of the Telephonic arm wrestling installation to be put on the desk of US president Reagan in the White House, and the other half on the desk of Soviet leader Gorbachov in the Kremlin. If there were a disagreement between both countries it could be settled by the two leaders arm wrestling.

The Telephonic arm wrestling installation was not meant for competition per se but was conceived of as an exploration in using the sense of touch for remote communication. Moreover, the installation was not so much designed for using the sense of touch to communicate information [see also 179] but rather for social communication through touch at a distance. The Telephonic arm wrestling installation, in this sense, can be seen as the first device for mediated social touch [219]. Given that this device stems from before the end of the Cold War, you might expect that others have followed suit in quick succession. This is not the case, however. In the remainder of the 1980's as well as the 1990's only a handful of prototypes for mediated social touch were developed. Undoubtably this slow development has its origins in the fact that mediated social touch was a very novel concept at the time,

¹A video of Norman White explaining the concept and demonstrating the device is available at <https://vimeo.com/44733790> (last accessed 28-07-2016).

the term itself not having been coined until 2006 [219]. What is more, the technology available at the time made mediated social touch technically very challenging due to the issue of limited network bandwidth. Indeed, Norman White explains that the first version of the Telephonic arm wrestling installation was plagued by networking issues due to the telephone line that was used. This issue was later addressed in a new version, created in 2011 for the Strategic Arts Initiative 2.0 event organized by Dutch centre for art and media technology V2², which used modern networking technology.

Technology has improved considerably since the late '80's and significant advances have been made in the development of devices for mediated social touch. In 2014, the first commercially successful, or moderately successful, product to feature mediated social touch capabilities was announced: the Apple Watch. The Apple Watch contains a functionality that Apple calls "digital touch", and that allows one wearer to tap his or her watch and send this pattern of taps to another person wearing an Apple Watch who can see and feel the taps.

As can be observed from Table 6.1, despite technological challenges, researchers and designers have developed a variety of devices for mediated social touch. Many of these efforts were explorations to see what was possible with the available technology and to see how people would use haptic communication technology that was not meant for task-oriented purposes (e.g. related to the operation of machinery [179]), or for sensory substitution for those with impairments, such as aids for the blind [178, 179, 219].

Table 6.1 lists a number of devices for mediated social touch. The devices listed have been discussed in some detail by others [219, 432, 430]. Here, the focus is on discussing some of the underlying principles that have informed the design of these devices. We will take a look at a number of aspects that are also important in actual social touch, such as the body location to which touches are applied, the type of touch that is applied, and the meaning that a person could perceive in a touch.

²<http://v2.nl/events/strategic-arts-initiative-2.0> (last accessed 08-08-2016)

Table 6.1: Selection of prototypes for mediated social touch.

Prototype	Meaning	Type of touch	Body location	Actuation ^a	Modalities ^b
Vibrobod [128]	Affection	Abstract, contact	Hand, abdomen, upper leg	Vib.	T, A
The Bed [129]	Affection	Contact	Hand, arm, chest, abdomen	Temp., vib.	T, V, A
The Hug [126]	Affection	Hug	Hand, arm, chest, abdomen, upper leg	Temp., vib.	T, V, A
Hug over a distance [369]	Affection	Hug	Torso	Force	T
Huggy pajama [489]	Affection	Hug	Chest, abdomen, back	Force	T
HaptiHug [497]	Affection	Hug	Torso	Force	T, V, A
Thermal hug [196]	Affection	Hug	Lower back, side	Temp.	T
Squeeze device [523]	Affection	Squeeze	Upper arm	Force	T, A
Stroking device [141]	Affection	Stroke	Hand	Force	T
Kissenger [436]	Affection	Kiss	Lips	Force	T, V, A
Affective tele-touch [75]	Affection	Contact, press, tickle	Lower arm	Force, vib., temp.	T
Tele-handshake system [231]	Greeting	Handshake	Hand	Force	T
Tele-handshake [9]	Greeting	Handshake	Hand	Force	T, V
Remote Handshake [372]	Greeting	Handshake	Hand	Force, temp.	T, V, A
YourGloves [197]	Inclusion	Holding hands	Hand	Force	T
HotHands, HotMits [197]	Inclusion	Holding hands	Hand	Temp.	T
Shaker [477]	Playful affection	Abstract	Hand	Force	T
inTouch [61]	Playful affection	Abstract	Hand	Force	T
HandJive [165]	Playful affection	Abstract	Hand	Force	T
Tug of War [36]	Playful affection	Abstract	Hand	Force	T, V, A
KUSUGURI [174]	Playful affection	Tickle	Hand	Vib.	T, V
The Tickler [293]	Playful affection	Tickle	Hand	Force.	T, V
HaptiTickler [498]	Playful affection	Tickle	Side	Vib.	T, V, A
Telephonic arm wrestling [530]	Playful aggression	Arm wrestling	Hand	Force	T
ComTouch [86]	Symbolic	Abstract	Hand	Vib.	T, A
CheekTouch [392]	Symbolic	Abstract	Hand, cheek	Vib.	T, A
ForcePhone [250]	Symbolic	Abstract	Hand, cheek	Vib.	T, A
POKE [393]	Symbolic	Poke	Hand, cheek	Force, vib.	T, A
RingU [410]	Symbolic	Abstract	Finger	Vib.	T, V
Gestural haptic interface [413]	Symbolic	Abstract	Hand	Vib.	T

^aVib. = Vibrotactile, Temp. = Temperature

^bT = Touch, V = Vision, A = Audition

This last aspect deserves some further explanation. Two researchers, Jones and Yarbrough [272], conducted a seminal study in which participants reported on the social touches they received and applied, in what sort of situations these touches occurred, and what sort of meaning, if any, they ascribed to the touches (see also Section 4.4). The researchers sifted through all the data to find combinations of touches,

situations, and meanings that were most often reported by the participants, resulting in seven broad categories with eighteen subcategories.

The categories defined by Jones and Yarbrough [272] are useful for the categorization of devices for mediated social touch because such devices are usually designed with a specific type of touch and situation in mind. A device attached on a person's upper arm designed to provide a squeezing touch cannot be used to apply a pat on the shoulder. Thus, based on the categories of Jones and Yarbrough, and the design philosophy behind the specific device, we can determine what general meaning is likely to be communicated by the device. Note that one extra category was added to those of Jones and Yarbrough [272]. The category 'symbolic' is used here to categorize devices that provide touches that are more abstract in nature and for which the meaning arises from a shared symbolism decided upon by the users of the specific device.

Apart from the aspects of mediated social touch devices that are closely related to actual social touch, other aspects that are not relevant or applicable in actual social touch but are more or less unique to mediated social touch, are also listed in Table 6.1. These aspects have to do with the technology used to apply a mediated social touch. This includes the type of actuation that is used and whether or not touches are accompanied by feedback from other modalities, such as the visual and auditory modalities.

The prototypes listed in Table 6.1 were selected from the available literature on the basis of three criteria. First, devices should have a real functioning haptic component in them. In other words they should be able to provide an actual physical sensation. On the basis of this criterium, purely conceptual prototypes (e.g. paper prototypes) were not included. Second, the devices should be aimed at social interactions. So, haptic devices aimed at task-oriented communication were excluded [179]. Third, the devices should feature a form of input and output that represents social touch in some way. This criterium was used to stress the importance of considering social touch not just as output, but also as input [see also 221, 279].

Let us now take a look at each of the columns of Table 6.1 to try

and gain some insights into the design of mediated social touch devices. We will leave the creative naming of devices for what it is and take a look at the categories from Jones and Yarbrough [272], and the types of touches that are featured in the different prototypes. From these categories we can observe that the majority of prototypes aims to communicate general positive affect, which in the papers describing the design of the devices is often labeled ‘intimacy’. Intimacy matches closely to what Jones and Yarbrough call ‘affection’, and which they describe as “generalized positive regard beyond mere recognition or acknowledgement of the other.” [272, p.39]. Examples of this are expressions of love and liking. Not surprisingly, touches that communicate these meanings occur mostly in intimate relationships. This actually matches closely with the central idea behind most prototypes in this category [e.g. 141, 369, 443]. It should be noted, though, that these ideas are mostly based on the assumption that mediated social touch has the same inherent intimacy as actual social touch, something which could be disputed [see also 219].

Another category that represents a large number of prototypes describes playful affectionate touches. Such social touches serve to lighten an interaction and can be used to communicate that a certain behavior is not to be taken too seriously [272]. Prime examples of such touches may be pinching a cheek or tickling someone. In the design of prototypes we can see these types of interactions appear in a literal fashion, such as prototypes for tickling [174], or in a more abstract way, such as prototypes that invite people to communicate through touch in a general playful, explorative manner [e.g. 61, 165, 477]. Note that the Telephonic arm wrestling installation [530] falls within the ‘playful aggression’ category, which contains touches such as a punch on the shoulder as is common between male friends [272].

A third category that deserves some further discussion is the one that was added to the categorization of Jones and Yarbrough [272], namely the ‘symbolic’ category. In this category we find devices that feature non-task oriented haptic social interactions, that are not necessarily closely related to actual social touch. The devices in this category are the most explorative and do not necessarily have a clear pre-

defined use or interaction specified in their design [e.g. 86, 393, 413]. This is contrary to, for example, devices that are aimed at hugging, which feature one clear interaction style and a very likely meaning to be communicated therein. In the symbolic category the designers of the devices mostly considered meaning to arise from the interaction between specific interaction partners, and freedom in the use of these devices for the means that the user sees fit is considered important here [86, 392, 393]. However, we should note that it is entirely possible that other categories are also relevant here. For example, devices in this category could also communicate playful affection during a phone conversation [e.g. 393].

Next, let us look at the areas of the body that are stimulated by the devices listed in Table 6.1. This is important to consider because the interpretation of an actual social touch can depend on the location of the body it is applied to, for example when communicating emotions [244]. Not only that, but there are distinct differences in the neurophysiological organization of the hairy and glabrous skin [282] which may have some implications for social touch [356]. Also, the skin is not equally sensitive all over the body, thus while on the arm we may be able to distinguish two contact points clearly, this might not be the case when the contact points are placed the same distance apart on the back [472].

Figure 6.1 shows which parts of the body are stimulated by the devices listed in Table 6.1. Areas with a darker shade of grey indicate that more devices stimulate this area of the body. What can be observed from this image is that a relatively large area of the body is stimulated overall. This is mainly because there are certain prototypes that cover a larger body surface, such as the torso or upper legs. Examples of such devices are those that create a hugging sensation, either through a wearable vest [369, 489], or through a devices placed on the user's lap [126, 128].

Still, most of the devices for mediated social touch have focussed on stimulating the palm of the hand. This is an understandable choice given that the palm of the hand and fingers are also most likely to be used in the manipulation of a device. Note, though, that the devices of which the touches signal affection often do not stimulate the hand or

Figure 6.1: A depiction of body locations that are stimulated by prototypes for mediated social touch. The darker a specific body location, the higher the number of prototypes that stimulate this location on the body.

stimulate the hand as well as other body parts. While the hand is often used in actual social touch interactions it is not considered the most suitable body part for affectionate touches [244, 356]. The fact that the glabrous skin lacks CT afferents [281, 317, 385, 504], which have been suggested to be of importance to the detection of specific affective touches (i.e. stroking touches), underlines this notion.

Looking at the types of touch that devices apply and the types of actuators that they use to do so, stimulation of CT afferents seems to not have been a major concern in the design of these prototypes. Many prototypes feature static types of touch that do not feature any form of movement over the skin to which CT afferents are particularly sensitive. In addition, vibrotactile actuators are used quite often, and CT afferents are not sensitive to vibrotactile stimuli [41, 47, 145]. As in actual social touch, designers of mediated social touch devices seem to consider mediated social touch as a phenomenon that is much broader than just the application of stroking touches (see also Section 3.2.2 for a discussion of this point in relation to actual social touch). We could also ascribe the lack of stroking touches to technological limitations

in the design of these mediated social touch devices as it is not at all easy to produce a continuous stroking sensation over the skin [see also 152, 320, 365, 402].

In addition to using haptic feedback some of the prototypes in Table 6.1 feature other modalities. It could be argued that practically all devices are by definition multimodal because in most cases one will be able to see a force feedback device move, or hear a vibrotactile actuator buzzing. Still, some of the devices for mediated social touch have incorporated other modalities as an integral part of the design of the device. Auditory and visual information in particular, can be useful for creating a setting in which the touches are used. Think, for example, of devices that involve having a conversation over the phone where mediated social touch is used to add emphasis to certain words or for playful affectionate interactions [e.g. 86, 393]. We could say that the touch component in these devices is meant to support information from other modalities.

Conversely, there are devices in which feedback from other modalities, particularly visual feedback, is used to enhance the touch component of the device in question. An example is to show a hand that receives or is used to apply a mediated social touch [174, 372]. In Section 5.1 we have already briefly discussed how visual feedback of the person applying a touch can alter perceptions of such a touch [182], and other research indicates that seeing a touch being applied can result in responses by the observer that are similar to responses to actual touch [50, 349, 365]. The use of visual feedback could offer opportunities for enhancing the, relative to actual human touch, poor sensory qualities of mediated social touch devices. We will revisit the importance of visual feedback to social touch technology in general in Chapter 11.

Clearly, researchers and designers have been quite busy creating many compelling devices for mediated social touch. These devices bring together technology for producing touches and sensing touches in order to create communication possibilities that are in some ways like actual social touch. So how does the attempt at mediated social touch from the planet's biggest technology company stack up against

these efforts? People who I have spoken to that actually own an Apple Watch, do not use the digital touch function very much. And when they use it, they usually do so to demonstrate it to friend. Nevertheless, Apple's attempt is not a bad one. The input matches the output quite well, as in both cases it involves a 'tap'. There is multimodal feedback in the form of circles that form on the display to show where someone has tapped and you are encouraged to use the function only with people who are important enough to you to be put in a 'friends' list. Why then, is the digital touch function not convincing to Apple Watch owners? One explanation is that the sensation itself still feels quite mechanical. Another explanation has to do with the meaning ascribed to the touch. The meaning of the touches is muddled by the fact that the same signal is used for incoming text messages, phone calls, and other general feedback. But perhaps more importantly, tapping is generally used to get someone's attention. Jones and Yarbrough describe such touches as serving to "direct the touch recipient's perceptual focus toward something" [272, p.42]. But in the implementation in the digital touch function there is nothing to direct someone's attention to in particular, other than the somewhat unconvincing touch itself. Additionally, there is no verbal support which in all cases accompanies attention-seeking touches [272]. In sum, there is a mismatch between the haptic sensation and the likely goal of Apple's digital touch. An implementation with a more affectionate or playful form of touch would have been a better approach.

The issues with digital touch in the Apple Watch have of course been explored and in most cases improved upon in the devices listed in Table 6.1. Nevertheless, despite researchers' and designers' best efforts to create compelling mediated social touch devices, it is not a given that touches by these devices will be perceived in the same way as actual social touch. This has been a point of criticism of the field of mediated social touch in general: too much exploration of design solutions and too little focus on empirical studies into the underlying factors of mediated social touch [178, 219]. We will see in the next chapter, however, that this criticism is being addressed by researchers working on mediated social touch.

CHAPTER SEVEN

HOW MEDIATED SOCIAL TOUCH AFFECTS US

Love. A topic that has been favored by writers since the very earliest forms of storytelling and that continues to fill the pages of novels worldwide. A concept that has claimed its own genres in film and is the core theme of anything from romantic comedies to action movies. And, let us be frank, it is what most of us hold dearest in life. Love for a person can be so deep it borders on reverence, and touches upon the divine:

“Dorian Gray leaped to his feet, with flushed cheeks and burning eyes. ‘Harry! Sibyl Vane is sacred!’ ‘It is only the sacred things that are worth touching, Dorian.’”

That which we love most we want to touch, fondle, hug to our chest and protect. Something which Oscar Wilde describes with wit and elegance in his only novel, *The Picture of Dorian Gray*. The story itself features both intense love and tragic loss, and this loss too, is accompanied by a supportive pat on the back or comforting hug. Ambrose Bierce in the *Devil’s Dictionary* cynically declares love a “disease curable by marriage”, but in disease or illness too, touch can be soothing (see Section 4.1).

Social touch then, is central to those feelings that stir us most deeply. The connection between touch and the expression of intimate

feelings or its soothing qualities is not just something that authors intuitively include in their novels. As we have seen in Chapter 4 there is evidence that touch does actually feature in rather a large number of important social interactions, and can profoundly influence the individuals in such interactions. The question is, do these effects of actual social touch carry over to situations where the touch is mediated by technology? And if so, which factors contribute to this most strongly?

Where researchers working on actual social touch are faced with problems such as the limitations of observing touch, the difficulty of controlling environmental and sensory factors, and the behavior of the persons involved (see also Chapter 4), the primary problem faced by mediated touch researchers is that the touch sensation is not actual touch and there is no person present. As we have seen in the previous sections there have been numerous attempts at making devices that ameliorate these issues. Nevertheless, some have argued that there have been a lack of research efforts to unearth the factors underlying mediated social touch [178, 219]. With this in mind, in the next sections we will see how throughout the years researchers have taken an increasing interest in investigating mediated social touch more thoroughly.

There are two general approaches that can be identified in mediated social touch research [465]. In the first approach studies aim to make direct comparisons between mediated social touch and actual social touch to see what the similarities and differences are between the two. The research discussed in Chapter 4 serves as a benchmark for these studies. One example is the Midas touch effect that researchers have been working on replicating using mediated social touch [e.g. 217].

In the second approach the connection between actual and mediated social touch is considered to be less strict. Here, the focus is more on how novel forms of haptic feedback, or novel applications of haptic feedback, can affect mediated interpersonal communication. Important in these efforts is the investigation of how mediated social touch can contribute to feelings of 'being together while separated', a concept that is referred to as 'social presence' [258]. In the following sections both approaches to mediated social touch will be discussed.

7.1 MEDIATED SOCIAL TOUCH IN AFFECTIONATE INTERACTIONS

Like the baby rhesus macaques that were the unfortunate subjects of Harlow's seminal studies [227], humans too, crave and need physical contact. The sad story of the Romanian orphans who received almost no social touch and were much worse off for it, illustrates this need poignantly [77, 98, 332, 374]. Such a craving for touch endures in later life, and most profoundly affects people in a romantic relationship for whom a touch may benefit their overall well-being [121] and immediate responses to stressful events [102, 127, 345].

The idea of the power of a loving touch, inspired perhaps by the writings of authors such as Wilde, has led researchers and designers to create devices for mediated social touch that focus on affectionate interactions. If indeed such prototypes could come close to affecting their users in ways as profound as social touch within a romantic couple does, then we need not really be separated from our loved ones ever again. Wherever we are we could just use a well designed piece of technology and get the benefits that, as the research on actual social touch conducted to date indicates, accompany loving, caring, intimate social touch.

So what should the capabilities of such a hypothetical device be? One study found that perhaps something as simple as a pillow shaped in a way that invites hugging, can do the trick [481]. Elderly participants were invited to have a phone conversation with an experimenter who was in another location. One group of participants used a bluetooth speaker for the conversation while another group of participants used a human-shaped pillow with an integrated speaker and phone [303]. The idea behind the design of the pillow was that users could hug it while making a phone call. The researchers compared the levels of the stress hormone cortisol in the participants' blood and saliva, before and after the conversation. The results showed that the participants who used the hugging pillow had a significantly greater decrease in cortisol after the conversation, as compared to the group of participants who used a bluetooth speaker to have the conversation.

The authors suggest two aspects that are important to their findings [303]. First the hugging posture itself may have influenced cortisol

levels, the idea being that body postures can affect the neuroendocrine system [79]. With regard to this explanation it is important to note that the first author of the paper on the effects of body postures on the neuroendocrine system [79], has declared that she does not believe that such effects are real and cites numerous methodological issues with the conducted work [78]. We should therefore seriously question the validity of this first explanation.

As a second explanation for the effects of the hugging pillow [303], the authors suggest that the soft tactile stimulation of the pillow stimulates CT afferent fibers, and they speculate that such stimulation can have an influence on neuroendocrine responses. This last explanation especially is questionable, firstly because the pillow did not produce any stroking motion to which CT afferents respond most vigorously. Secondly, because there is currently no direct evidence for a connection between CT afferent stimulation and cortisol reduction.

Another explanation for the findings may be that the participants attributed the passive hugging to their friendly communication partner, thus receiving a form of passive mediated social touch. It could be that this idea of receiving a hug from a friendly person accounts for the findings [see also 303]. Ideally, the study should have featured a third group of participants that just hugged the pillow to investigate the effects of hugging without any communication taking place. It would also be interesting to see how devices that actually produce a hugging sensation [e.g. 369, 489] would compare to just a human-shaped pillow.

Other researchers have investigated how mediated touches attributed to either a romantic partner or a stranger, can help in reducing stress responses. In a somewhat informal study with a relatively small group of participants, the effects of mediated social touch on heart rate were investigated [75]. In the study participants watched a sad video and heart rate measures were taken before, during, and after watching the video. In one group, participants simply watched the video while in another group participants watched the video and afterwards an experimenter placed his hand on their forearm. In a third group, participants received a mediated social touch in the form of warmth and

vibrations on their forearm. Results from the study showed that the sad video increased participants' heart rates. In the no-touch group, participants' heart rates continued to increase after watching the sad video, while in both the human touch and mediated social touch groups heart rates were found to decrease after watching the sad video. Thus, it would seem that both actual social touch as well as mediated social touch can help people recover from physiological stress induced by a sad video.

Some care has to be taken with interpreting these results, however. It is worth noting that sad movies, at least those not sad enough to cry over, typically elicit a *decrease* in heart rate [299], while in this study the movie seemed to result in increases in the heart rate of participants [75]. So based on the heart rate measures it does not seem as if participants experienced sadness *per se*. Furthermore, it is not entirely clear from the description of the experiment who applied the touches in both touch conditions, for how long, and with what intensity. As we know from research into actual social touch, such factors matter in social touch interactions.

The same authors conducted a follow-up study in which they investigated how heart rate and skin conductance measures, both physiological indicators of autonomic nervous system activity [67, 299], would respond to mediated social touch from a stranger or an actual touch from a loved one [74]. The same device as in the previous experiment was used: five force-sensitive resistors controlled the intensity of vibration of 5 vibration motors on the output side, while a temperature sensor coupled to a Peltier element made it possible for the person on the output side to feel the temperature of the other person's palm. Finally, a bend sensor was used to initiate a tickling sensation produced by a DC motor and feather.

Similar to the previous study, three groups of participants watched a sad movie clip. One group did not receive any form of touch while one group received touch from the mediated social touch device. Participants in the final group were accompanied by their spouses who applied a touch to the forearm. The touches were applied at a particularly emotional moment in the movie and contact was kept for the

remainder (about four minutes) of the movie. The emotional moment in the movie seemed to coincide with an expected drop in heart rate [299], but only for the no touch group [74]. In both touch groups the emotional moment, which was accompanied by a touch, did not result in a drop of heart rate that is indicative of sadness. Skin conductance measures were relatively flat overall, and did not seem to be affected by the touches in either touch condition. However, skin conductance was overall much lower in the human touch condition.

Again, we have to take care with interpreting these findings, because, as in the previously discussed study [75], the physiological responses are not all indicative of a sadness response [74]. Though it would seem that for the heart rate measures, both actual social touch and mediated social touch were able to attenuate a sadness response. For the skin conductance measures however, it seems that the mere presence of the participant's spouse resulted in an overall lower level of skin conductance. This is plausible, because simply seeing an image of a loved one can already have measurable positive effects, such as lowering a person's pain response [345].

Another study has circumvented this issue by investigating whether mediated social touch has any benefits over a simple visual signal, where recovery from sadness is concerned [148]. In this particular study participants first watched a sad movie, followed by a funny movie. Participants were instructed to use one of two devices to share the moments they found enjoyable in the funny movie with what they believed was another participant, who would also share his or her feelings about the funny movie. In actuality there was no other participant and the feedback that actual participants received was scripted. With one device, participants pressed a button to signal funny moments, and received visual feedback in the form of a light. The other device was a mediated social touch device that could be squeezed to produce a squeezing sensation on a second connected device. Thus participants could squeeze the device to indicate moments they enjoyed in the funny movie and would receive scripted squeezes back.

One hypothesis of the study was that the funny movie in combination with mediated social touch would help participants recover from

the sadness induced by the sad movie, more so than visual feedback would [148]. A number of questionnaires were administered before, and after participants watched the movies. Participants' heart rate, skin conductance, and the duration of their smiles were measured while they watched the movies. The subjective measures confirmed that both movies were rated as sad and funny respectively. While the physiological measures were in line with these findings, they only showed significant differences for the funny movie. Importantly, no significant differences between the visual condition and the mediated social touch condition were found for any of the measurements. Therefore, this study found no support for the idea that mediated social touch can help a person recover from sadness, more so than a simple visual signal can. We should note though, that the sad movie may not have induced sadness to the same extent as the funny movie helped participants cheer up. Thus the funny movie by itself may have already aided recovery from any sadness to such an extent that the feedback, being either mediated social touch or a visual cue, really did not matter anymore.

Based on the studies that have thus far been conducted it would seem that mediated social touch has no consistent effects on the physiology of the recipients of such a touch, at least in studies where participants watched a sad movie [74, 75, 148]. It is also worthwhile to point out some differences between these studies. First, two of the studies primarily used warmth and vibration [74, 75] as a method of stimulation, while the other used a squeezing sensation [148]. Second, two studies used a relatively long period of stimulation (i.e. up to four minutes) [74, 75], while the other used several touches of shorter duration (i.e. up to 15 seconds) [148]. More structural investigations are needed to look into exactly how different types of haptic feedback, not necessarily mediated social touch, applied for a set duration can affect a person's physiology. Such investigations are needed also because physiological responses to actual social touch are not always straightforward [315, 532].

So where does that leave us with recommendations for a mediated social touch device that can be used for affectionate interactions, and

that, preferably, will be the topic of many a future romantic novel? We can, as of yet, not make any clear recommendations about how such a device could affect a person's physiology. We could however think about what sort of affectionate messages such a device could convey.

7.1.1 The communication of affect and emotion through mediated social touch

A series of experiments into the way actual social touch can be used to communicate emotions has shown that people are actually quite consistent in how they touch someone to communicate a certain emotion [242, 244, 245]. For example, anger is likely communicated by grabbing while love is much more likely to be communicated by stroking. What is more, when a person feels such a touch, he or she can with reasonable accuracy also say what the other person means to communicate (though there are gender differences [242]). These studies have inspired researchers to investigate to what extent mediated social touch can be used for the communication of specific emotions.

A very limp, 'dead fish' handshake may lead you to make certain unfavorable assumptions about the personality of the person in question [87], but a handshake could potentially communicate more information than that. At least that was the hypothesis of researchers who were interested in how a force feedback joystick, positioned so that participants could mimic handshaking, could be used for the communication of discrete emotions [27]. To this end they had participants use the force feedback joystick to 'encode' seven distinct emotions, such as anger, fear, and joy, by making a handshake-motion. As in the studies into the communication of actual social touch [242, 244, 245], participants used distinct movements to encode certain emotions. For example, slow, steady, and short movements were used for sadness, whereas for joy, participants used long, jerky, and fast movements [27, p.340].

Next, another group of participants was invited to the lab, where they were asked to hold onto the force feedback joystick and imagine that someone was shaking their hand [27]. The participants' task was to guess which emotion was being communicated. Overall, recognition

accuracy of the emotions was above what would be expected by chance alone. However, a third experiment revealed that recognition accuracy of emotions communicated through an actual handshake was considerably higher than those communicated through the force feedback joystick. Probably, the addition of other haptic signals such as the pressure applied by squeezing someone's hand, explains this difference.

The idea that the successful communication of emotions can be affected by the type of haptic feedback that a person receives, as well as the method of input that is used to deliver the haptic feedback, is supported by other research as well [414]. Researchers developed a device that could recognize subtle finger touch gestures, as well as squeezing gestures, and translate them to vibrotactile feedback [414]. A study was conducted in which pairs of participants, each with one of the devices in hand, were asked to communicate certain affective states to each other by touching and squeezing the device. The affective states were extremes on the dimensions of valence (pleasant, unpleasant) and arousal (relaxed, aroused). The results of the study showed that the 'senders' used both stroking touches and squeezes to encode all types of affective states, but that the recognition accuracy of these expressions depended on the type of gesture used. Squeeze gestures were found to be more suitable for the communication of low valence, high arousal states, while the stroking touch gestures were found to be preferable for the communication of high valence, low arousal states. Only when this was taken into account was the recognition accuracy of valence and arousal above chance level.

From this we can conclude that the type of input can have an effect on the way emotions are communicated through mediated touch. Like in actual social touch however, there are other factors that influence the perception of mediated social touch as well. These factors include the general context in which the touch takes place, the relation between the people applying and receiving touches, and the body location to which the touches are applied.

In one study participants used a relatively simple 'haptic turning knob', a device, like the rotating lock on a safe, that could be rotated

on two directions and that could provide active resistance to the turning motion [462]. Participants used two such devices in two scenarios that differed in their level of intimacy. In the low intimacy scenario participants played a Pong-like game and used the knob to control the paddles, receiving haptic feedback that was determined by the impact force of the ball. In the high intimacy scenario the interaction looked as if participants rubbed their hands against each other, and the haptic feedback was that of 'friction' between the two hands.

In both scenarios participants were instructed to communicate four different emotions (angry, delighted, relaxed, and unhappy) to each other. What is of particular interest here is that in one group participants were strangers to each other, while in another group they took part in the study as a romantic couple. The results from the study showed that participants in both groups could communicate each of the four emotions at above chance level. However recognition accuracy for the emotions was highest in the high intimacy scenario when the pair of participants consisted of a couple in a romantic relationship.

Finally, another study has found evidence that the body location to which a mediated social touch is applied can influence the affective experience of such a touch [218]. In this particular study participants used an instant messaging program to chat with what they believed was another participant but which was in actuality an experiment confederate. Participants wore a vest that could deliver vibrotactile feedback to their stomach, lower back, upper back, lower arm, and upper arm, and were made to believe that this feedback was applied by the ostensible other participant. One group of participants was made to believe that they were communicating with someone of the same gender, while the other group of participants was made to believe they were communicating with someone of the opposite gender.

During the chat session participants received mediated social touches to the five body locations and were asked a number of questions after each touch of which the real question of interest was how pleasant they thought this touch was. The results from the study showed that the gender of the toucher did not affect the pleasantness of the mediated social touch but that the body location to which touches

were applied did have an effect. Touches to the stomach, arm and wrist were found to be less pleasant than those applied to the back, while touches to the stomach were found to be even less pleasant than those on the arm.

Current research into mediated social touch suggests that, like actual social touch [242, 244, 245], mediated social touch can be used for the communication of discrete emotions with a reasonable level of accuracy. Thus a mediated social touch device for affectionate communication could focus on the communication of discrete emotions. A force feedback joystick used as if to shake someone's hand, seems to be the most promising approach in this regard. Nevertheless, other studies have shown the importance of taking into account the method of input, the relationship between the people communicating, the specific scenario in which a mediated social touch takes place, and the body location to which a touch is applied. If we would have to offer up a point of critique it would be that the approach to affectionate communication taken in all these studies is quite artificial. Participants were asked to imagine how they would express an emotion, and were only allowed to express this emotion through touch. In reality, when a person really experiences, for example, happiness, it is unlikely that he or she would communicate this through a carefully thought out touch gesture without also showing other expressions, such as smiling. Though note, this point of critique is not confined to mediated social touch as studies into the expression of emotions through actual social touch face the same issues (see also Section 4.4.1).

7.2 A VIRTUAL MIDAS TOUCH?

If King Midas of Greek mythology would have lived today he would surely have Instagrammed, Twittered, and Snapchatted - on a golden smartphone, mind you - to stay in touch with the people he cared about. At the very least, this would minimize the risk of turning them to solid gold upon the merest touch, as was the unfortunate Midas's fate. That is, if we assume that King Midas' power to turn everything he touches to gold does not work in social interactions that occur mediated through technology. For King Midas's peace of mind we might

consider, does the Midas touch effect also occur for mediated social touch?

In social touch research the Midas touch effect describes how a simple touch can result in the recipient of the touch being more inclined to show pro-social behavior towards the person applying the touch [114], such as helping to pick up dropped items [206]. The investigation of the Midas touch effect, not through direct human-to-human touch but mediated through haptic feedback technology, is a clear example of a line of research that seeks to find parallels between the experience of actual social touch and mediated social touch.

Research into the Midas touch effect for actual social touch has thus far predominantly taken place in ecologically valid settings [e.g. 114, 207, 251]. This means that the people participating in the studies were generally just going about their business and were unaware that they were taking part in the study. An experiment confederate would apply a touch and measures, such as will a person help pick up dropped items, and if so, how many, were used to judge pro-social behavior. As we have discussed in Chapter 4, such an approach has the benefit of the manipulations taking place in a natural setting thus any findings may more easily generalize than studies conducted in highly controlled laboratory settings that can be quite unlike actual social settings. However, in such a natural setting it is very difficult to control for factors other than touch that might also influence pro-social behavior.

In contrast, mediated social touch, because of its inherent artificial nature, is less suited to be applied in ecologically valid settings. In fact, the use of haptic technology to apply a touch likely makes any social interaction in the wild ‘unnatural’ to some extent. Thus researchers working on mediated social touch have conducted controlled and semi-controlled lab studies to investigate how mediated social touch could affect a person’s pro-social behavior. In essence, researchers have been looking into a ‘virtual Midas touch’ effect [222].

The first study to look into the possibility of a virtual Midas touch employed what can best be described as a semi-controlled design, where participants were invited into the lab, but where care was also taken to make the interaction in the lab as close as possible to a nat-

ural setting [222]. As a cover story, participants were invited into the lab to evaluate a text messaging system that also had one-directional mediated social touch capabilities. Participants were either assigned to a condition where they would receive mediated social touches in the form of vibrotactile feedback to their upper arm from a female confederate, or to one of two control conditions: one where the explanation for not receiving touch was that the confederate did not apply any, while the other explanation was that the system had unfortunately malfunctioned.

A bogus questionnaire designed to make participants believe they were actually evaluating the system was administered after the chat session [222]. The actual measure of interest, however, involved the confederate walking over to the side of the room where the participant was and ‘accidentally’ drop a number of coins from her wallet. Whether the participant helped to pick up the coins, as well as the number of coins picked up, were used as indicators of a potential Midas touch effect. It is worth noting that as the touches were mediated, the confederate could be kept blind to the actual condition. The experimenter had ultimate control over whether or not a touch would be felt by the participant, thus while the confederate always applied touches, they were not always felt by the participant, depending on the experimental condition. Being able to work with a blind confederate would not have been possible with actual social touch and reduces the chances that the confederate unwillingly adjusts other behaviors, such as vocal and facial expressions, depending on the experimental condition.

In both control conditions combined, 45 percent of participants helped the confederate pick up coins, compared to 60.9 percent of participants in the mediated touch condition [222]. This difference, however, turned out to be not statistically significant. Similarly, the number of coins participants picked up did not differ significantly between the groups.

To see how their findings stacked up against those of studies into the actual Midas touch using a similar ‘dropped items’ paradigm, the researchers calculated the effect size - an estimation of the percentage of additional participants that will exhibit helping behavior when they

receive a social touch - for three Midas touch studies as well as their own virtual Midas touch study [222]. From this analysis it became apparent that in both cases the effect size was 15.9 percent. Thus, for both an actual social touch, and a mediated social touch, 15.9 percent more people are likely to help compared to when no touch is applied.

From these findings it would seem that there are similarities in the way vibrotactile mediated social touch and actual social touch can affect people's helping behavior. This would suggest that both mediated and actual social touch affect the recipient in a similar way, despite clear differences in the somatosensory qualities of actual and mediated social touch, (i.e. how they 'feel'), the presence of additional social cues, and the setting in which studies took place [222].

Nevertheless, the differences in helping behavior between the touch and no-touch conditions were not statistically significant [222]. To get to the bottom of how a mediated social touch could produce a significant positive effect on helping behavior the same researchers conducted another set of studies following the same general protocol as in the previous study, with one key difference: in one study the confederate was aware of whether or not she was operating in a touch or no-touch condition (i.e. the confederate was 'non-blind') [217]. This difference turned out to be key as only in the study where the confederate was non-blind did mediated social touch positively affect helping behavior to a degree that was statistically significantly different from the no-touch condition. In the situation where the confederate was blind to the experimental condition, as in the previous study [222], mediated touch enhanced helping behavior but the difference was not statistically significantly compared to the no-touch condition.

Thus, concluded the researchers, the Midas touch effect seems to be subject to a confederate bias where the confederate, unwillingly, adjusts other social behaviors depending on the experimental condition [217]. As in actual social touch it is not possible to have a completely blind confederate (though see [194] for a work-around using two confederates) it is highly likely that a confederate bias also plays a role in the Midas touch effect found for actual social touch [217]. Still, a meta-analysis of Midas touch studies showed that touch almost al-

ways enhances helping behavior to some extent, and that this is the case for both actual and mediated social touch [217]. So, although other signals from a confederate likely enhance any effects of an actual or mediated social touch, a social touch is more likely to increase, rather than decrease helping behavior.

You may have noticed that the previous studies all investigate a very similar type of pro-social behavior, namely helping behavior in the form of helping to pick up all kinds of dropped items. In the discussion of the Midas touch effect for actual social touch (Section 4.3) we have seen how social touch may affect other types of helping behavior. It is possible that social touch, and by extension mediated social touch, does not equally affect all types of pro-social behavior. This notion was investigated by researchers using a well-known experimental paradigm from game-theory, called the Ultimatum game [468]. In this economic decision game participants took on either the role of proposer or responder. A proposer was tasked with dividing 30 cents between him or herself and the responder and would send an offer to the responder with or without an auditory or vibrotactile signal (i.e. mediated social touch applied to the palms of both hands). The responder had to decide to either accept or reject the offer. Participants played multiple rounds and at some point switched roles. In actuality, both the signals and the responder's answers were scripted and computer controlled.

Two types of pro-social behavior were considered in this study: the first relating to direct compliance in the form of a responder either accepting or rejecting an offer, and the second relating to later offers made by a participant who, in a previous round, took on the role a responder but was now a proposer [468]. Results showed that both audio and tactile signals enhanced direct compliance (i.e. accepting offers). Further results obtained from electroencephalogram (EEG) measures taken during the experiment, however, showed a unique effect of touch on increases of memory related brain processes (i.e. P3 event related potential, after increased offers [468]). This was found not to affect compliance (i.e. accepting or rejecting an offer), but did influence later generosity: participants who received a mediated touch were later more likely to offer more money to the other person who had applied the

touch. Thus, the interpretation of the mediated social touch in context (context being an increased offer having been made), can result in a person adopting a more favorable attitude towards the person that applied the touch later on (i.e. offer more money). The researchers suggest that this may be similar for actual social touch [468].

The previous study was able to show effects of mediated social touch on pro-social behavior while ruling out confederate bias by using a game-like setting. Another way to control for confederate bias in the Midas touch effect, and at the same time enable manipulation of contextual factors such as the setting in which a touch takes place, is by using immersive virtual reality (VR) environments. Such VR environments typically require a person to wear a stereoscopic 3D head-mounted display (HMD). Commercially available examples of such devices are the Oculus Rift, HTC Vive, and Samsung Gear VR, which can all detect a person's head movements allowing someone wearing such an HMD to look around in a virtual world. And because the elements in a virtual world can be constructed from the ground up, from the look of the room a person appears to be in, to the table and chair in the room, as well as the avatars (i.e. humanlike virtual representations) of other people present in the same virtual space, a researcher can have control over the factors that might influence the interpretation of a touch.

One group of researchers used a rather elaborate VR setup to investigate how mediated social touch could affect compliance to a request that was made [58]. The setup in question not only tracked a person's head movements, but, by having participants wear a Power Rangers-worthy full-body Lycra suite with visual markers and an optical tracking system, could also track participants' body movements. With the use of a duplicate of this setup two or more people can be in two separate physical locations but share the same virtual space. In this particular study two participants and one confederate shared the same virtual space and it was the task of the confederate to convince both participants to sing, a task which is usually met with reluctance and embarrassment [58]. One group of participants would only see the touch while another would also feel the touch through a vibrotactile display worn on the upper arm.

Results of the study showed that the illusion of being touched by the confederate's avatar was stronger for participants who could both see and feel the touch. Nevertheless, there was no difference between the visual-only and visual-tactile touch conditions, as all participants were found to be willing to sing [58]. Because there was no no-touch control condition in this study, it is difficult to say what the effect of touch, visual or visual-tactile, was exactly. Though, as will be discussed in more detail in a later chapter, simply seeing the touch without feeling it could have already affected participants [e.g. 365]. Alternatively, as was rightfully remarked by the researchers, it could also be that the request to sing was not experienced by participants as a difficult or embarrassing request at all [58]. Remember that the extent to which an actual social touch affects pro-social behavior depends on the type of request that is being made [e.g. 205, 536](see also Section 4.3).

To conclude, there is some quite compelling evidence that mediated social touch, in the form of relatively mechanical vibrotactile stimulation, can elicit a virtual Midas touch effect that is similar to the Midas touch effect for actual social touch. King Midas, then, might do well to stay away from mediated social touch devices, lest his power to turn anything he touches to gold also operates mediated through technology.

Besides showing similarities between the actual and virtual Midas touch, this section has also highlighted how mediated social touch can be used as a tool to gain insights into the effects of actual social touch. In particular, the fact that mediated social touch does not require a person to be physically present with all types of social signals that such a physical presence usually includes, is helpful in isolating the effects of touch from the effects of other social signals that may contribute to enhancing pro-social behavior.

7.3 MEDIATED SOCIAL TOUCH AND PRESENCE

A loud insistent buzzing noise wrenches you from an undoubtably well-deserved night's rest. Sleepily, you rub your eyes with one hand, reaching over to the night stand, knocking over an empty glass, and groping for the source of the infernal noise. Your fingers brush over the

smooth surface of your smart phone and you fondle its curved edges, identify the shape of the off-button, and a satisfying click confirms that the alarm is now off. You turn around to lay on your back again feeling your comfortable mattress form itself once again to your body. Struggling to not just drift off again, you reach over to your right, the warmth of the mattress betraying the recent presence of your significant other. Reluctantly, you throw the comforter off of you, the cold air of the bedroom doing little to dispel the drowsiness. In a final act of desperation, you swing both legs around and your feet touch the cold bedroom floor. Leaning forward, testing whether your legs will support your weight, you lift yourself from the mattress, and, bumping your shoulder against the doorpost, slowly stumble towards the shower.

The early morning, eyes still glued shut, and caffeine deprived brain still working to boot-up, is perhaps, as the above excerpt illustrates, the time of day we rely more on our sense of touch than any other. Nevertheless, we rarely pause to think about the exact contribution of our sense of touch to our perception of the world, let alone its role in the interactions with others, as has been made apparent in the introduction of this book. One reason for this is that the way we perceive the world and interact with others is inherently multi-sensory, as we draw on information from all our sense [178]. In many ways, such signals can offer redundant information: we may hear the alarm clock on our smart phone go off, see its display flashing, and feel the vibrations it generates.

When we consider mediated communication, however, such redundant signals are not always present. During a phone conversation we can only hear the person on the other end of the line and not see them, let alone touch them. Similarly, interactions in many shared virtual environments (SVE) are limited to the auditory and visual senses. Nevertheless, researchers have been working on integrating haptic technology into SVE's in order to enable a person in an SVE to interact with objects physically, feeling their weight, shape, and size [474], essentially interactions that are enabled by the discriminative qualities of the sense of touch.

The availability of congruent high-fidelity sensory information is

an important determinant of a psychological phenomenon called ‘presence’, or the feeling of ‘being there’ in a mediated environment [258]. Presence can be described as “the perceptual illusion of non-mediation” [323], thus a person that experiences a high degree of presence is in essence unaware of the fact that his or her experiences occur through a technological medium [see also 325].

Two general categories of presence can be defined, namely physical and social presence [258], though more detailed conceptualizations of presence also exist in the literature [323]. Physical presence refers to the experience of being physically located somewhere, for example in a virtual bedroom with a virtual alarm clock going off. Social presence, on the other hand, refers to the feeling of being together with another person. A regular telephone, for example, provides limited physical presence but can provide a strong sense of social presence [258].

Haptic technology used in SVE’s can not only allow a person to feel objects in the virtual space, potentially enhancing feelings of physical presence, but can also be used for interactions with other people in the SVE. A central question here is how mediated social touch contributes to the feeling of actually sharing the SVE with another person. In other words, to what extent mediated social touch contributes to social presence. This is an example of a line of research that is not directly comparable to actual social touch, since actual social touch is non-mediated, thus the concept of presence does not apply.

Some of the earliest studies to empirically investigate mediated social touch in general did so to investigate how mediated social touch would affect social presence in SVE’s [33, 63]. In one study researchers used a standard desktop computer to display a ‘ring on a wire’ game where participants had to move the ring over the wire without the ring making contact with the wire [33]. Participants could manipulate the ring using a force feedback device and their movements were displayed in the virtual space with a cursor. Using two such setups two participants could both interact with the ring and had to collaborate in order to move it along the wire. In one experimental condition they would only see the cursor of the other participant while in a second condition they could also feel the forces that the other participant applied to the

ring. Results from this study, with a relatively small sample size mind (i.e. ten participants), showed that over several trials participants in the condition with visual and haptic feedback experienced a stronger sense of ‘togetherness’ (i.e. social presence), than did participants in the visual only condition.

Since this first study found an indication that receiving haptic feedback from another person in an SVE, that is, mediated social touch in the form of force feedback, can enhance feelings of social presence, several more studies have been conducted that have used a similar approach. In one such study participants had to collaborate on a shared virtual desktop in order to solve a jigsaw puzzle [189]. Participants in one group could communicate only visually while participants in another group could communicate through visual feedback as well as mediated social touch by applying force to one another’s thumb. It was found that participants in the visual-haptic condition experienced a stronger sense of social presence than participants in the visual only condition [189].

Similarly, another study found that social presence was enhanced when two participants could feel the forces they both exerted on an object while handing over the object in an SVE using a force feedback device, more so than when just seeing one another’s cursors and not receiving force feedback [438]. Though note, that an earlier study by the same authors using a similar experimental design, found no significant effect of haptic feedback on social presence [439].

A study in which medical students collaborated on a simulated needle insertion task found that when the students received force feedback of one another’s actions, social presence was enhanced compared to receiving just visual feedback [89].

Finally, a study in which participants played a desktop-sized rope-pulling game found that when participants attributed haptic feedback in the form of forces applied to their rope to another remotely located player instead of to the virtual environment (i.e. the natural elasticity of the rope), social presence was enhanced [36].

Based on the thus far discussed studies we can quite confidently say that mediated social touch in the form of force feedback from another

person present in an SVE, can enhance feelings of social presence. Yet the concept of social presence is not limited to collaborating in an SVE and is also relevant in situations where people engage in more general forms of mediated communication [258].

Something else to remark is that all of the studies into mediated social touch in SVEs, featured a collaborative task. Research into actual social touch has demonstrated that while social touch in a collaborative context may work beneficially (e.g. enhance pro-social behavior), social touch in a competitive context might have negative effects [76]. This idea was at the basis of a study to investigate whether the effects of mediated social touch would depend on the context in which the touch took place [63]. In this study, participants were invited to the lab to play a game in which they would have to navigate through a maze that was visible on a computer screen. The game was controlled using a standard computer keyboard. Participants were told that an ostensible other participant had already completed the maze, and, depending on the experimental condition, were told that this participant would either help them navigate the maze (i.e. collaborative), or obstruct their navigation by giving false hints (i.e. competitive). Participants received feedback either through arrows visible on the computer screen, or through a force feedback joystick that would move in a direction indicated by the other participant.

The results from this study indicated that participants who received haptic feedback in the competitive condition felt more powerful and more positive in general [63]. This was the exact opposite of findings for the haptic collaborative condition. The researchers suggested that the fact that participants in the haptic condition could ‘push back’ against the feedback they received played a role here. For the competitive condition especially, this idea of pushing back made participants feel as if they were more in control of the feedback they received from their ‘opponent’, which made them feel more powerful and more positive overall. Thus, mediated social touch in the form of force feedback may not only affect participants’ perceptions in collaborative tasks, such as enhancing feelings of social presence in an SVE, but can also affect how they feel towards another person in competitive settings.

In Section 6.3 we discussed how the method of input might be an important component in the design of mediated social touch devices. Considering this in relation to presence, where the match between input and output is important for the level of presence a person experiences [258], we could ask ourselves to what extent the match between input and output in mediated social touch is important for enhancing feelings of presence.

One study investigated how visual feedback of the input medium could influence the perception of mediated social touch [220, 221]. To this end, participants wore a vest with vibration motors in it that allowed for their abdomen, upper and lower back, and shoulders to be stimulated. A confederate would use two different input methods to apply several touches to the participant's body. The first method featured a mannequin body that was equipped with touch sensors of which the location matched that of the vibration motors worn by the participant. The second method was a touch screen with buttons describing the body location that was touched. On a television screen, participants could view the confederate applying the touches to either the mannequin or the touch screen. For some touches the confederate would stand closer to the input device, while for other touches the confederate would keep more distance between himself and the input device [221].

Though, overall, participants found the touches to feel quite unnatural and did not experience a strong sense of presence, both measures of naturalness of the sensation and presence were found to be higher for the mannequin touches [220]. In addition, physiological arousal, measured through electrodermal activity, was higher for touches applied through the mannequin, but only when the confederate maintained a larger distance from the mannequin [221]. This last finding is surprising as you would perhaps expect that if participants viewed the mannequin as a representation of their own body that they would experience more arousal when someone invaded their personal space [221]. Nevertheless, findings from this study show that a combination of visual feedback of a morphologically congruent input method can enhance the perceived realism of a touch, as well as the experience of presence.

Further evidence for the idea that the view one has of the input used to administer a mediated social touch is important, was found by researchers working on a device that allowed two people in distant locations to shake hands [372]. The device featured a screen below which a robotic hand could be grasped. The hand could provide a squeezing sensation as well as communicate body heat. Two of these setups could be used by two people in different locations to see and hear each other, and to shake hands through the physical hand.

A study was conducted in which the view of the other person's hand, visible through the screen, was altered in several ways [372]. It was found that the most compelling illusion of shaking hands was achieved by positioning the person on the screen in such a way that it seemed as if the hand sticking out from under the screen, was actually the hand of the person visible on the screen. Next, this setup was used to compare a video chat with and without the handshake, to see how shaking hands remotely could affect social presence [372]. It was found that the interaction with a handshake enhanced social presence, as well as enhanced perceived friendliness of the communication partner.

Thus, it would seem that appropriate visual feedback in combination with a synchronized haptic sensation can enhance (social) presence. Notwithstanding the potential benefits of visual feedback of the input device in mediated social touch, we could think of situations in which no visual feedback is available, or in which visual feedback would be overly distracting. How might mediated social touch be used to enhance social presence in such situations?

To date, two studies that investigated this question have been conducted. In the first study participants were invited to the lab to listen to a story told by a professional actress [523]. The story featured some particularly emotional moments at which time participants either received visual feedback, mediated social touch in the form of a squeeze to their upper arm, or no additional feedback at all. Moreover, one group of participants was told that the feedback they received was initiated automatically by measuring the storyteller's emotional arousal, while another group of participants was told that the feedback was purposefully applied by the storyteller, who squeezed an input device at

a moment in the story she found particularly emotional. In actuality, all feedback was applied automatically at pre-determined moments in the story. The results of the study showed that only in the purposeful touch condition did participants indicate that they felt statistically significantly closer to the storyteller than the no-signal condition [523]. While other results showed a trend towards a reduction in negative emotions, and an increase in joviality (e.g. happy, joyful, cheerful), these effects were not statistically significant.

Another study sought to investigate these findings on reported closeness to the storyteller in more detail [276], using a standardized questionnaire to measure social presence [228]. The experimental procedure was highly similar to the one used in the previously described study [523], using the same recorded story, told by the same storyteller, and applied mediated social touches with a similar squeeze to the upper arm. Participants were divided into one of three conditions: a no-touch control condition, a condition in which the touches were applied during the same emotional story moments as in the previous study, and a random touch condition in which touches were randomly applied during the story. In both touch conditions, participants were told that the storyteller applied touches purposefully during moments in the story she experienced as particularly emotional. In actuality, as in the other study, all touches were fully scripted. Results from this study showed no difference in experienced social presence between the three experimental conditions.

These last two studies indicate that mediated social touch in combination with auditory feedback does not increase social presence in a significant way. One explanation is that it is difficult for participants to actually attribute the mediated social touch to the storyteller, since no indication other than the touch itself is given. Indeed, other research investigating the effects of mediated social touch on social presence, featured visual feedback, either in the form of a cursor in an SVE, or in the form of visual feedback from the input device used to apply a mediated social touch. Based on the current body of research, we might thus conclude that mediated social touch does enhance social presence but only in the presence of additional visual cues.

7.4 THE MATTER OF MEDIATION

With this, we can end this chapter on a somewhat positive note: mediated social touch is not just expressed in the design of fascinating prototypes but can actually affect the recipient of a touch. To date, research on the way mediated social touch affects a person's physiological responses is inconclusive, but studies have indicated that mediated social touch can be used quite reliably to communicate discrete emotions. Thus there is at least some support for the assumption that mediated social touch can serve affectionate communication. Moreover, we have seen how a series of studies has found that mediated social touch can elicit the Midas touch effect to a similar extent as actual social touch can. These studies also highlight how mediated social touch can be used as a tool to gain insights into actual social touch that are otherwise hard to obtain. Specifically, studies into the virtual Midas touch effect have found indications that the Midas touch effect may, at least in part, be explained by a confederate bias (i.e. the confederate unconsciously adjusting other behaviors when also applying a touch). Finally, several studies have shown that mediated social touch, especially when used with congruent visual feedback, can enhance social presence.

Nevertheless, Mediated social touch as a research field is still relatively young [509], and as is indicative of the fledgling status of this field of research, is not without its growing pains. One such issue is that it is not always clear when and how we might expect mediated social touch to produce effects similar to actual social touch. Findings from virtual Midas touch studies are quite surprising when you consider the stark difference between vibrotactile feedback and a human touch, and would suggest that simple mechanical stimulation can produce effects similar to actual social touch. Yet when considering studies into effects of mediated social touch on physiological responses, we can argue that the forms of haptic feedback used there are a closer approximation of actual human touch, yet no clear effects comparable to actual social touch have been found in this line of research. Part of the issue is perhaps that the ways in which actual social touch affects people are also not entirely clear yet (see Chapter 4).

In addition, the methods used in mediated social touch research are typically less well formalized than those used in actual social touch research. Many mediated social touch studies have relied on questionnaires that were created ad hoc to suit the specific setting of the study, rather than using standardized questionnaires [e.g. 212]. Clearly, there is room for methodological improvements here.

Moreover, studies into mediated social touch, unlike studies into actual social touch, often feature very deliberate and consciously applied touches. Naturally, this is to some extent inherent to the field of research that relies on rather intrusive hardware for the application and reception of touches. The use of VR technology and SVEs could be beneficial here, because these technologies allow for richer settings in which to incorporate mediated social touch, that are more like situations in which actual social touches are applied. For example, the use of avatars that can be touched in an SVE might be a compelling way to conduct further research.

Finally, while the different touches in actual social touch research differ in, for example, the distance of movement over the skin, or the amount of force that is applied, they are comparable in the sense that they are likely to be applied with a human hand. In mediated social touch, however, it is not only characteristics such as movement that differ but the methods of stimulation provided to the skin may be very different. Compare, for example, the sensation produced by a vibration motor to that produced by a force feedback joystick or a Peltier element. The use of a diverse range of actuators in mediated social touch research makes it difficult to compare findings. Would a virtual Midas touch, for example, also be found for mediated social touch consisting solely of thermal stimulation?

In the chapters that follow some of these issues will be addressed in more detail, including the use of virtual environments, investigations into aspects of touch that might be communicated by other modalities, and making comparisons between sensations produced by haptic technology and actual touches. We will start in the next chapter by addressing the issue of the diversity of hardware that is used in mediated social touch research. In the next chapter the iterative design

process of a device for mediated social touch will be discussed. The aim of this device is to provide a more standardized research tool for mediated social touch research.

CHAPTER EIGHT

THE DESIGN OF THE TASST: TACTILE SLEEVE FOR SOCIAL TOUCH

Before the invention of the phonograph by Thomas Edison in 1877, and later the gramophone by Emile Berliner in 1887, the only way to listen to music was to go out and attend a concert by the band, ensemble or orchestra in the flesh. This limited the music that you could listen to, to that which a specific band was particularly good at playing. If you wanted to listen to something else the only solution was to go and see a different band. The introduction of the phonograph and especially that of the gramophone player changed all this. Now there was a device which you could have in your home, provided you were affluent enough, that allowed you to listen to any kind of music that you liked, right from the comfort of your favorite arm chair!

Similar observations can be made for visual images and the development of all kinds of display technology, from early photographic methods, to the invention of the cathode ray tube and liquid crystal displays. However, as we have seen in the previous chapters, the development of haptic devices that are capable of stimulating our sense of touch in a variety of ways is a much more recent one. Furthermore, where even an early '30's gramophone could cover roughly half of the human auditory spectrum (from 60 to 7000 Hz), there is no real haptic equivalent of the gramophone. Put differently, haptic devices that exist to date can, generally, only deliver a single type of haptic sensation, such

as a vibration pattern or squeezing sensation. And where cameras, microphones, monitors, and speakers can be bought in stores, haptic devices are much less widely available.

So, in order to be able to investigate the use of haptic technology for social touch the most viable option is to design custom hardware with available basic sensors and actuators. This is indeed what many researchers have done as we have seen in Section 6.3 in the design of a wide variety of prototype devices for mediated social touch. Like a live band that is specialized in one genre of music, many of these devices were designed to deliver a particular type of touch, for example delivering a tickling sensation [174], or to arm wrestle [530]. While such focussed devices might be able to deliver one type of touch very well (after all attending a concert by a specialized band is still a compelling experience), they are not very suitable for wider application. Nevertheless, it is an understandable approach to use the limited hardware available to try and emulate one specific type of touch in a way that comes close to actual social touch. On the other hand, such specialized devices make it difficult to compare findings from studies into mediated social touch, as any difference could be explained by differences in the way mediated touches were administered.

In social interactions we use a wide variety of different touches [272]. To comfort someone, we might use a stroking touch, while a squeeze or poke might be used in playful situations. Think also of all the types of touch used to communicate emotions [242, 244, 245], which include grabbing, pinching, stroking, slapping, squeezing, and many more. With so many different types of touches used in social touch interactions, it may not be a viable approach to design a device for each type of touch separately. Firstly, this would require the creation of a vast number of prototype devices. Secondly, it would limit users to only apply and receive one type of touch at a time.

One solution to this problem would be to design a device that operates like a human hand, and can apply all, or most, of the touches that a human hand can apply. Indeed, such devices have been created [122, 429]. Nevertheless, these robotic hands are very costly, lack robustness, and typically require a large amount of control hardware,

which often comes with the requirement of a stationary setup, limiting interaction possibilities. Moreover, integration of such a hand into a mediated social touch interaction might not be so straightforward [see also 372].

Another solution is to rely on peoples' ability to look past, or rather feel past, the limitations of the hardware and the degraded haptic sensations that such hardware generates, compared to actual human touch. Indeed, when we look at studies into the virtual Midas touch effect (i.e. using mediated social touch to try and enhance pro-social behavior in the recipient) for example, it stands out that the virtual Midas touch effect is comparable to the Midas touch effect observed for actual social touch, despite the fact that the vibrotactile sensations used in virtual Midas touch studies are quite unlike actual social touch [e.g. 217]. Similar observations can be made for the use of mediated social touch to communicate discrete emotions [27].

This is by no means to say that high fidelity haptic sensations are not important for creating compelling mediated social touch experiences and feelings of social presence [258]. Nevertheless, based on the current state of research in mediated social touch it would seem that the degraded sensations generated by current haptic technology are not an insurmountable obstruction for mediated social touch per se [see also 509]. Chapter 6.3 listed various prototype devices for mediated social touch, among which devices in the category that was related to 'symbolic' meaning (see Table 6.1). Such devices use relatively simple actuation methods that allow for a variety of different haptic sensations to be communicated. Potentially, when such a device is used in an interaction clearly framed as social touch, such different sensations can be interpreted as different types of touch.

The most likely candidate actuator for the creation of a device following this line of reasoning is a type of vibrotactile actuator. Such actuators are generally small, require little power to run, and can be easily placed on the body. Moreover, there is ample research on the perception of vibrotactile feedback that could be valuable for the creation of different sensations [271, 506]. Especially when placed in a grid forming a so-called 'tactile display' [271, 506], vibration motors

can be used to create relatively detailed ‘patterns’ that offer a design space for the creation of different vibrotactile sensations.

When we consider such vibrotactile sensations in the light of mediated social touch we can essentially view these different sensations as abstractions of different types of touch. For example, a single, brief, localized vibration point is more likely to be interpreted as a ‘poke’, than as a rubbing sensation. Similarly, a moving vibrotactile stimulus is more likely to be interpreted as a stroking touch, rather than as a hitting touch.

With this we may have a method of applying different types of touch, albeit in an abstracted way, with a single device. This covers the output side of a device for mediated social touch but as discussed in Chapter 6, a compelling mediated social touch interaction also requires an appropriate method of applying touches. Therefore, we also need to consider how a toucher can apply touches to a sensor, the information from which might then be used to generate the appropriate vibrotactile sensation at the receiving end.

We have learned from the previous chapters that a match between input and output [258] and especially one where the input device is also morphologically congruent with the output [220, 221], has the most potential for creating a strong experience of social presence [258]. As a vibrotactile display produces a cutaneous sensation (i.e. it stimulates receptors in the skin, rather than exerting forces on the muscles and joints), a method of sensing cutaneous features of touches made by the toucher is necessary for there to be a match between input and output. A prime candidate for such a sensor, which has also been previously used in prototype devices for mediated social touch [86], is a force-sensitive resistor (FSR). An FSR can detect the amount of force applied to its surface and when a number of FSRs is placed in a grid, we basically have a sensor-surface that can detect the force, location, and duration of touches.

When we combine a grid of vibration motors with a grid of FSRs we have a simple setup that, on one end, can detect a touch and on the other end can reproduce a touch. A one-to-one coupling of FSRs and vibration motors can be used to reproduce the amount of force applied

to an FSR as a vibration of a certain intensity in the vibration motor. One practical advantage of this setup is that it is easy to construct with readily available, and inexpensive components, thus making it easily attainable to many researchers. This is important in that using similar setups to conduct mediated social touch research can make it easier to make meaningful comparisons between potential findings from this research. What is more, abstract forms of different types of touch can be communicated using this setup (e.g. poking a single FSR, will produce a brief vibration in a single location).

This basic concept was the starting point of the development of the Tactile Sleeve for Social Touch (TaSST). The concept described above and the versions of the TaSST that followed from an initial prototype were conceived of as research prototypes that would make it possible to conduct studies into mediated social touch. As such, potential commercial applications, or acceptance of such a device by potential users, were not considered too much during the design process. In the next few sections the iterative design process of the TaSST will be outlined, starting with a simple FSR grid as described above, and ending with a wearable device that can be used to communicate touches at a distance, from very subtle to rough touches. Each version of the TaSST was tested in an explorative study to investigate its potential for mediated social touch research.

While perhaps not quite a tactile version of the gramophone, the TaSST does represent an effort to produce a device that could enable a more standardized approach to the study of mediated social touch. Exactly how successful this effort turned out to be will become clear from the following sections, as well as from later parts of this book.

8.1 PROOF OF CONCEPT: THE PROTO-TASST

The oldest currently known hominid, *Sahelanthropus tchadensis*, dates back some six or seven million years ago, right around the time the human and chimpanzee evolutionary lines started to diverge [69]. Only a few scattered remains of *Sahelanthropus* have been found [69], but luckily relatively intact skeletons of slightly later hominids, such as *Ardepithecus ramidus*, who lived around 6 million years ago in what

is now known as Ethiopia, have been excavated [223]. Standing at about 1.2 meters tall, ‘Ardi’, having just descended from the trees to enjoy a ground-dwelling upright existence, was still quite ape-like in appearance [343]. Still later, around 3.5 million years ago, but very closely related to Ardi, Lucy (*Australopithecus africanus*) too, was small and ape-like [343], though her transition from tree to ground was far from graceful as the latest research into her unfortunate death indicates [284].

Though genetically and physically different from chimpanzees (chimpanzees walk on their knuckles where our hominid ancestors walked upright), these proto-humans are thought to have exhibited much of the same behaviors that chimpanzees show today [343]. Like chimps, Ardi and Lucy, living in slightly larger social gatherings than chimps do, expressed emotional bonds of kinship and friendship primarily through grooming behavior [343], in other words, through social touch. Not only that, but, again similar to chimps, Ardi and Lucy probably also made basic vocalizations and gestures for communication [343].

Fast forward a few million years to current-day humans and you will find complex social structures and a bewildering array of signals for social and emotional communication including the communication of affect and emotion through social touch [272]. Compared to simple grooming, current research shows that we modern humans can use our sense of touch for the communication of fairly detailed information.

In a series of experiments, Hertenstein and colleagues have demonstrated that when people are asked only to use their sense of touch to communicate a number of discrete emotions, such as love, anger, or sympathy, to another person this other person can, with a reasonable degree of accuracy, guess which emotion is being communicated [242, 244, 245]. This seems to work when touches are restricted to the forearm [245], and works even better when the whole body is available to touch [244]. What is more, people seem to be quite consistent in the types of touch that they use for the expression of specific emotions. Love, for example, is most often communicated by stroking, anger by hitting, and sympathy by patting. Note, that

Figure 8.1: The proto-TaSST: a grid of force-sensitive resistors (FSR) used to detect touches. The foam sheet used to cover the sensors is not depicted.

these examples are all touches that mainly feature cutaneous stimulation, although some emotions, such as happiness, were communicated mainly through kinesthetic touches such as swinging the other person's arm. The studies of Hertenstein and colleagues offer a useful paradigm to test the capabilities of a device for mediated social touch. This is because when people are asked to use the device in a mediated social touch setting where they express a number of discrete emotions through touch, we might expect them to apply touches that are generally similar to those used in the expression of emotions using actual social touch. Moreover, it is a paradigm in which a diversity of different touches can be used, thus making it possible to test to what extent a mediated social touch device is capable of communicating this diversity.

With this paradigm in mind a sensor grid was constructed that could be used to detect touches representative of certain discrete emotions. The grid consisted of three columns and four rows of FSRs (12 in total) attached to a rigid surface (see Figure 8.1). The sensors were covered with a semi-soft foam sheet to represent a skin-like surface. An Arduino Uno and custom software were used to record the force applied to each individual FSR, as well as the duration of each sensor

activation. As the sensors were arranged in a grid it was also possible to get a rough idea of where a touch was applied on the foam surface.

The idea was that each individual sensor could be connected to a vibration motor where the intensity and duration of vibration could be controlled by applying a certain amount of force for a certain time to one or more FSRs. The vibration motors would be arranged in a grid identical to the FSR grid and place on a relatively flat area of a person's body, such as the forearm, to make it possible to feel the touches applied to the FSR grid. This setup was in essence the very first version of the TaSST. A proto-TaSST if you will.

To investigate to what extent this proto-TaSST could be used for the expression of emotions through touch an informal pilot study was conducted to test the capabilities of the FSR sensor grid. A small number of participants (1 female, 4 male) was invited to use the sensor grid, covered with a foam sheet, to express six emotions. The expressions were recorded on video and data from each individual sensor was logged. The six emotions that the participants were asked to express were: anger, disgust, fear, love, sympathy, and gratitude. These emotions were chosen because they represented three negative and three positive emotions that were found to be recognizable through touch to the forearm in the studies of Hertenstein and colleagues [245].

It was explained to participants that it was their task to communicate six different emotions by touching the foam sheet, which they were told represented the forearm of another person. Participants were told that the data from the sensors would be recorded and played back to another person through a grid of vibration motors, after which the other person would have to decode the emotion from the vibrations.

From the videos it was observed that participants mostly used brief and forceful touches for the negative emotions (two participants used more prolonged touches for disgust), whereas for the positive emotions they used more prolonged touches covering more sensors. The sensor data was more difficult to interpret, because the FSRs required quite some force to register any touch at all. Therefore, a stroking touch that was meant to express love, and that was applied as one would generally stroke a loved one - that is, gently - would not register properly.

Figure 8.2: Example data from one participant expressing a number of discrete emotions using the proto-TaSST.

Participants also noted that the rather small, flat surface of the sensor did not really represent a human arm. This made it difficult to express certain emotions for which, for example, a squeeze was thought to be the most appropriate touch.

As an illustration of how the sensor data could offer additional insights, Figure 8.2 shows sensor data from a single participant. Keep in mind that this is just an example, but when we look at the difference in sensor activation between positive and negative emotions we can observe that for negative emotions, this particular participant used brief, high intensity touches, whereas for positive emotions this participant mainly used touches of a longer duration that were applied with moderate force. Looking at the rather distinct patterns of activation for each individual emotion as well, it is thought possible that when this sensor data is ‘played back’ through a grid of vibration motors, another person could recognize the emotions being expressed.

Still, the data presented in Figure 8.2 should really only be seen as a best-case example as in the data from other participants emotions were much less clearly distinguishable. That being said, this informal pilot study did reveal some interesting things regarding the concept of using a combination of an FSR grid and vibration motor grid for mediated social touch. First, the FSRs, especially with the foam sheet covering them, were not sensitive enough to pick up certain touches. Positive emotions, which participants most often wanted to communi-

cate through fairly subtle touches to the surface of the device, were particularly difficult to detect.

Second, the flat shape of the sensor grid did not represent a human forearm accurately enough. Touches that required the curvature of a forearm, such as squeezing or pinching touches, could not be applied to the sensor grid. Finally, participants did use touches within the limits of the sensor grid in an expressive manner representative of the emotional expression through actual social touch, such as expressing anger by hitting, and expressing sympathy by patting.

Bearing in mind the obvious limitations of this pilot study, such as the small number of participants and limitations of the data recording, we can take away a few things from the study. With relatively limited hardware, people, when instructed that their touches will be used in a social scenario, may be inclined to touch a device in a manner that is similar to applying touch to an actual human. Though clearly, a sensor grid with a higher level of sensitivity to touches is needed, especially for the detection of touches that represent positive emotions. In addition, a device that resembles the shape of a human forearm might allow participants to use a wider variety of touches to express emotions, and, in accordance with previous studies [220, 221, 372], might also enhance experienced social presence when the input device can be viewed by the recipient of the mediated touches.

8.1.1 Design rationale of the TaSST

Like early hominids coming to grips with social and emotional communication in increasingly more complex social structures [343], the pilot study that featured the ‘proto-TaSST’ served as an exploration of the communication capabilities of a force sensor grid connected to a grid of vibration motors. And, much as the early hominids’ communication capabilities compared to homo sapiens’ abilities, so too were the capabilities of the proto-TaSST found to be somewhat limited. This was mainly to do with a lack of sensitivity in the sensors and the general shape of the input device.

Nevertheless, with the findings from the pilot study a clearer picture emerged of what a potential research prototype for mediated so-

cial touch could look like. The general concept of the prototype device from the pilot study was extended, taking into consideration the notion that social touch, and by extension mediated social touch, is used in a wide variety of situations [see also 272]. It was decided to create a wearable device that incorporated both touch input and touch output. As the use of vibration motors would already require a person to wear something on their body in order to feel a touch, the design of a fully wearable device made particular sense.

The idea of creating a wearable device for mediated social touch has a number of implications. First, materials used in the construction should be relatively soft and pliable, as they need to accommodate differences in body shapes and sizes. Second, keeping in line with the concept of the proto-TaSST, input and output need to be integrated in some way, as the body offers limited space for both. Third, the body location to which mediated touches are applied needs to be carefully considered, as some body locations are generally more appropriate for social touch [247, 483], and mediated social touch [218], than others. Not only that, but not all areas of the body are equally sensitive to vibrotactile stimulation [93, 405, 506], thus the placement of vibrotactile actuators needs to be carefully considered as well.

Keeping in mind the studies on the communication of emotions through actual social touch [245], as well as the pilot study, and the considerations outlined above, it was evident that there was one body part that was most appropriate for a wearable mediated social touch device: the forearm. The forearm is an appropriate location for social touch [247, 483] and mediated social touch [218] to be applied, and it is relatively sensitive to a variety of vibrotactile stimuli, in terms of detecting the location of a vibrotactile stimulus [94, 271, 383, 405]. Moreover, as the forearm has been found to be an appropriate location for the perception of moving vibrotactile stimuli [184, 420], it could be used for dynamic touches as well. Though not as sensitive to vibrotactile stimulation as the hand [271], the forearm offers a relatively large surface area on which to receive and apply touches, it is easily accessible to touch, and is a convenient location for wearable technology [186].

With this, the Tactile Sleeve for Social Touch, TaSST for short, was born. The central idea was that of a wearable sleeve consisting of a grid of vibration motors on top of which a layer of soft force sensors is placed. The complete TaSST system consists of two sleeve, where the input layer of one sleeve controls the output layer of the second sleeve. This approach allows two people to synchronously engage in mediated social touch by touching their own forearm. When two people both wear a TaSST on their forearm, a touch to the forearm of the sender is felt as a vibration on the forearm of the receiver.

Data from each sensor is directly represented as vibrations in the output layer. The amount of force applied to the input layer of one sleeve is used to control the intensity of vibration of the vibration motor in the second sleeve that corresponds to the location of the specific sensor. So if one person were to press on the sensor closest to the wrist and in the centre of the sleeve, the other person would feel a vibration in the vibration motor closest to the wrist and in the centre of his or her sleeve.

This direct connection between input and output is different from other approaches in which sensor data is first recorded and processed, possibly with the use of machine learning techniques to extract features and classify a detected touch as a certain type of prototypical touch, that could then be rendered on the output layer. A problem with this approach is that the feature extraction and classification of touches is in itself still a considerable research challenge [279], and might thus not be directly usable. What is more, processing of data takes time and would therefore cause a delay between sending and receiving touches, making a rapid back-and-forth style communication more difficult.

The TaSST concept shares certain features with other mediated social touch prototype devices, such as ComTouch [86], Force-Phone [250], and CheekTouch [392]. Unlike these devices, the TaSST can register both the intensity and location of a touch, allowing for a wider variety of touches important in social touch interactions to be communicated. A similarity to other mediated social touch devices is that the TaSST was also envisioned to be used in conjunction with

other communication technology. In particular video conferencing applications such as Skype and Facetime were considered, because they allow users bidirectional audio-visual communication that can be easily combined with mediated social touch. This might be especially important considering that appropriate multimodal feedback, especially visual feedback, can be important in creating a compelling experience of mediated social touch [372], as well as can enhance social presence [220, 221].

The proof of concept pilot study and the design rationale outlined above led to the conception of a general design for the TaSST. This general design was refined through several iterations, of which the three most important ones are outlined in the next sections. Each iteration was followed by an explorative study to assess the viability of the TaSST for mediated social touch applications.

8.2 TASST 1: DO ANDROIDS DREAM OF ELECTRIC SHEEP?

Philip K. Dick, as the title for his most well-known novel, posed the rather fascinating question: “Do androids dream of electric sheep?” The novel, as well as the movie adaptation *Blade Runner*, explores topics surrounding artificial intelligence and synthetic humans, a topic which we shall revisit in relation to social touch in Part IV. With consideration to the novel’s title you might perhaps wonder about another, related question: if there were such a thing as an electric sheep, what would its wool be like?

The first design of the TaSST provides a rather compelling answer to that question. The TaSST 1 consisted of a single sleeve, worn on the forearm, with an input layer and an output layer that were both controlled by an Arduino Mega microcontroller. The input layer was a 4 by 3 grid of 40mm by 40mm Lycra pads filled with conductive wool (Bekeart Bekinox w12/18). Conductive wool is unfortunately not a material that one obtains from shearing electric sheep, in fact, as Rick Deckard notes in regard to his own electric sheep, this act would actually yield real wool. Conductive wool consists of regular sheep’s wool mixed with very thin stainless steel fibers and is typically used in the carpeting of airplanes as a way to discharge static electricity.

(a) The output layer of the TaSST 1.

(b) The TaSST 1 worn on the forearm.

Figure 8.3: The TaSST 1.

However, due to the mix of regular wool and metal fibers, when a tuft of wool is compressed its electrical resistance changes, effectively making it a soft, flexible FSR. The advantage of using such conductive wool sensors is that the wool-filled compartments are relatively sensitive, detecting changes in force of around 0.4 N. Moreover, the size of the sensors can be easily customized, the sensors do not require a rigid surface to function unlike conventional FSRs, and they are easily integrated into garments, making the sensor grid suitable to wear on the body.

Because the wool in the sensor pads had the tendency to settle after being touched, producing noise in the data stream, it was necessary to calibrate the input layer before use. To calibrate the sensors the wool was first fully compressed and then left untouched to determine the lower and higher resistance thresholds. Data from the compartments was smoothed using a low-pass filter and sampled with a 20 Hz sampling rate.

The layout of the output layer of the TaSST 1 matched that of the input layer. The output layer consisted of a 4 by 3 grid of pancake style eccentric mass vibration motors (KOTL C1226A001F) attached horizontally to a felt sheet (Figure 8.3(a)). The motors were 12mm in diameter and 2.7mm in height. The vibration motors were positioned in such a way that they were approximately in the centre of the corresponding sensor pad. The individual motors were placed about 40mm

apart. This spacing was chosen because it still allowed for relatively accurate identification of the location of individual motors so that it would still be possible for a person to feel, for example, two pokes being applied on either side of the wrist [94, 383].

The vibration amplitude of each motor was controlled by the amount of force that was applied to the corresponding wool-filled sensor compartment of the sensor pad, so that more force resulted in stronger vibrations in a roughly linear fashion. The vibration motors were controlled using pulse width modulation (PWM). PWM basically encodes a message into a number of pulses. Here it specifically referred to the amount of time a voltage was applied to the vibration motor in relation to the amount of time no voltage was applied. When the amount of time was relatively high, a higher amplitude vibration was produced. Based on previous research into the perception of vibrotactile stimuli, seven PWM levels were defined, resulting in seven perceptually different levels of vibration [383, 506]. To calculate the exact PWM values the system used the conductivity range of the wool between fully compressed (lower threshold) and uncompressed (higher threshold), and divided this range into seven equal levels relating to the PWM levels used to control the motors.

It is worthwhile to note that there is a clear downside to vibration motors like those used in the TaSST 1 for the application of vibrotactile feedback. The design of these motors does not allow the vibration frequency and amplitude to be controlled independently. So when a motor is made to produce a stronger vibration, the frequency of the vibration also changes. Pacinian corpuscles, primarily responsible for the detection of vibrotactile stimuli, are most sensitive to vibrations of between 150-300 Hz [271], so ideally a vibrotactile stimulus should always fall within that frequency range, something which cannot be achieved consistently, for all amplitudes with a vibration motor.

Nevertheless, compared to linear actuators of comparable size and cost for which frequency and amplitude can be controlled independently, eccentric mass vibration motors have a significantly higher amplitude of vibration, making the vibrations produced by these motors easier to perceive than the relatively 'soft' vibrations produced by a lin-

ear actuator. Moreover, prototype devices for mediated social touch following a design concept similar to that of the TaSST successfully used eccentric mass vibration motors [86, 250, 392], as did studies into the effects of mediated social touch [e.g. 217, 218].

A person wore the TaSST 1 by first putting the output layer, with the motors facing downwards, on the dorsal side (i.e. the top) of the forearm. Velcro straps were used to secure the output layer to the arm. The input layer was attached to the top of the output layer using Velcro. The total size of the TaSST 1 was 160mm by 120mm by 30mm. The TaSST 1, as described in this section, was used in a user study to assess to what extent it could be used for the communication of different types of touch.

8.2.1 Touching and being touched

A user study was conducted to assess the capability of the TaSST 1 to communicate different types of touch that are relevant in social touch interactions. The main aim of the study was to see how well participants could match vibrotactile feedback received through the output layer of the TaSST 1 to a touch made to the input layer of the TaSST 1.

There is a large variety of touches that people may use in social interactions [272], such as when communicating discrete emotions [242, 244, 245]. From this large set it was important to derive a workable set of touches that could reasonably be expected to be communicated through the TaSST 1. As the design of the TaSST 1 only allows for stimulation of the skin's surface in the form of vibrations, the touches that can be communicated through it are limited to touches that stimulate the cutaneous sense and not the kinesthetic sense [326].

Morrison and colleagues [366] propose three categories of touch that contain different types of touch that share certain commonalities. The first category is titled “simple”, and contains touches that are brief, intentional and relatively restricted to certain body locations, such as the arm or hand. An example of simple touch is a waiter applying a brief touch to a diner's shoulder when bringing the check to the table, possibly with the aim of receiving a higher tip [114]. Getting someone's

Figure 8.4: The types of touch that were recorded with the TaSST 1.

attention by tapping him or her on the shoulder would be another example of a simple touch. Somewhat different from simple touches are touches in the “protracted” category [366]. Touches in this category are typically longer in duration and often involve mutual skin-to-skin contact where a form of pressure is applied. Examples are shaking hands, squeezing someone’s arm, or hugging someone. Finally, the category “dynamic” contains touches that feature continuous, often repetitive movement over the skin. An example of such dynamic touches would be stroking someone’s back to comfort them.

For each of these three categories of touch [366], two touches that were most often observed in the studies by Hertenstein and colleagues [245], and that feature cutaneous stimulation exclusively, were selected. For the ‘simple’ category these touches were ‘poke’, and ‘hit’. For the ‘protracted’ category, ‘press’, and ‘squeeze’ were selected. Finally, for the ‘dynamic’ category ‘rub’, and ‘stroke’ were selected.

The hypothesis was that when a person, familiar with the way the TaSST 1 worked (i.e. applying a touch to the input layer of one sleeve to produce a vibration pattern in a second sleeve), received a vibration pattern to his or her forearm, he or she would recognize this vibration pattern as a specific touch that had been applied to the input layer of the TaSST 1. For example, a vibration pattern that featured back-and-forth activation of two adjacent vibration motors would be recognized as a rubbing touch.

To this end, simple (poking and hitting), protracted (pressing and squeezing), and dynamic (rubbing and stroking) touches were recorded with the input layer of the TaSST 1 (Figure 8.4). Each touch was ap-

plied by the experimenter and recorded multiple times to arrive at a well recognizable version of the touch (i.e. a prototypical touch of each specific touch type).

Four variations of each touch were recorded with different locations and orientations (e.g. two strokes over the length and two strokes over the width of the input layer). These locations and orientations were chosen to be close to, or farther away from body landmarks such as the wrist, edge of the arm, and elbow [94, 383], as well as be oriented along or across the arm. Only a small subset of all possible variants was selected in order to have a workable set of stimuli.

As the touches were recorded by the experimenter in a controlled setting prior to the experiment, the recordings should be considered a 'best case' scenario. To get an idea of how clearly each prerecorded touch would be recognized when 'played back' through the output layer, participants had to imitate the touch they received by touching the input layer.

Participants

The study featured 10 participants (8 male, 2 female) who were all students and staff members of a university. The mean age of participants was 28.3 ($SD = 2.9$). The mean circumference of participants' non-dominant wrist was 169.2 mm ($SD = 13.1$ mm).

Procedures

The participant was first directed to a chair and desk behind an opaque screen. Here the participant was asked to read and sign an informed consent form. The participant was then given a written explanation of the experiment that also contained a description of the way the TaSST 1 worked. Next, the measurements of the participant's wrist were taken. The output layer of the TaSST was attached around the participant's non-dominant arm, so that the middle of the output layer was aligned with the centre of the participant's wrist. The input layer was attached to the top of the output layer.

The participant was told that someone on the other side of the screen would apply a number of touches to an identical sleeve. It

was the participant's task to think about how the person on the other side had touched his or her sleeve, and to try to imitate this touch by touching his or her own sleeve. In reality the participant received the 24 prerecorded touches in random order (Figure 2). After receiving each touch twice consecutively, the participant imitated the touch on his or her own sleeve, and indicated verbally that he or she was ready to receive the next touch. Finally, the participant indicated his or her age, gender, and general comfort level while wearing the sleeve. During the experimental procedure, the participant wore headphones playing white noise to block out the sound produced by the vibration motors. The entire procedure was video-recorded from two different angles (top-down and from the side).

Results

Based on the description of each touch type by Morrison and colleagues [366] three parameters were defined to assess how well participants were able to imitate the prerecorded touches they received through the output layer of the TaSST 1. The focus was on how participants touched the sleeve (type of touch), how long they touched the sleeve (duration), and how much of the sleeve they touched (surface area). The type of touch was obtained from annotated video data. The duration of the touches was recorded from the moment of first contact with the surface of the input layer, until the last moment of contact. The data was averaged for the four variants of each touch. Finally, the surface area was obtained by counting all unique sensors that a participant touched while imitating a prerecorded touch. If a participant touched a sensor twice this was counted as a single sensor activation. This way rub, for example, had a surface area of two, since only two unique sensors were activated. Again, the data was averaged for the four variants of each touch.

Initially, sensor readings from the input layer of the TaSST 1 would be used in combination with the recorded videos. However, upon inspection of the sensor data, a malfunction in the input layer was discovered, resulting in overly noisy and altogether unusable sensor data. As the focus of this study was on the type of touches that participants

Table 8.1: Cross tabulation for individual touches. Adjusted residuals in brackets. The category ‘other’ contains tap, tremble, pinch, scratch, and massage.

Response	Hit	Poke	Press	Squeeze	Rub	Stroke	Other	Total
Stimulus								
Hit	0 (-.4)	25 (4.3)	8 (-.6)	1 (-1.4)	0 (-1.0)	2 (-1.6)	4 (-1.8)	40
Poke	0 (-.4)	18 (1.8)	8 (-.6)	3 (-.1)	0 (-1.0)	3 (-1.1)	8 (-.1)	40
Press	1 (2.2)	8 (-1.9)	13 (-1.0)	3 (-.1)	0 (-1.0)	6 (.5)	9 (.3)	40
Squeeze	0 (-.4)	9 (-1.6)	12 (1.1)	9 (3.7)	1 (.2)	4 (-.5)	5 (-1.4)	40
Rub	0 (-.4)	10 (-1.1)	7 (-.9)	0 (-2.0)	3 (2.7)	3 (-1.0)	16 (3.5)	39
Stroke	0 (-.4)	9 (-1.6)	8 (-.6)	3 (-.1)	1 (.2)	12 (3.7)	7 (-.5)	40
Total	1	79	56	19	5	30	49	239

made to the TaSST 1, something which can currently still be more accurately done through visual observation than through analysis of sensor data [279], the sensor readings were not used in the analyses. Instead, all the described parameters were obtained from frame-by-frame analysis of the recorded videos similar to the method used by Hertenstein and colleagues [242, 244, 245].

As measures of effect size generalized Eta squared (η_G^2) and partial Eta squared (η_p^2) are reported for all F -test, Cohen’s d is reported as a measure of effect size for all one-sample t -tests [304], though note that the effect sizes are inflated likely due to the small sample size.

Type of touch Based on the videos, two raters, unfamiliar with the order in which the touches had been applied, coded each touch made by participants. The coding scheme that was used was based on the one used in a study on expression of emotions through touch to the forearm [245]. The coding scheme included the following items: rubbing, poking, stroking, massaging, pressing, squeezing, scratching, hitting, tapping, trembling, and pinching. Substantial inter-rater reliability on the types of touch was obtained with Cohen’s $K = .78$, $p < .001$, 95% CI [.716, .836].

In a first discussion round between the raters consensus was obtained on all touches. Table 8.1 shows the cross tabulation of all in-

Table 8.2: Cross tabulation for touch categories. Adjusted residuals in brackets.

Response	Simple	Protracted	Dynamic	Total
Stimulus				
Simple	49 (3.4)	22 (-1.3)	9 (-2.7)	80
Protracted	25 (-3.2)	38 (3.4)	17 (-.0)	80
Dynamic	35 (-.3)	8 (-1.9)	25 (2.7)	79
Total	109	79	51	239

dividual touches that were made by participants (columns) and the touch that the vibration pattern was meant to communicate (rows). What stands out is that, overall, participants mostly used poke (79), press (56), tap (29), and stroke (30) to touch the sleeve. Furthermore, when a vibrotactile stimulus for poke, press, and stroke was presented, participants responded most often with a poke, press, and stroke respectively. The strongest confusion was found for hit, to which none of the participants responded with a hitting touch. Instead, for hit, participants mostly applied a poking touch. Similarly, when presented with a squeeze, participants mostly applied a pressing touch, whereas for rubbing touches, participants mostly applied a tapping touch.

It is quite interesting to observe that for one touch from each category (simple: poke; protracted: press; dynamic: stroke), participants indeed applied the same touch when they received the matching pattern, whereas for the other touches from each category (simple: hit; protracted: squeeze; dynamic: rub) there was considerably more confusion.

The cross tabulation in Table 8.1 violated the assumption of minimum expected cell counts for a Chi-square test of independence. Thus, touches were recoded into the three categories of touch (i.e. simple, protracted, and dynamic). From this data, a new cross tabulation for the prerecorded (stimulus) and coded (response) touches was made (Table 8.2). From this cross tabulation we can observe that for sim-

ple and protracted touches participants indeed responded most of the time with simple and protracted touches respectively. For dynamic touches however, participants mostly responded with simple touches. Nevertheless, there was a statistically significant association between prerecorded and coded touches ($\chi^2(4) = 23.42, p < .001$). This association was small to moderate (Cramer's $V = .221$) [104].

When we look at the adjusted residuals for this cross tabulation we can see that for each prerecorded touch category the residual is largest for the matching touch category of the coded touches. This indicates that these stimulus-response combinations were the most different from the assumption of the null hypothesis of independence, thus these values contributed most strongly to the association between stimulus and response.

Some participants also made specific remarks about how well they were able to imitate touches. One participant remarked that because the input layer consists of separate thick compartments, he/she was more inclined to use simple and protracted touches. Moreover, another participant remarked that the very soft input layer gave the impression that considerable force was required for a touch to be registered. Therefore this participant was inclined to use more protracted touches.

Finally, participants indicated that the sleeve was relatively comfortable to wear ($M = 3.90, SD = .99$, scale of 1-5 where 1 is "very uncomfortable", and 5 is "very comfortable"). Wrist size did not influence comfort levels ($F(1, 9) = 2.97, p = .123, \eta^2 = .271$).

Duration of touches First, the duration of the touches made by participants was compared to the duration of the prerecorded touches with one-sample t -tests and using a Bonferroni correction for multiple comparisons (i.e. $\alpha = .05/6$).

Statistically significant differences were found for hit ($t(9) = 3.53, p = .006, d = 1.116$), squeeze ($t(9) = 4.16, p = .002, d = 1.316$), and stroke ($t(9) = -5.18, p = .001, d = -1.638$). As can be observed from Figure 8.5 in the case of hit and squeeze participants significantly overestimated the duration while in the case of stroke participants underestimated

the duration. When we look at Figure 8.5 we can see that for these touches the difference with the prerecorded touches are substantial.

An identical analysis was conducted but this time with touches collapsed into their touch categories. For all categories, that is simple ($t(9) = 3.57$, $p = .006$, $d = 1.129$), protracted ($t(9) = 4.07$, $p = .003$, $d = 1.287$), and dynamic ($t(9) = -4.90$, $p = .001$, $d = -1.550$), the duration of touches made by participants differed significantly from the prerecorded touches. In general, for brief simple touches, as well as for protracted touches participants had the tendency to overestimate the duration, while for longer dynamic touches participants seem to have had a tendency to underestimate the duration.

Bearing this in mind we can nevertheless observe from Figure 8.5 that the duration data of touches made by participants follow a trend that is similar to the prerecorded touches. This trend indicates that when imitating the touches they received participants showed a tendency to distinguish temporally between different touches in a similar fashion as the prerecorded touches were distinguished temporally. For example, hit was briefer in duration than poke, and both were briefer in duration than press.

To explore the way participants distinguish between touches temporally the touches made by participants were compared to each other using a repeated measures ANOVA. The overall analysis indicated a significant difference between the mean duration of the different touches ($F(5, 45) = 3.96$, $p = .005$, $\eta_G^2 = .275$, $\eta_p^2 = .305$), but subsequent pairwise comparisons with Bonferroni correction did not show differences between individual touches. If we forgo the Bonferroni correction and, in the spirit of the exploratory nature of the study, accept a higher Type I error rate (i.e. a higher chance of wrongfully accepting the alternative hypothesis), the pairwise analyses show some significant differences. First, the duration of poke was significantly shorter than that of squeeze ($p = .025$), rub ($p = .016$), and stroke ($p = .030$). The same was true for hit, for which the duration was also significantly shorter than for squeeze ($p = .020$), rub ($p = .019$), and stroke ($p = .034$). When we look at the duration data in Figure 8.5 the results from these comparisons do seem to make sense.

Figure 8.5: A comparison between the duration of the prerecorded touches (stimulus) to the duration of touches made by participants to the TaSST 1 sensor layer (response). Error bars indicate ± 1 standard error.

To further explore this, touches were aggregated over the three touch categories and another repeated measures ANOVA was conducted. Again a significant difference was found between the mean durations of each touch category ($F(2, 18) = 6.00, p = .01, \eta_G^2 = .348, \eta_p^2 = .400$). This time, subsequent pairwise comparisons with Bonferroni correction revealed a significant difference ($p = .046$) between simple ($M = 1107.62$ milliseconds) and dynamic ($M = 2422.75$ milliseconds) touches.

Surface area of touches To assess potential differences between the surface area touched by participants in response to a vibration pattern they received, a comparison (one-sample t -tests with Bonferroni correction) was made between the average number of motors activated for each prerecorded touch and the average number of sensors touched by each participant. Significant differences were found for hit ($t(9) = 3.75, p = .005, d = 1.186$) and poke ($t(9) = -6.55, p < .001, d = -2.071$). For poke participants overestimated the surface area of the touch. It is possible that the felt sheet to which the motors were attached vibrated when motors were activated. In the case of a relatively localized touch such as poke these vibrations might have been perceived as activations of surrounding vibration motors.

Conversely, for hit, participants underestimated the surface area of the touch they received. This might be due to the fact that hit was very brief in duration (see Figure 8.5). It is conceivable that the duration was too brief for participants to feel hit as activation of four motors and instead perceived activation of a smaller surface area.

To explore this further, touches were aggregated over the three touch categories and compared to the prerecorded touch categories using an identical method as described above. No significant differences emerged between the average number of motors activated and the average number of sensors touched by participants.

Next, the average number of sensors touched by participants for each type of touch were compared using a repeated measures ANOVA. The overall analysis indicated a significant difference between the mean number of sensors touched for the different touches (Greenhouse-Geisser correction applied, $F(2.29, 20.64) = 5.65, p = .009, \eta_G^2 = .228, \eta_p^2 = .386$). Subsequent pairwise comparisons with Bonferroni correction revealed a significant difference between the number of sensors touched for hit and squeeze ($p = .027$), and hit and stroke ($p = .017$). Basically this further supports the idea that participants underestimated the surface area of a hitting touch, here compared to squeezing and stroking, due to the fact that hit was characterized by a very brief vibration.

Conclusions

The TaSST 1 features a design based on the ideas from the proof of concept prototype and study: a grid of vibration motors allows touches to be felt by the wearer, and a matching grid of soft force sensors allows for touches made to the surface of the TaSST 1 to be registered. One important feature of the TaSST 1 are the conductive wool-filled sensor pads that offer more sensitivity and better wearability than traditional FSRs.

An explorative study was conducted to see how well the TaSST 1 would perform when it was used to communicate different types of touch that are important in social touch interactions [366]. The study investigated how well participants could intuitively match a specific touch to a given vibration pattern that they received through the output layer of the TaSST 1. Thus, the study provided insights into the match between touch input and output in the TaSST 1. Participants received a vibration pattern and were asked to touch the sleeve in a way that they thought another person had touched another sleeve to produce the specific vibration pattern.

Analyses of the video recordings showed that for one touch from each touch category that participants received, specifically poke, press, and stroke, most of the time they also responded by applying that type of touch to the input layer. Poke, press, and stroke, which were also the types of touch that participants used most overall. It could be that the design of the TaSST 1 invites these types of touch more than it does other types. It could also be that people are generally more inclined to apply poking, pressing, and squeezing touches, than they are other touches.

For the duration of touches the focus was on for how long participants touched the TaSST 1 in response to receiving a vibration pattern of a certain duration. Participants showed a tendency to overestimate the duration of briefer touches, in particular hit and squeeze, and a tendency to underestimate the duration of longer touches such as stroke. It is also possible that participants have a general tendency to touch for a certain duration irrespective of the type of touch they apply. Nevertheless, the graph plotting the duration of touches that participants

applied (Figure 8.5) showed a pattern that was comparable to that of the duration of the vibration patterns. Thus it would seem that participants did distinguish between different touches by touching for a shorter or a longer duration, just not to the same extent as the pre-recorded touches were distinguished from each other in terms of their duration.

Finally, when looking at the surface area of the TaSST 1 that participants touched when they received a certain vibration pattern, we can see that especially for simple touches participants touched either too much or too little of the sleeve. For poke, participants overestimated the surface area, possibly due to the material of the sleeve also vibrating. The surface area of hit was structurally underestimated. A likely explanation for this is that, although hit activated four vibration motors, it was very brief in duration. Participants may have had trouble feeling all four motor activations for the brief moment they were active.

Though obviously far from conclusive given the explorative nature of the study, these findings did provide some indication that the concept of the TaSST 1 (controlling vibration motors with force sensors) could be used for the communication of different touches. The TaSST 1 seems to better support simple and protracted touches, as those were most likely to be applied in response to any vibration pattern received by participants. As was remarked by one participant, the ‘cushiony’ shape of the sensor pads invited participants to apply more of these types of touch. Though we should also remark that for some touches in these categories, the surface area of touches was difficult to perceive, possibly due to the construction of the output layer. This may have also had an impact on what types of touch participants were most likely to apply. We can thus conclude that changes to the TaSST 1’s input and output layer might improve its capability for communicating different types of touch.

The general aim of the TaSST is to offer more freedom of expression by allowing different types of touch to be communicated, with the ultimate goal of creating a more standardized set of hardware that could be used for future mediated social touch research. This goal was not yet reached with the TaSST 1. Nevertheless, the explorative study did

provide some insights into how to improve on the design of the TaSST 1 in order to make it more suitable for mediated social touch and the communication of different types of touch.

8.3 TASST 2: I FELT TOUCHED

The expression “I felt touched” refers to an emotional experience by a person. In Section 4.4 we have already seen that there are many more examples of expressions that use touch, or touch related words to denote intimacy, affect, or emotions. Even when we colloquially refer to internalized emotions we do so using the term “feelings” [314]. Conversely, the rather dry, unemotional description “I touched felt” would refer to a person touching a piece of fabric, likely made of wool, that was constructed through a felting technique. As we shall see in this section, both uses of the word ‘felt’ are relevant to the TaSST 2.

The TaSST 1 featured a soft, almost fluffy, input layer made up of several ‘cushions’ filled with conductive wool. This resulted in a rather thick sleeve which was less than ideal as a wearable interface. Moreover, as we learned from the results of the explorative study the shape of the input layer favored the use of simple and protracted touches [366] while its softness suggested to some participants that more forceful touches were required.

Therefore it was decided that the input layer needed to be thinner, firmer, and smoother. To achieve this, a technique that is known to hobbyists, fashion designers, and manufacturers of luxurious iPad cases, was used: dry felting. Dry felting involves taking tufts of wool, putting them in a mold with a particular shape, and pushing a hooked needle repeatedly through the tufts of wool. What this will do is make the wool get tangled together, and, depending on for how long one continuous, produces a relatively solid pad of felted wool. The same conductive wool (Bekeart Bekinox w12/18) was used as for the TaSST 1 with a 40mm x 40mm x 10mm mold, to shape the raw conductive wool into square pads with roughly the same dimensions as the mold. The pads of wool were covered with a Lycra fabric resulting in overall thinner and firmer sensor compartments that still allowed for 7 distinct levels of force to be detected, the same as for the TaSST 1. The reduced

(a) The components of the TaSST 2, from left to right: the output layer, the input layer, and the control box. (b) The TaSST 2 worn on the forearm.

Figure 8.6: The TaSST 2.

thickness of the sensor compartments also made the input layer of the TaSST 2 smoother overall. Especially when compared to the thicker ‘cushions’ of the TaSST 1, the hope was that this would invite more diverse touches from people touching the surface of the TaSST 2.

The explorative study with the TaSST 1 indicated that participants had difficulties feeling how many motors were active at any one time, especially for relatively brief stimuli. Therefore, changes were made to the output layer of the TaSST as well. First, the vibration motors were placed perpendicular to the surface of the output layer. The idea behind this was that when the motors are positioned horizontally the direction of rotation of the motor will produce a vibration that moves over the skin’s surface. Conversely, with the motors placed in a perpendicular position, the rotation direction of the motor is towards the skin, thus producing a vibration that indents the skin rather than moving over its surface. It was hypothesized that this would produce vibrations that were more easy to localize [see also 392, 405].

One additional change that was made to the output layer was that excess material was removed from the felt sheet to which the vibration motors were attached. The aim here was to reduce the extent to which the material surrounding the vibration motor would vibrate upon activation of the motor.

Finally, all of the control hardware necessary to use the TaSST 2 was hidden away in a box, which connects to a PC and power socket (Figure 8.6(a)). This was purely for practical reasons, making the TaSST 2 easier to set up, and less susceptible to hardware failure due to movements made by the user.

All in all, the TaSST 2 improved on the TaSST 1 in terms of wearability, with a more compact sensor layer (Figure 8.6(b)). This new, felted sensor layer with a flatter and smoother surface would hopefully invite more diverse touches from users. Finally the output layer was improved to enhance the localization of individual vibration motor activations. Like the TaSST 1, the TaSST 2 was used in an explorative study to investigate to what extent these changes improved the TaSST 2 for use in mediated social touch interactions.

8.3.1 Expressing emotions

The explorative study that featured the TaSST 2 revisited the idea that was explained in relation to the proto-TaSST, namely that the communication of emotions through touch is a convenient paradigm to investigate the extent to which a device is capable of communicating different types of social touch. Especially considering that the design of the TaSST 2 required users to touch their own forearm, there were some fairly clear expectations of how participants in a study into emotional expression using the TaSST 2 would apply touches based on research into the communication of emotions in actual social touch [245].

Not only that, but previous research had indicated that people could indeed communicate, with some degree of accuracy, different discrete emotions through mediated social touch [27, 462]. Unlike these studies into the expression of emotions through mediated social touch, however, the TaSST 2 stimulates the cutaneous sense rather than the kinesthetic sense [326]. Investigating the expression of emotions with the TaSST 2 might not just be a useful paradigm to evaluate the TaSST 2 with, it might also provide some insights into how suitable a mediated social touch device focussed on cutaneous stimulation is for the communication of emotions compared to approaches that focus on kinesthetic stimulation.

With this in mind a study was designed in which participants were asked to express eight different emotions by touching the input layer of the TaSST 2. The emotions that participants were asked to express were taken from the list used by Hertenstein and colleagues [245] and included five basic emotions: anger, fear, happiness, sadness, and disgust. In addition, three emotions that are most likely to arise from interpersonal interactions were selected, namely: love, gratitude, and sympathy. These emotions were selected because in the study of Hertenstein and colleagues most of them were found to be accurately recognized when communicated through touch to the forearm [245].

The explorative study using the TaSST 2 was quite similar to one of the experiments reported by Bailenson and colleagues [27], in which they invited a group of participants into the lab to use a force feedback joystick to express a number of discrete emotions. Later, a separate group of participants would receive each emotion ‘played back’ through the force feedback joystick and would be asked to guess which emotion it was. In the explorative study reported here, participants wore the output layer and input layer of the TaSST 2 on their forearm and were asked to express the eight emotions by touching the TaSST 2. Unlike the study by Bailenson and colleagues [27], participants could play back the recorded touch through the output layer of the TaSST 2 to assess how well their expression was represented as a vibration pattern. Participants could re-record each expression as often as they liked. The idea behind this approach was that it would result in insights into how well the input and output of the TaSST 2 matched, and whether, with several recordings, participants would end up with an expression which they would be fairly confident would be recognized when played back to another person.

Participants

The study featured 16 participants (11 male, 5 female) with a mean age of 28.13 ($SD = 9.18$). Participants were all staff members and students from two universities. Note that for one participant, the expression of sadness was not properly recorded and was thus dropped from the analyses.

Materials

A single TaSST 2 sleeve, consisting of an input and output layer, was used for the explorative study. Participants recorded and played back touches using a custom software program. An online survey was used to ask the participants questions during the study.

Procedures

First the participant signed an informed consent form and was given a written explanation of the procedures. Next, the TaSST 2 was attached around the arm of the participant (Figure 8.6(b)). It was explained to the participant that it would be his or her task to express a number of emotions using the TaSST 2. It was explained that these expressions would be recorded and played back to other participants, whose task it was to try and recognize the emotion that was expressed.

Before expressing the emotions the participant was given the chance to try out the TaSST 2 and the recording program. The participant was required to click the record button, touch the input layer of the TaSST 2, click the stop button, and then click the play button to feel the touch being played back through the output layer. After this trial session the recording program would show, at random, one of the eight emotion words. It was the participant's task to express this emotion following the same recording procedure as in the trial session. The participant could click the play button to play back the recorded touch through the output layer, and decide to either record a new touch and discard the previous one, or move on to the next emotion word. After having successfully recorded an emotion the participant was asked to indicate how well he or she was able to express the emotion on a 7-point Likert scale ranging from 1 (Not at all) to 7 (Perfectly). Finally, for each emotion, the participant was asked in an open-ended question to describe the touches he or she applied ("Describe, in your own words, what sort of touches you used to express this emotion"). After recording all eight emotions, the participant indicated his or her age and gender. During the procedure, the participant wore headphones playing white noise to block out the sound produced by the vibration motors.

Results

A number of different metrics was used in the analyses of the results of the TaSST 2 explorative study. Unlike the explorative study for the TaSST 1, in this study the data obtained from the TaSST 2's sensors was also incorporated in the analyses. Four different metrics were derived from the sensor readings for each expression. First, the number of unique sensor pads that was touched for each emotion (i.e. the surface area). A high score would indicate a participant had used a large surface area to express the emotion whereas a low score would indicate the expression had been restricted to a smaller area. Second, the intensity (arbitrary unit between 0-255) averaged over all sensor pads touched during an expression. Third, the total duration of the expression in milliseconds, from the first to the last moment of contact with the input layer. And finally, the average duration in milliseconds of the time that elapsed between the activation of two or more sensors, further referred to as 'gap duration'. Basically these were the moments during the expression of an emotion that the input layer of the TaSST 2 was not touched. This last metric would give some insight into how people touched the sleeve. Touches that featured a lot of continuous contact with the sleeve would have a low gap duration. An example of such a touch would be a squeezing, or pressing touch. On the other hand, touches that are characterized by repeated contact would have a high gap duration, such as in the case of repeated poking or hitting.

Two metrics were used to get an indication of how well participants were able to express each emotion. First, the number of recordings that participants made would indicate how many tries they needed to arrive at an expression that was at least somewhat satisfactory. Second, participants were asked, for each final recorded expression, how confident they were in this final expression.

Finally, for each emotion that they expressed, participants described, in their own words, how they touched the sleeve to express the emotion. This would, irrespective of the data obtained through the sensors of the TaSST 2, provide insights into how participants touched the sleeve to express certain emotions.

Figure 8.7: Data from four different metrics obtained through the TaSST 2's input layer in the expression of eight discrete emotions. Error bars indicate 95% confidence interval.

Generalized Eta squared (η_G^2) and partial Eta squared (η_p^2) are reported as measures of effect size for all F -tests, and Hedges' g_{av} is reported as a measure of the effect size for all t -tests [304].

TaSST 2 sensor data For each of the four metrics obtained from the TaSST 2's sensors a repeated measures ANOVA was conducted to see if there were any statistically significant differences in the expression of individual emotions.

A significant difference between the mean values of the number of

sensor pads touched for each emotion was found ($F(7, 98) = 2.60$, $p = .017$, $\eta_G^2 = .096$, $\eta_p^2 = .157$). However, a pairwise comparison with Bonferroni correction did not reveal any significant differences between the individual emotions. If, as for the TasST 1 study, in the spirit of the exploratory nature of this study, we accept a higher Type I error rate (i.e. wrongfully accepting the alternative hypothesis), and do not apply a Bonferroni correction, we find significant pairwise differences. These less conservative pairwise comparisons show that for fear, participants touched a larger surface area of the TasST 2 than they did for gratitude ($p = .006$), sympathy ($p = .045$), and sadness ($p = .007$). Similarly, participants, on average, touched more sensor pads to express anger than to express gratitude ($p = .040$), sympathy ($p = .024$), or sadness ($p = .005$). Finally, participants also touched a larger surface area to express happiness than they did to express gratitude ($p = .006$), sympathy ($p = .036$), sadness ($p = .040$), and disgust ($p = .036$). These findings make sense when you look at the graph in Figure 8.7(a) that shows that for fear, happiness, and anger, participants touched the largest number of sensor pads.

To explore the difference between positive and negative emotions, the individual emotions were aggregated to derive a positive category (happiness, gratitude, sympathy, and love), and a negative category (fear, anger, sadness, and disgust). A paired-samples t -test revealed no significant difference ($t(14) = -.298$, $p = .770$, $g_{av} = .062$) between the average number of sensor pads touched for positive ($M = 6.92$, $SD = 1.98$) or negative emotions ($M = 7.08$, $SD = 2.98$). This would suggest that differentiation of emotions through the surface area of a touch does not so much depend on the valence of the emotion (i.e. whether it is a positive or negative emotion), but more on the specific emotion itself.

Next, a repeated measures ANOVA was carried out for the intensity data (Figure 8.7(b)) obtained through the input layer of the TasST 2. No significant difference was found between the mean intensity values for each emotion ($F(7, 98) = 1.35$, $p = .235$, $\eta_G^2 = .051$, $\eta_p^2 = .088$). To explore if there would be a difference in the intensity of touches for positive and negative emotions, the emotions were aggregated into a

category for positive ($M = 103.95$, $SD = 9.90$) and a category for negative ($M = 102.50$, $SD = 12.38$) emotions. However, a paired-samples t -test revealed no significant differences ($t(14) = .556$, $p = .587$, $g_{av} = .122$). Thus it would seem that the intensity of touches was not a clear differentiator for the different emotions.

Similar analyses were performed for the average duration of touches per emotion (Figure 8.7(c)). A repeated measures ANOVA revealed no significant difference in the mean duration for each emotion (Greenhouse-Geisser correction applied, $F(1.20, 17.67) = 1.25$, $p = .289$, $\eta_G^2 = .064$, $\eta_p^2 = .077$). When the emotions were aggregated into positive and negative, again, no significant difference ($t(14) = .396$, $p = .698$, $g_{av} = .068$) was found between the duration of positive ($M = 3919.28$, $SD = 1029.16$) and negative emotions ($M = 3349.34$, $SD = 864.80$).

Finally, the same analyses were conducted for the average gap duration of the touches per emotion (Figure 8.7(d)). A repeated measures ANOVA revealed no significant difference in the mean gap duration for each emotion ($F(7, 98) = 1.60$, $p = .144$, $\eta_G^2 = .081$, $\eta_p^2 = .102$). When the emotions were aggregated into positive and negative, again, no significant difference ($t(14) = 1.12$, $p = .280$, $g_{av} = .343$) was found between the duration of positive ($M = 1607.85$, $SD = 1306.86$) and negative emotions ($M = 1191.77$, $SD = 965.12$).

Based on these findings it would seem that neither the average duration of a touch, nor the gap duration were metrics that clearly distinguished between touches made for the expression of different specific emotions, or for the expression of positive or negative emotions.

Confidence in expression Two metrics were assessed to see how easy or difficult participants found the expression of the different emotions with the TaSST 2. As participants were allowed to re-record each expression as many times as they liked, a good indication of how difficult it was to express a certain emotion is to look at how often participants re-recorded it.

A repeated measures ANOVA was conducted to investigate differences in the average number of recordings per emotion. The ANOVA

Table 8.3: Mean confidence ratings and mean number of recordings for each emotion.

Emotion	Confidence	SD	Nr. of recordings	SD
Anger	5.13	.92	2.27	1.10
Fear	4.40	1.12	2.87	3.07
Happiness	4.27	1.44	3.93	3.81
Love	4.20	1.57	4.00	4.24
Sadness	4.20	1.21	3.80	3.10
Disgust	3.67	1.76	2.67	2.02
Gratitude	3.87	1.46	4.20	5.29
Sympathy	3.87	1.60	4.20	2.96

did not show a significant difference between the average number of recordings per emotion (Greenhouse-Geisser correction applied, $F(2.87, 40.20) = 1.09$, $p = .375$, $\eta_G^2 = .045$, $\eta_p^2 = .072$). To investigate whether there was a potential difference in the average number of recordings for positive and negative emotions the data for individual emotions was aggregated to derive average recordings for positive and for negative emotions. However, there was no statistically significant difference ($t(14) = 1.71$, $p = .109$, $g_{av} = .442$) in the average number of recordings between positive ($M = 4.08$, $SD = 3.26$) and negative emotions ($M = 2.90$, $SD = 1.48$).

Next, a repeated measures ANOVA was conducted for the average confidence rating per emotion but no significant differences were found ($F(7, 98) = 1.58$, $p = .077$, $\eta_G^2 = .088$, $\eta_p^2 = .120$). A paired samples t -test for the aggregated confidence ratings did not show a significant difference ($t(14) = -1.64$, $p = .121$, $g_{av} = .388$) between average confidence ratings for positive ($M = 3.97$, $SD = .99$) and negative ($M = 4.33$, $SD = .76$) emotions either.

From the above analyses we can conclude that the participants in the explorative study with the TaSST 2 overall, found the expression of emotions neither very easy, nor very hard. On average, participants used 3.49 tries to arrive at a final recording for each emotion.

Table 8.4: Open-ended responses of the types of touch used by participants to express an emotion, compared to the coded touches from Hertenstein et al. [245].

Emotion	Open-ended responses	Coded touch from Hertenstein et al.
Anger	Squeezing Hitting Pressing	Hitting Squeezing Trembling
Fear	Squeezing Grabbing Pressing	Trembling Squeezing Shaking
Happiness	Grabbing	Swinging Shaking Lifting
Sadness	Grabbing	Stroking Squeezing Lifting
Disgust	Pushing Pressing	Pushing Lifting Tapping
Love	Stroking	Stroking Finger interlocking Rubbing
Gratitude	Pressing Stroking Grabbing	Shaking Lifting Squeezing
Sympathy	Stroking Patting Holding	Patting Stroking Rubbing

Open-ended responses Besides the data obtained through the sensor pads of the TaSST 2's input layer, the way participants described what touches they made to express a certain emotion also gave insights into the types of touch that were used. As participants were instructed to describe the touches they made in their own words, a wide variety of open-ended responses was recorded. After inspection of the participants' responses five general themes emerged. The first theme is about

descriptions referring to the duration and timing of touches. For example, some remarks show that for happiness participants used fast touches (5x), for anger long touches (4x), and for sympathy repetitive touches (2x) with long pauses (2x). The second theme relates to the intensity of touches. Some remarks indicate that for anger participants applied hard touches (8x), while for gratitude they applied calm touches (4x). The third theme consisted of descriptions of touches that were related to the location of a touch. For example, for love, back-and-forth movements (2x) over multiple sensors (2x) were mentioned, while for anger some remarks indicated participants touched a lot (2x), and used different sensors (2x). The fourth theme contained descriptions that were more descriptive or metaphorical in nature. For example, for fear some participants remarked that they tried to communicate a startle (2x), while for happiness participants touched playfully (2x), and for sadness they tried to mimic crying (3x). The fifth and final theme featured descriptions about the type of touches participants made.

The type of touch is of particular interest because previous studies have linked specific touches to the expression of emotions through touch to the forearm [245], thus comparisons can be made. Table 8.4 lists the types of touch that were most often described in relation to a specific emotion in the current study next to a list of the types of touch most often used in the expression of emotions through actual social touch [245]. We can observe from this table that for the majority of emotions there are similarities between the touches that participants described for the current study and the ones that are most often used in the expression of emotions through actual touch to the forearm. It would thus seem that some participants tried to express emotions using the TaSST 2 in a manner that is comparable to the way people generally communicate these emotions through actual social touch.

Conclusions

The TaSST 2 improved on the design of the TaSST 1 in several ways. A dry felting method was used to produce sensor pads that were thinner and more firm; this resulted in an overall smoother sensor surface. The orientation of the vibration motors in the output layer was

changed from horizontal to perpendicular and excess material was removed from the output layer, all with the aim of making the vibrations produced by each vibration motor feel more localized.

As with the TaSST 1, an explorative study was conducted to investigate the use of the TaSST 2 in a scenario relevant to mediated social touch. The study presented here was inspired by research on actual social touch [245], research on mediated social touch [27, 462], as well as early experiences with the proto-TaSST (Section 8.1). In the explorative study with the TaSST 2 participants expressed eight different emotions by touching the input layer of the TaSST 2. The expressions were recorded and participants could play back the touches that they had recorded through the TaSST 2's output layer. Participants could re-record their expression as many times as they liked until they were satisfied with the recorded expression.

What stood out from the analyses of the metrics recorded through the input layer of the TaSST 2 is that none of the metrics showed any clear differentiation between the expressions of different emotions. This was the case for the specific emotions as well as for aggregated data for positive and negative emotions.

One explanation for this lack of any difference between the expressions is that participants simply did not touch the sleeve differently to express each emotion. Nevertheless, this is not a very plausible explanation given the notion that people, for actual social touch at least, do indeed express specific emotions with specific touches [245]. Moreover, the open-ended responses indicate that in the current explorative study participants also tried to use different types of touch to express the emotions.

Another explanation would be that the differences in expression were relatively subtle. For example, perhaps people do touch longer to express love than to express disgust, but the difference in duration may only be relatively small. The explorative nature of the study, with a relatively small sample size, might not have had the statistical power to reveal these subtle effects.

It could also be that touches did differ for the expression of different emotions but that these differences did not express themselves in

the metrics used to conduct the analyses. The derived metrics were based on the capabilities of the TaSST 2, but it could be that participants made touches to the input layer that were difficult to register properly. One example would be movement characteristics of a touch (e.g. stroking), which are difficult to derive from data obtained by the TaSST 2's relatively low-resolution sensor grid.

Finally, it is also conceivable that the design of the TaSST 2 in general was not optimal for the communication of emotions through touch. If we look, for example, at the intensity data we can see that there is relatively little variation in the mean intensity levels used to express different emotions. It is possible that despite the fact that the sensor layer of the TaSST 2 can detect seven different levels of intensity, the overall range of sensitivity is not good enough to distinguish emotional expression on this dimension. Nevertheless, if the hardware was indeed found to be severely lacking we may expect low confidence ratings for the expression of the emotions. In the current study, the confidence ratings for all emotions were average and did not indicate any clear difficulties in the expressions. Though we should also note that for the three emotions with the lowest confidence ratings (disgust, gratitude, and sympathy), the standard deviations are relatively high. This would indicate that these emotions were harder to communicate overall and that this was more so for some participants than for others. We should also not forget that all participants used multiple recordings for all emotions, which might indicate that the first, intuitive touches, never resulted in a satisfactory expression of the emotion concerned.

To conclude, as with the explorative study with the TaSST 1, the explorative study with the TaSST 2 provided insights into the use of the TaSST for mediated social touch interactions. Though the TaSST 2 improved on the TaSST 1 in several ways, it was concluded that there was still considerable room for improvements to the design of the TaSST 2. From the explorative study it became clear that the input layer needed additional improvements to make it sensitive to very subtle touches, such as those that might be used to express love, while still being able to detect rougher touches, such as squeezing, used to express anger. Another thing to consider was the coupling between input and output.

For the TaSST 2, as for the TaSST 1, the relation between forces exerted on the input layer and the intensity of vibration was linear. For certain touches however, this means that it may have been difficult to perceive the vibrations produced by the motors. An approach where there is a minimum level of vibration intensity that can be perceived and that is linked to the subtlest touches detectable through the input layer might make the TaSST more appropriate for the communication of subtle touches.

8.4 TASST 3: A HELPING HAND

The paramecium is a remarkable little critter. Shaped like the sole of a dress shoe, this single-celled organism can be found in various places but prefers to spend its time in sweet water [466]. The paramecium just also happens to be an excellent swimmer and propels itself through the water by using tiny hairlike cilia that it moves like the oars of a Roman galleon [384]. When we look at a paramecium through a microscope we can see that its world is full of obstacles and other organisms that it needs to avoid. Without ears or eyes, the paramecium uses its sense of touch to navigate its world. When a paramecium is happily swimming along and feels that it bumps into an obstacle it reverses its ‘rowing’ motion, turns a set number of degrees, and continues on its way, similar to how an Olympic swimmer turns during the 100 meter breaststroke. It will keep repeating this process until it is swimming freely again [384]. When the paramecium is swimming freely and feels that something is touching its backside it will actually speed up to get away from whatever might be threatening it [370].

The completely touch-based existence of the paramecium might be hard to imagine, yet there are other creatures, mammals such as the star-nosed mole included, for which the sense of touch is of paramount importance to making sense of the world. The sense of touch is the primary channel through which some people get information about their surroundings and their most important way for communicating with others [229, 425]. This is especially true for people with deafblindness.

Deafblindness is a condition where both the visual and auditory

senses are degraded to such an extent that a person's ability to acquire information through these senses is severely limited, even with the help of certain visual or auditory aids [425]. It is important to make a distinction between people with acquired deafblindness and people with congenital deafblindness [116, 425]. People with acquired deafblindness have gradually lost their hearing and sight as they aged and are typically still capable of using speech and other forms of language-based communication (including speech reading, such as *Tadoma* [415]) [116].

Conversely, people with congenital deafblindness are either deafblind at birth or become deafblind at a very early age before they develop language [118]. Due to a lack of auditory and visual sensory input people with congenital deafblindness also develop mental and behavioral disabilities [118, 425, 458]. People with congenital deafblindness often require round-the-clock personalized care and help in their daily lives [116, 118, 425, 460], and, due to the combination of physical and mental disabilities, have severe problems in communicating with other people [116, 229].

It is not too difficult to conceive that people with deafblindness must rely heavily on their sense of touch to make sense of the world around them, not to mention to communicate with others. In fact, social touch is the primary means through which people with deafblindness communicate and this is especially true for people with congenital deafblindness who have under or undeveloped language skills and have difficulty using symbolic forms of communication [116, 229].

It is for people with congenital deafblindness, then, that mediated social touch may be especially beneficial as a means to intuitively communicate with others at a distance. This notion served as an important drive and inspiration for the further development of the TaSST. The idea of using the TaSST, or a TaSST-like device for social communication with people with deafblindness actually sprouted from contact with the Dutch organization *Bartiméus* which specializes in care for people with visual handicaps, including people with congenital deafblindness.

The specific situation described by this organization was that up to eight people with congenital deafblindness permanently or semi-

permanently share a living space and receive round-the-clock care. An issue is that when a caregiver is not in close physical proximity to a client, for example when dealing with another client in a different room, the first client has no way of knowing where the caregiver is and has only limited means to attract a caregiver's attention. Among these limited means are unwanted behaviors (such as self-harm and undressing) that do typically elicit a response from a caregiver but that are harmful to the client.

Potentially, with sufficient practice, the TaSST could be used by a client with congenital deafblindness to alert a caregiver of a certain need. The caregiver, in turn, could respond through the TaSST to let the client know he or she will be there to help within a certain time-frame. Such a new way of communication between client and caregiver could potentially help reduce unwanted behaviors and would thus be beneficial to both the working environment of the caregiver and the quality of life of the client.

Although there was no formalized research project, the possibilities of this approach were explored in two workshops where researchers and caregivers who worked with people with congenital deafblindness on a daily basis explored haptic technology, including the TaSST, experienced artificial deafblindness, and discussed the possibilities of using mediated social touch in the daily care routine of people with congenital deafblindness.

This direction is a slight departure from the original aim of the TaSST, namely, to create a research prototype that could be used in various studies into mediated social touch. The approach outlined in this section is more directly aimed at potential real-world applications of the TaSST and devices like the TaSST. Despite this difference, it was useful to explore applications of the TaSST as this might provide valuable insights into aspects of the design of the TaSST that are useful to both applied and research scenarios. Not only that, but insights into certain aspects of the TaSST's design, such as requirements for robustness and wearability, are difficult to obtain through experimentation but might be obtained by engaging with a potential target audience of mediated social touch devices.

8.4.1 Workshops: TaSST and deafblindness

Communication with people with congenital deafblindness can be extremely challenging and often requires long-term training of both the client and the caregiver [458]. For this reason, workshops were organized for caregivers who worked with clients with congenital deafblindness on a daily basis, as well as for behavior experts. In addition, researchers visited one of the living spaces to get a better idea of the living situation of the clients. This helped in interpreting discussions during the workshops.

The first workshop was organized with three caregivers, two behavioral experts, and three researchers. The workshop started with an introductory round in which the general aim of exploring the use of haptic technology in the day-to-day care for people with congenital deafblindness was outlined. Next, the caregivers and behavioral experts got the opportunity to try out the TaSST 2, as well as some commercially available vibrotactile displays (Elitac Science Suit). A round of brainstorming followed this demonstration session in order to generate ideas on how the available hardware could be used during the daily routine of the caregivers. Next, the researchers presented the current state of the art of wearable haptic technology in order to further inspire discussion in a final brainstorming session.

During the second workshop three caregivers and three researchers were present. The workshop started with a presentation by the caregivers in which they talked about the daily routines in one of the living spaces with a focus on how they communicated with their clients and how this communication developed over a longer period of time. Next, the researchers got to experience artificial deafblindness and got to experience how caregivers typically communicate with people with deafblindness. Finally, a newly developed version of the TaSST, the TaSST 3 was used to see how well one could communicate with a person made artificially deafblind.

Insights from both workshops, as well as from the visit to the residency of a group of clients with congenital deafblindness, are combined in the following sections. The language used in the workshops was Dutch, thus all quotes have been translated.

Touch communication and care for deafblind clients

The task of providing daily care to clients with congenital deafblindness rests with the caregivers and includes support with activities such as drinking, going to the bathroom, and general entertainment usually involving a form of social touch (e.g. hugging). In addition, the caregivers keep track of the clients' overall development and well-being. The behavioral experts work with several client groups, though not on a day-to-day basis. Part of their task consists of keeping track of individual clients' mental developments and advising the caregivers on how best to approach their clients.

Clients can identify caregivers through touch, as well as through odors, such as perfumes that caregivers wear and for that reason almost never change. Identification through touch can occur through objects that the caregivers wear, such as bracelets or wristwatches. Actual communication between clients and caregivers occurs through touch gestures, also referred to as 'on-body signing'. Clients learn these touch gestures through extended periods of practice, with some gestures taking a year or more to learn. Touch gestures may differ between clients and while most caregivers remember the communication preferences of each of their clients, there are detailed documents that chronicle a client's developments and the gestures he or she has learned. The decision to teach a new touch gesture is made by caregivers in consultation with behavioral experts. The type of gestures that is used in the communication between a client and caregiver is highly personalized, and differs from client to client. The level of detail of a certain touch gesture also differs between clients and is dependent on the capabilities of the client and the amount of time spent practicing a certain gesture. For example, some clients may only be able to communicate that they want something to drink, while other clients may also be able to detail the type of drink that they want using a more complex gesture. Most clients are comfortable with gestures applied to either the hands or lower arm, but there are clients for whom those body locations are off-limits. For some clients, the upper-arm, back of the neck, back, and sometimes even legs are used for touch communication purposes.

Figure 8.8: A participant artificially made deafblind during a workshop on touch communication using the TaSST with caregivers of people with deafblindness.

The challenges of communicating purely through touch gestures become all the more apparent when one is made artificially deafblind with a mask and earphones (Figure 8.8). In the second workshop, researchers were made artificially deafblind and were guided by the caregivers in a number of tasks using touch gestures that are typically used with clients with congenital deafblindness. Experiencing artificial deafblindness really drives home the idea that the world you experience ends at your outstretched fingertips; anything that is not within physical reach basically does not seem to exist anymore, and is therefore very hard to relate to. For this reason it is not uncommon for people with deafblindness to become introspective and focus on the self rather than on the outside world [see also 425, 460].

In one instance the artificially deafblind researchers were presented with a piece of cake and their task was to cut off a piece and present it

to a fellow researcher. This exercise highlighted several issues. First, it is difficult to recognize foreign objects, even objects that you may be familiar with from previous encounters. Second, it is difficult to interpret the function of such an object without any clear context. Knowing what to do with a piece of cake and a knife when you yourself do not feel like having cake is not necessarily immediately clear. Third, it is very hard to notice the presence of another person who is just beyond the reach of your arms. Fourth, though the touch gestures made by the caregivers, which involved holding and moving one's hand to a knife to cut the cake, while helpful, can be difficult to interpret without a clear context and require significant repetition before their meaning becomes clear. Thus, when one is made artificially deafblind, cutting a piece of cake is anything but a piece of cake.

Both workshops provided some remarkable insights into the challenges that people with deafblindness face on a daily basis, especially those with congenital deafblindness. Not only that, but the incredible efforts required for communication between clients and caregivers is striking.

What is particularly interesting about the way clients and caregivers communicate through touch is that they use a variety of different touch gestures that are often tailored to the client. This is in some ways similar to the way the TaSST was used in previous explorative studies in which participants used different types of touch to mimic certain vibration patterns, or used different types of touch to record expressions of discrete emotions. While the TaSST 1 and TaSST 2 were not fully successful in this regard, the goal of the TaSST as a research device and the potential use of the TaSST in the daily communication between clients and caregivers seem to align. Both benefit from the communication of various types of touch.

Nevertheless, it also became clear from the workshops that there is a need for a clear context in which to interpret communicative touches and a need for repetition when learning new touch gestures. This is especially the case for people with congenital deafblindness who also suffer from mental disabilities. Finally, personalization does not just relate to the type of touch gesture that is made, but also to the body

location to which it is made. Something which is difficult to do with the design of the TaSST 1 or the TaSST 2.

The opportunities and challenges of using the TaSST and similar haptic technology in the communication between clients with congenital deafblindness and caregivers was an important topic in the further discussions during both workshops.

Mediated social touch and deafblind care

During both workshops different versions of the TaSST were available that could be used by the behavioral experts and caregivers to get a feel for the possibilities of haptic technology. The goals were to think about possible ways in which this type of technology could be used in the daily communication between clients and caregivers, and to think about ways in which the technology would need to be improved for this purpose.

The possibility of using touch gestures to communicate with a client at a distance was one of the applications that caregivers, especially, saw as beneficial. One of the scenarios that was considered involved both the client and the caregiver wearing a TaSST-like wireless device. The client's device would be tailored to their specific preference in terms of materials used and location on the body where the haptic feedback could be felt. The caregiver would either wear a TaSST-like sleeve that could be used to communicate touch gestures, or could use a tablet computer to select certain touch gestures that would then be sent to the client's device.

Other applications that were discussed, not all necessarily related to social communication, included using the TaSST for navigation purposes. Another application involved the client wearing a device where input and output would be linked, so that a client could engage in different forms of self stimulation, for example through mimicking certain signals in a game-like scenario [see also 229]. One behavioral expert remarked that such an approach would be more valuable to the client than more passive forms of relaxation where the client is not encouraged to perform any activity on their own:

“What makes it innovative, or what makes it fun is that it is not the device that does something on its own, but that the device does something because you yourself do something.”

Workshop participants considered several stimuli that could be applied in such a setting, including vibrations, and puffs of air. Another suggestion was to design the device in such a way that it would allow the client to progressively try out and learn additional interaction possibilities.

In addition to brainstorming about possible applications, participants in both workshops also thought about requirements for the hardware. One of the caregivers described the number of items that they carry around on a daily basis and expressed some concern for another device being added to the mix:

“We now have our phone and a little bag. In addition we have to wear our referral object around your hand [i.e. an object through which the client can identify the caregiver]. If you are unlucky you also have to carry your own phone. It drives you nuts.”

Considering this, another caregiver explicitly expressed appreciation for a wearable device, stating that:

“I would like it if you wear it on your own body. Firstly, because you also have to carry around your telephone which is incredibly annoying. Secondly, it is easy to leave it somewhere when you are doing something and you forget to take it with you again.”

Nevertheless, there were also caregivers who saw the benefits of using a tablet computer, expressing concern that wearing a sleeve-like device for an entire day, especially a warm day, might be unpleasant. A requirement related to this was that any wearable device should be washable and water resistant for situations such as spilled drinks, washing, and bathing.

The haptic sensations produced by a potential tactile communication device were also considered. After trying out the TaSST, participants considered it important that there should be as little delay as possible between input and output so that communication can be direct. In addition, the vibrations produced by the devices that were present during the first workshop are far removed from the sensation of actual human touch. Vibrations of a longer duration especially were considered undesirable, and one participant remarked:

“Could it not be that, if you touch it very briefly, the vibration becomes much more like pressure.”

This suggestion is similar to devices that use haptic feedback to provide an artificial ‘clicking’ sensation, such as the trackpads in Apple’s latest Macbooks. Participants also considered a volume knob so that clients could decide for themselves on the strength of vibrations that they would receive. Apart from vibrotactile feedback participants considered pressurized pads to produce sensations of force on the skin, and using warmth to simulate the feeling of body heat.

A number of issues were discussed in terms of how to interact with a touch-based communication device for client-caregiver communication. In a typical communication setting between a client and a caregiver, the caregiver initiates the communication by a predetermined, welcoming touch, such as a tap on the shoulder, or the soft blowing of air. Such signals let the client know that a person is present and that they can expect additional touch gestures, as well as being able to start to communicate through touch themselves. Both the caregivers and behavioral experts considered this an important element in client-caregiver communication and one that needs to be somehow incorporated into the design of a tactile communication device.

Participants also thought about how to use the device with multiple clients. Ideally, one caregiver should be able to communicate with all clients present in a residency through a single device. Therefore, the device should allow a caregiver to switch between multiple clients and make it possible for the caregiver to identify the source of an incoming signal.

Conclusions

The workshops that were conducted with behavioral experts, and caregivers of people with congenital deafblindness were a departure from the type of studies conducted with the TaSST 1 and TaSST 2, which were aimed at developing a research prototype for mediated social touch. Nevertheless, these more hands-on workshops were an interesting exploration of the possibilities of using the TaSST in a more applied setting, not to mention that they provided valuable insights into possible improvements to the TaSST's design. In addition, the workshops showed that caregivers use a variety of touches to communicate with their clients and thus the idea of the TaSST 1 and the TaSST 2 to communicate different types of touch was to some extent supported by the needs of the caregivers. Similarly, participants in the workshop expressed the importance of limited delay between input and output, a notion that was also central to the design of the TaSST 1 and TaSST 2.

Other insights regarding the design of the TaSST and its potential use in real-life settings, such as in caregiver-client communication, were that it should be able to apply touches to different body locations, that the overall strength of the vibrotactile feedback should be adjustable, that the material should be customizable, and that it should be waterproof and washable. These requirements were not necessarily in line with the original aim of the TaSST as a research prototype, but are nonetheless important to consider in a research context as well, for example when conducting longitudinal studies on mediated social touch.

Overall, both caregivers and behavior experts were enthusiastic about the possibilities of using the TaSST in the daily care of people with congenital deafblindness. Nevertheless, we should also be mindful of the limitations. The TaSST is not suitable for all clients per se. For example, some clients are averse to anything worn on the body except for very specific items of clothing and would therefore most likely not accept a TaSST-like device. Moreover, the cognitive capabilities of some clients may be too limited for them to fully grasp the idea of remotely communicating with a caregiver, which makes the entire

(a) A sensor unit consisting of three knitted wool sensor pads separated by regular wool. (b) The input and output layers of the TaSST 3. After experimentation, the knitted wool sensors in the input layer were replaced by conductive foam sensors.

Figure 8.9: Components developed during the design of the TaSST 3.

idea of mediated social touch difficult to use. Furthermore, a device that would actually benefit the clients would need to be tailored to the client's specific disabilities, both mental and physical, and match with their current communication practices. Finally, teaching a person with congenital deafblindness to use a TaSST-like device should be seen as a long-term endeavor that would involve extensive practice over the course of a year or more. Such long-term use would require a robust device that can function consistently without breaking down. This is quite unlike a research device that needs to function for the duration of a few experimental sessions.

The limitations notwithstanding, the workshops were useful in thinking about the TaSST in a broader context and have shaped some of the decisions regarding the design of future versions of the TaSST.

8.4.2 Final TaSST prototype

The design of the TaSST 2 was further refined in parallel with the workshops that were organized with behavioral experts and caregivers of people with congenital deafblindness, and based on the findings from the explorative study with the TaSST 2. The most notable differences between the new TaSST 3 and the TaSST 2 are in the overall design

and wearability of the sleeve, as well as the construction of the input layer (see Figure 8.9(b)).

What became clear after both explorative studies with the TaSST 1 and the TaSST 2 was that the sensitivity of the input layer still needed further improvement. Especially when we look at the intensity data in the explorative study with the TaSST 2 we can observe that participants were not very successful in differentiating between different emotions using the force of a touch. Such differentiation may be important, however, when we consider that many social touches are rather gentle in nature [246, 272], and that gentle touch may have special significance in social touch interactions [e.g. 317].

To improve the sensor layer a hybrid sensor was developed that detected the intensity of touch through a similar method as used in the previous versions, namely by measuring internal resistance of conductive wool pads. However, in addition, several insulating and conductive materials were used to create a capacitive touch layer, similar to how a touch screen on a mobile phone, or a touch pad on a laptop works. The capacitive layer was capable of detecting light touches, such as brushing one's finger over the surface of the TaSST 3. The combination of resistive and capacitive sensing made it possible to detect subtle touches, detected through the capacitive part of the sensor, and intense touches, such as squeezing, detected both through the capacitive and resistive parts of the sensor.

Several slight variations of this sensor design were tested. A first version used knitted conductive wool sections (see Figure 8.9(a)), in combination with knitted non-conductive sections for the sensor pads. However, as the wool would start to fray with extended use, resulting in noisy readings, a second version of the hybrid sensor was developed. In this second version of the sensor, conductive foam, found in the packaging of computer chips, was used instead of the wool. Similar to the conductive wool used in previous versions of the TaSST, the conductive foam changes its resistance when compressed, and so the conductive foam served as the resistive part of the sensor. One clear advantage of the foam over the knitted wool pads is that it was a much more stable material as its properties do not change much with ex-

Figure 8.10: A model wearing the final version of the TaSST. Photo by Local Androids.

tended use. An additional benefit of using the conductive foam is that it was much easier to shape than the knitted wool sensors.

Not only did the new hybrid sensor design result in a much more sensitive input layer, the input layer's thickness was also further reduced. In order to make the sleeve thinner overall, it was decided to position the vibration motors used in the TaSST 2 in a horizontal position again, similar to the orientation of the vibration motors in the TaSST 1. As wearability would be an important concern if the TaSST were to be used for longer periods of time, and on a daily basis, any potential reduction in localization accuracy due to the placement of the motors was taken for granted.

Finally, the mapping between input and output was improved by the inclusion of a chip for the processing of haptic signals (i.e. the Texas Instruments DRV2604). The subtle touches, detected through the capacitive layer of the TaSST 3's input layer, were translated to a

minimal vibration amplitude that could still be perceived. Thus, even on very light contact, the vibration motor would produce a vibration that could still be felt. Higher levels of intensity were translated to vibrations within a perceptible range, up to about 75% of the motors' maximum amplitude. Additionally, very brief touches (such as the 'hit' used in the TaSST 1 study) that in previous versions of the TaSST would produce only a slight vibration, were now coupled to a vibration that could be more easily perceived by increased speed with which the motor accelerated to the appropriate rotation velocity, and active stopping (i.e. using the motor itself to stop the vibration) to produce 'sharper' vibration sensations.

The final TaSST prototype can be seen in Figure 8.10. The term 'final' refers to the TaSST as presented within the scope of the current chapter. At the time of writing the TaSST is actually still being developed further, to a large extent inspired by the workshops with behavioral experts and caregivers of people with congenital deafblindness. One important direction of development that is planned for future versions of the TaSST, or rather, future implementations of TaSST-technology, is modular sensor/actuator units. Such units could be connected to each other in any arrangement and would allow someone to design wearable devices that can detect and produce touch on different areas of the body. Such a modular design might be particularly useful to create tactile communication devices that can be tailored to the needs and capabilities of people with congenital deafblindness. Not only that, but it might offer researchers interested in mediated social touch a tool that they can customize to fit their study design better.

8.5 THE TASST AND BEYOND

Most mobile phone users hallucinate about twice a month [136]. No, they are not on psychoactive drugs, do not suffer from mental afflictions such as schizophrenia, and are not stranded in the desert, tricked by a *Fata Morgana*. The majority of mobile phone users experiences a phenomenon called phantom vibration [136, 428]. A phantom vibration is the feeling that your phone is vibrating from an incoming phone call or text message when it is not really. You might even experience

such a hallucination when you are not carrying your phone! Research on phantom vibrations is still relatively scarce but some initial explanations for this perceptual phenomenon have been proposed [136, 428]. One plausible explanation is that we have learned to ignore certain vibration sensations that bear no real relevance, such as clothing chafing against one's leg, or a muscle twitching. However, because we are all too keen to check up on every Facebook, Snapchat, and Whatsapp message we receive, and because many mobile phone users set their phone to vibrate instead of using an auditory signal, what were previously irrelevant vibrations that could easily be ignored are now considered personally relevant. Through the vibration function of the mobile phone we have thus learned to pay close attention to any vibrations that we feel, whether it is a relevant signal from our mobile phone, or an irrelevant vibration produced by clothing brushing against our legs [136, 428].

So, the reason that most of us mobile phone users who have their phones set to vibrate experience phantom vibrations is because we ascribe meaning to a vibrotactile stimulus. Nevertheless, in most cases the vibrotactile feedback serves as an alert, and is in itself meaningless (though some mobile phones offer the possibility to set personalized vibration patterns). We find a vibration signal meaningful because we connect it to an incoming audiovisual message that is important to us.

Despite the fact that social communication through text messages and the like can be accompanied by haptic feedback we do not experience this haptic feedback as a technology mediated form of social touch. This is because the haptic sensation in this case is not attributed to another person but to your mobile phone notifying you of, for example, a message from a friend. This difference is subtle but important. In mediated social touch a person on one end applies a touch to a sensor with the express aim of making another person on the other end feel this touch through haptic feedback. In this latter situation the haptic feedback that one feels is related, in more or less direct ways, to the input of the sender rather than to a mobile phone and messaging application. Thus, for this type of interaction to be experienced as mediated social touch, the sender needs to have the feeling that they are

applying a touch to another person's body, while the receiver needs to have the feeling that a felt haptic sensation was applied by the sender.

Since the original idea behind the TaSST was to develop a device to be used in studies into mediated social touch, a valid question is: to what extent we can expect users of the TaSST to attribute the vibrotactile sensation to another person. Note that the explorative studies with the TaSST were not aimed at answering this question *per se*. Nevertheless, from other studies into mediated social touch as well as the design process of the TaSST, we can make some suggestions as to an answer to this question.

Actually, it may already be enough to simply tell a TaSST user that the vibrotactile sensation that he or she is feeling is applied by another person. This was the approach taken in the first explorative study with the TaSST and has proven to work in other studies that used vibrotactile feedback as well [e.g. 217, 218]. Of course, the success of this approach depends on whether or not the user or participant actually believes that touches are applied by another person.

Where most studies on mediated social touch focussed on the output side or to what extent haptic feedback affects people in ways similar to actual touch, social touch is of course reciprocal: when you hug someone, you are also hugged, the same as when you shake hands with someone. Indeed, if mediated social touch should really be a close approximation of actual social touch we should consider it in the light of bidirectional communication in which touches can be both applied and received. This aspect of social touch was incorporated into the design of the TaSST from the beginning, with a single sleeve incorporating both an input and an output layer. In such a setup, it is important to carefully consider the way that touch input is represented as touch output, as became evident from the explorative study with the TaSST 2. An appropriate match between input and output is also important in creating a compelling experience of social presence [258] and it may very well be that an appropriate match between touch input and output is important in compelling mediated social touch interactions [220, 221].

In this way the TaSST is of course limited by the actuators used, as vibrations feel different from an actual touch. Nevertheless, the

amount of force, duration, and location, of touches made to the TaSST's input layer are represented by the output layer. Moreover, though this was not investigated beyond the workshops with caregivers of people with congenital deafblindness, it is plausible that fast, bidirectional touch communication actually enhances the feeling that touches are received from, and applied to, another person. Some indication that this is indeed the case is found in research into the use of mediated social touch in SVE's [e.g. 33].

The explorative studies with the TaSST were aimed at investigating its communicative capabilities with the goal of improving on the overall design. Both explorative studies indicate the challenges of designing a device for mediated social touch that can detect a range of socially relevant touches, as well as rendering these touches with a certain degree of accuracy. The workshops that were conducted to explore the applications of TaSST-like devices were encouraging and showed the potential of two-way touch communication in the context of care for people with congenital deafblindness. When we look at studies into mediated social touch, it does also seem that the general design of the TaSST may be quite suitable for a variety of study designs.

Still, we may ask ourselves what other elements might contribute to a more compelling experience of mediated social touch with a device such as the TaSST. First versions of the TaSST featured a relatively direct representation of the touches made to the input layer in the output layer. Another approach would be to use additional processing to enhance the touch output at the cost of an increased delay between applied and received touches. For some touches (specifically 'hitting') this approach was already implemented in the latest version of the TaSST. More elaborate approaches are also possible, making use of haptic apparent motion illusions where a single vibrotactile stimulus can be experienced to move over the skin, creating a kind of brushing sensation [262].

Another aspect that might improve the experience of mediated social touch with devices such as the TaSST is to provide visual feedback of the other person [372], actions of the other person [33], or the input device that the other person uses to deliver a mediated social

touch [221]. This approach is especially promising considering the fact that research shows that there are similarities in the way that people process and experience social touches that they feel and social touches that they merely observe [365].

While the following chapters do not contain any further studies with the TaSST as such, they do contain references to the design of the TaSST, and will, in some cases, feature technology that was developed as part of the TaSST. The development process of the TaSST then, served as an important source of inspiration for further studies into social touch technology. In the next two chapters we will see how tactile illusions can be used to enrich the sensations that can be produced by relatively simple actuators, such as the vibrotactile actuators used in the TaSST. We will also see how we might not even need to touch at all, as we look into the way that observed social touch is perceived by people.

PART III

TOUCH THAT ISN'T QUITE: SENSATION AND MODALITY

CHAPTER NINE

INK, RUBBER, AND RABBITS: HAPTIC AND TACTILE ILLUSIONS

Most people have had the pleasure of reading, or having read to them as a bed time story, a book by Roald Dahl. Dahl is perhaps most famous for his children's books, which include classics such as *Charlie and the Chocolate Factory*, *James and the Giant Peach*, and *The Witches*. Less well known but equally fantastic are Dahl's adult short stories, of which *Skin* is one of my personal favorites. The story centers around an elderly gentleman, a former tattoo artist, now poor and decrepit, who, in his younger, more exuberant years allowed a long since deceased but now world-famous artist, to tattoo the love of his life on his back. When art collectors discover that the tattoo is indeed an as yet undiscovered work by the famous artist, the elderly gentleman's life takes an interesting turn.

Tattoos usually conjure up images of skulls, snakes, and dragons that adorn the biceps of members of a motorcycle gang, not a piece of art on the back of an elderly gentleman. What is perhaps more surprising still, and something even Dahl would have had a hard time coming up with, is a researcher with a tattoo that actually helped his research. Yet this is exactly, albeit in a more modest form, what Hulin [256] used in his study of a phenomenon called 'apparent tactual movement'. The tattoo in question was an unremarkable dot, or as the author puts it "a proximal cutaneous spot" [256, p.299], that served as a reference point for the placement of the actuators the researcher used [see also

117]. While not quite the same as a full artist's impression of a woman in the prime of her life, this modest tattoo does go to show the lengths this researcher was willing to go to for the accurate placement of the actuators he used for his investigations.

Accurate placement of the actuators used in Hulin's study [256] was important because the phenomenon he studied was partially dependent on an exact spacing between the actuators. Apparent tactual movement is a type of haptic perceptual illusion that occurs when the skin is briefly stimulated in succession in two different adjacent locations. For the majority of people it will seem as if there is a stimulus that is moving from one location to the other over the surface of the skin.

There are many more examples of such tactile illusions, though they are less well catalogued than visual or auditory illusions (though see [233] and [306]). You may be especially familiar with visual illusions as they are often shared online through social media and there are even annual competitions¹ for creating the best visual illusions. Perhaps not surprising, then, that often tactile illusions are discussed in conjunction with comparable visual illusions [177, 233].

Nevertheless, there are illusions that are purely haptic. When I was young, though I did not realize this until quite recently, I actually 'discovered' a haptic illusion of my own. In my parents' split-level house we had no fewer than seven staircases and each was connected by square metal rods that ran the full length of the house. Each rod was about 4 cm wide on each side. What I would do is stand with my back against one of these rods, and grip it over my head with both hands so that both my index fingers and thumbs were placed on the front and back surfaces of the rod, like holding a milk carton with both hands, ready to fling it overhead across the room, similar to the way that a football player throws the ball back into play. Then I would twist my body from left to right, and apply gripping force in the same direction with both my hands, as if trying to twist the rod. And sure enough, even when I try this little exercise today I experience that it is not me who is turning from left to right, but it is the rod that is rotating! If your house

¹See <http://illusionoftheyear.com> (last accessed 08-09-2016)

lacks the architectural features to try this out, a doorpost actually does the trick quite well too. This ‘twisting’ illusion is an illusion that likely falls in the kinesthetic effects category described by Hayward [233] (see also [13] for a similar illusion).

Hayward [233] provides many more examples of this type of haptic illusion and even provides tips for experiencing such illusions at home yourself. For example, crossing your index and middle finger while touching the tip of your nose can for some people produce the illusion of feeling two noses. This is known as the ‘Aristotle illusion’ [233]. Another example is that when an object feels cold, it is typically also judged as being heavier than an identical warmer object [473] [see also 70]. Thurnberg’s ‘thermal grill illusion’ can be experienced using cold and warm sausages placed next to each other so that you start with a cold sausage, then a warm one, followed by a cold one and so on. When you place your hand on top of the sausages you will likely experience a sharp, burning pain, even though the sausage themselves are neither very cold (18-24 degrees Celsius) nor very hot (36-42 degrees Celsius) [110, 306]. Another illusion occurs when you press your hands into a concave salad bowl for ten seconds and subsequently place your hands on a flat surface. The flat surface will now actually feel convex [515].

These examples all feature pure haptic illusions which rely on specific ‘blends’ of sensory input from different touch receptors, as well as the way in which the input from these receptors is constructed into a percept in the brain [306]. However, there are also haptic illusions that rely on cross-modal integration, or integration of haptic information with that of auditory or visual information [233, 306]. For example, when you rub your hands together, the sound produced will give you an indication of how smooth your hands feel. However when the sound of you rubbing your hands together is recorded and the high frequencies are boosted, you will experience your hands as feeling dryer and smoother than they are; like rubbing two pieces of paper together. This illusion is known as the rather unpleasant sounding ‘parchment-skin illusion’ [275]. A well-known visuo-haptic illusion is the Charpentier illusion. In this illusion people are asked to judge the weight of a large

box and a small box that actually weigh the same. Most people will, however, judge the small box to be heavier [233] [see also 70]. A final example of a famous class of haptic illusions is that of distal attribution [233] [see also 325]. Distal attribution refers to the experience of incorporating objects into the body-schema [335]. A blind person using a cane will actually experience the tip of the cane as part of their own body through which they can feel their environment [26, 325, 335].

The plasticity of the brain to incorporate foreign objects into the representation of the body [26, 325], is amply demonstrated by another illusion that is interesting to try out at home. Take a dish washing glove (the left one) and fill it with some sort of stuffing, such as cotton wool or coffee grounds, making sure to close off the end of the glove. The idea is that you end up with something that looks rather like a hand, but is obviously fake. Next, take a cardboard box and cut two holes in it, one at each end of the box, so that you can use it to cover your left hand and part of your left arm. Now take two identical soft brushes and ask someone to help you out with a small experiment.

This is what you need to do: sit across from each other at a table. Put your left hand and arm on the table, a bit to the left, and place the cardboard box over your left hand and arm so that they are out of your sight. Place your home-made fake hand to the right of the cardboard box in the same orientation as your real left hand. Now ask your assistant to use the brushes to synchronously stroke (about 3 cm/s works best [113, 511]) your real hand and the fake hand in the same location and with the same speed. After stroking for 30-60 seconds, for about 80 percent of people anyway [140, 318], something rather amazing will happen: you will start to feel as if it is not your own hand being stroked, but you will feel the fake hand being stroked!

The experiment described above is called the 'rubber hand illusion' [57]. The illusion depends on congruent visual and tactile input and does not work, for example, when the object being stroked does not look like a hand, or when the stroking direction is reversed [494] [see also 306]. In the classic rubber hand illusion [57], the congruent visual and tactile feedback are integrated, and lead to a mislocalization of the tactile sensation, in the sense that: "I feel my hand being stroked, and

I see a hand being stroked, thus it must be my hand.” Most studies into the rubber hand illusion investigated the integration of visual and tactile information [306], though in one study the rubber hand illusion was found to occur when participants were blindfolded and stroked the rubber hand themselves while an experimenter synchronously stroked the participants’ hand [140]. In this case, tactile and proprioceptive (i.e. kinesthetic) information are integrated to produce the perception that the rubber hand is the participant’s hand: “I feel my hand being stroked (tactile), and I feel that I am stroking a hand (proprioception), thus it must be my hand.” What speaks to the strength of the illusion is that participants will not only report feeling as if the rubber hand is their hand, but when asked to point to their real hand, participants will more often point towards the rubber hand than towards their own, hidden hand, a phenomenon called ‘proprioceptive drift’ [57, 140, 494].

The examples of haptic illusions described above show the variety of ways in which our sense of touch can be ‘tricked’ into feeling things that are not there, or feeling things differently depending on situational factors. Such situational factors include the positioning of your fingers, the type of surface you are touching, and information from other senses, such as the visual and auditory senses. So why are these types of illusions interesting for social touch technology? To answer that question, let us take a look again at the work of Hulin [256].

In his study, Hulin [256] used a type of electromechanical actuator, a solenoid, that drove a small shaft gently into the surface of the skin of his participants. This type of actuator thus produces a kind of ‘poking’ sensation. Yet what the researcher found in his experiment was that when two of these actuators were placed a certain distance apart and activated in sequence with a certain timing, participants perceived the successive ‘pokes’ as a motion over their skin. What we have here then, is a method of using relatively simple actuators that normally produce one type of sensation, but that through a haptic illusion can produce a quite different, more complex sensation.

Numerous investigations into spatiotemporal tactile illusions [306] similar to the work by Hulin [256] have been conducted under names such as ‘tactual movement’ [72], ‘apparent haptic movement’ [455,

456], and ‘tactile apparent movement’ [290, 291]. What is generally observed is that participants will experience a series of discrete taps or vibrations in adjacent actuators, as a single stimulus moving over the skin [306]. The burst duration (i.e. the time a vibrotactile actuator is active) and the inter-burst interval (i.e. the timing between activations of each vibrotactile actuator) are important parameters to achieve a vibrotactile motion illusion [262, 506]. Using the principal of apparent motion, researchers have designed vibrotactile displays that can guide people in a certain direction by having a vibrotactile stimulus move over the surface of the skin in the desired direction [262, 270, 507].

A related illusion of motion that nevertheless features a different method of stimulation is the ‘cutaneous rabbit’ illusion [185]. In this illusion successive taps or vibrations are applied to a single location on the skin close to the elbow, followed by successive taps to a single location close to the wrist. Instead of experiencing a series of taps close to the elbow followed by a series of taps close to the wrist people generally experience the first tap to be close to the elbow but successive taps to move over the skin towards to wrist, like a tiny rabbit hopping over the skin [185].

Apparent motion illusions are in essence a more complex version of the ‘funneling’ illusion, which is a type of tactile mislocalization illusion [233, 306]. This illusion involves brief simultaneous stimulation of two locations on the skin which often produces the percept of a single point of stimulation in between the two actual stimulation sites [90, 516]. The location of this perceived point of stimulation between actuators can be altered by increasing the intensity of stimulation of one actuator [306]. Thus, even though there may not be an actual actuator in a certain location in a tactile display, you could still create a sensation in that location by activating two adjacent actuators with equal intensity [10, 262].

Both funneling illusions [10, 262] and apparent tactile motion illusions [262, 270, 507], have been used in vibrotactile displays to stimulate locations where there is no physical actuator, and to provide sensations of motion with actuators that stay in place. The leap from these types of tactile display to social touch technology is not a very big one.

Think, for example, of the prototypes for mediated social touch discussed in Chapter 6.3, not to mention the TaSST (Chapter 8). Using tactile illusions, it may be possible to improve or extend the types of touch that can be communicated with a device like the TaSST, and create more compelling social touch technology in general. Apparent motion is an especially interesting phenomenon considering that stroking touches (i.e. touches that involve movement over the skin) may be especially relevant in certain types of social touch interactions [e.g. 356, 366].

Such sensations could be further enhanced by building on another type of illusion, namely the illusion of distal attribution [233, 325]. The rubber hand illusion, for example, has been used as a paradigm to study body ownership in virtual environments [257]. Body ownership might be especially important in social touch technology that uses virtual environments. Consider being present in a virtual environment with an avatar that represents your body in the environment. Having the feeling that your body is touched when the avatar is touched (i.e. body ownership of the avatar) might be especially important for social touch interactions in such a virtual environment. Visual feedback, such as in the classic rubber hand illusion, might be one way to achieve this enhanced sensation of body ownership [257].

So now we may have two ways of improving the experience of social touch technology. First, we might use tactile illusions, such as apparent motion, to create richer tactile sensations using vibrotactile displays such as the one found in the TaSST's output layer. Second, visual feedback of a touch might be used to further enhance social touch technology experiences. Both these approaches will be examined in the following chapters.

CHAPTER TEN

CARRESS TO IMPRESS: VIBROTACTILE STROKING

Cultural differences in social touch behavior can sometimes be striking. When we, in the Western world, invite someone over to our house as a guest we usually just shake their hand, or, if we know them well, give them two or three kisses on the cheek. We do not generally feel any need for more touching than that, perhaps with the exception of the occasional pat on the back or arm around the shoulder depending on the amount of wine that has been consumed during the evening.

This is in contrast to how guests and visitors are greeted in the Copper Eskimo culture. Upon arrival, even though you may never have visited before and are for all intents and purposes a stranger, men and women will approach, touch, and in particular stroke you as a means of welcome [363, p. 304]. The use of stroking touch, something which we in Western cultures often only reserve for people we are very close to, suggests that the Copper Eskimos do not seem to perceive anyone as a stranger, but instead treat them instantly as a close friend. It has even been suggested that men of the Copper Eskimo will 'lend' their wives to strangers to sleep against for bodily warmth during the cold nights [363, p. 304].

To anyone thinking about immediately traveling to Northern Alaska to experience this hospitality: do not bother. Like the common misconception that Eskimo's have a wide variety of words for snow [341, 411],

the notion that ‘wife-sharing’ occurs frequently among Copper Eskimos is untrue. While such practices did occur in the past, they occur much less frequently than is sometimes reported, and, rather than being a sign of promiscuity, have deep cultural, spiritual and social significance and are governed by complex rules [238].

Stroking touches on the other hand are of course far from uncommon, and not at all limited to greetings with the Copper Eskimos. Many mammals, such as cats, apply stroking touches in the form of licking and tooth combing, and all species of monkey and ape, as well as humans engage in grooming behavior that often involves some form of stroking [350, 363, 375, 427]. Human mother’s too, often apply stroking touches to their infants [155, 159, 176, 241] and such touches may be especially comforting for the infant [398, 480]. Not only that, but stroking touches are also the most common type of touch used to express intimacy and love [21, 244, 245].

Now as you might remember from Section 3.2 there is another reason that stroking touches are particularly interesting and that is the discovery of a type of nerve fiber called a CT afferent that responds selectively to slow stroking touches [134, 267, 301]. What is more, when people are asked to indicate how pleasant such a stroking touch feels, their responses neatly follow the same velocity-dependent inverted U-curve as the firing rate of the receptors [321]. Some researchers suggest that these CT afferents work in conjunction with other receptors to filter social touches from all other types of touch that we receive. This proposed function of CT afferents is referred to as the social touch hypothesis [366, 385, 386].

There are plenty of reasons, then, for social touch technology to consider stroking touches in the design of prototypes and studies. For example, many prototypes for mediated social touch are aimed at intimate communication [219], a type of communication that is best served by stroking touches [21, 244, 245]. In the explorative study conducted with the TaSST 2 we also saw that participants tried to communicate certain emotions using stroking touches. With the research on affective touch and CT afferents we have clear expectations of what a stroking touch applied through a social touch technology prototype should feel

like. We would expect people to rate the pleasantness of such a stroking touch with the same velocity-dependent inverted U-curve as they would for a real stroking touch.

The next question is how to generate an appropriate stroking touch using technology, bearing in mind the limitations of certain actuators. One approach is to use actual stroking through haptic force feedback devices as has been done in CT afferent research [152, 320, 365, 402]. A downside of this approach is that participants would have to sit relatively still which would limit social touch technology interactions to those that can occur while sitting in a chair. Another would be to use an air jet device that blows air onto the surface of the skin [496], which may offer a bit more freedom of movement [463]. Still, such devices require a noisy compressor to work. A final option, and one that has been mentioned in the previous chapter, is to use vibrotactile actuators and tactile apparent motion illusions to create a moving stimulus over the skin. In very early research by Von Frey [cited in 256], the sensation of tactile apparent motion was described as ‘stroking’ touch, while others have referred to vibrotactile apparent motion as a ‘brushing’ sensation [262]. Clearly, speaking of vibrotactile stroking might not be too far-fetched. Nevertheless, there is a problem with this approach: CT afferents are insensitive to vibrotactile stimuli [41, 47, 145].

So that is the end of that then. Or is it? There are some studies that show that when people merely observe a stroking touch they will rate this touch with a velocity dependent inverted U-curve similar to that for felt touch [365]. An explanation for this is that, rather than the innate non-learned processing made possible by CT afferents that project to affect-related brain areas such as the insula, a more cognitively involved process of interpretation occurs [353]. This process may be grounded in previous experiences with touch. Throughout their lifetime, most pertinently during infancy [see also 176], people have learned to associate stroking touches of a certain velocity (i.e. about 3cm/s) with pleasantness. When you observe a social stroking touch applied at about 3 cm/s velocity, you are more likely to judge it as pleasant and stroking touches with a velocity that differs as less pleasant, based on your previous experiences [365].

The detection of vibrotactile stroking stimuli made possible by using an apparent motion illusion [e.g. 262, 506] occurs through mechanoreceptors other than CT afferents, primarily through Pacinian corpuscles [282]. Nonetheless, such mechanoreceptors are also active when a real stroking touch is applied to the skin. Following the same reasoning as for observed stroking touches [353, 365] it is plausible that previous experiences with actual stroking touches are integrated with the sensation of stroking produced by a vibrotactile apparent motion illusion. Thus, when you feel a vibrotactile stroking sensation with a velocity of about 3 cm/s you are more likely to judge this vibrotactile stroking touch as more pleasant than vibrotactile stroking with a velocity that is either faster or slower, based on previous experiences. The velocity information from the vibrotactile stroking in this case serves as a cue for the more cognitively involved affective interpretation of the sensation, based on previous experiences [see also 353].

So, based on this line of reasoning, we would expect a person who receives a vibrotactile stroking touch to rate the pleasantness of this touch based on its velocity. As with actual stroking touch we would expect these ratings to form an inverted U-curve that depends on the velocity of stroking in the sense that stroking either too slow or too fast is less pleasant than stroking at a velocity of between 1-10 cm/s and in particular stroking at 3 cm/s [48, 151, 152, 317, 321, 367]. If such response similarities could be found this might be seen as evidence that vibrotactile actuators, despite the fact that they do not stimulate CT afferents, can be used to apply socially relevant stroking touches. This would open up opportunities for incorporating such touches into social touch technology prototypes. As a concrete example, in the explorative study with the TaSST 1 we saw that participants had some trouble in recognizing dynamic (i.e. moving) touches, such as stroking, that were recorded through the input layer. Devices such as the TaSST would be more appropriate for mediated social touch if they could apply vibrotactile stroking touches of different velocities.

A study was conducted to find out whether pleasantness ratings of vibrotactile stroking touches with different velocities would follow a velocity-dependent inverted U-curve.

10.1 STROKING TOUCHES WITH A VIBROTACTILE ARRAY

The first thing that is necessary to investigate pleasantness responses to vibrotactile stroking stimuli is a method to reliably generate such stimuli at different velocities. As there is not an actual physical movement over the skin - remember, we are talking about an illusion - velocity here refers to the perception of the speed of motion of a single vibration point over the skin. Luckily, others have already figured out how to generate such sensations, based on tactile apparent motion and funneling illusions, using vibrotactile actuators [261].

The Tactile Brush algorithm [261] was specifically developed to create a 'brushing' sensation over the skin in a two dimensional grid of vibrotactile actuators. In essence the algorithm adjusts the activation time (i.e. burst duration) of each individual actuator, as well as the timing of overlapping activation (i.e. inter-burst interval) of individual actuators. When the distance between individual actuators is known, the algorithm can be used to control the velocity and vibration intensity of a moving vibrotactile stimulus creating a 'vibrotactile stroking' sensation.

In the study presented here the Tactile Brush algorithm was used to generate vibrotactile stroking stimuli at five different velocities and two different intensities. The velocities chosen were: 0.5, 1, 3, 10, and 30 cm/s. These velocities differ slightly from those used in studies into actual stroking touches, in particular at the lower end. Here, 0.5 cm/s is used, instead of 0.1 and 0.3 cm/s [321] because even with the Tactile Brush algorithm it is very difficult to perceive any motion at all at vibrotactile stroking velocities below 0.5 cm/s.

The five different velocities were presented at two different vibration intensity levels because the force with which actual stroking touches are applied can affect pleasantness ratings of these touches [152]. The maximum amplitude of vibration was used here as an approximation of the force of a stroking touch. The idea here was that a more intense vibration would be perceptually similar to a stroking touch applied with a higher amount of force.

In the study, four vibration motors were placed in a straight line on a participant's arm. The participant received both the five high

Figure 10.1: Array of cylindrical vibration motors attached around a participant's arm.

intensity and the five low intensity vibrotactile stroking stimuli twice and was asked to indicate how pleasant the stimulus felt. Apart from indicating the pleasantness, the participant was also asked to indicate how fast he or she thought the stroking was, how continuous he or she thought the movement was, how straight he or she thought it was, and, how intense he or she thought the vibrotactile stroking stimulus was.

10.1.1 Participants

Participants were all students or employees of a university in the Netherlands. In total, 19 people participated of whom 15 were male. Participants' mean age was 31.1 ($SD = 10.4$) and 15 participants were right-handed.

10.1.2 Materials

Four Precision Microdrives 306-117 cylindrical vibration motors were attached to the ventral side (i.e. the inside) of the participant's non-dominant lower arm using stretchable fabric straps (Figure 10.1). Cylindrical vibration motors were chosen for the same reason that the

TaSST 2 featured perpendicularly placed pancake-type vibration motors: the direction of the vibration is towards the skin's surface, rather than horizontal to it. In tasks where participants are asked to identify the location of a vibration, such cylindrical motors seem to perform better [405].

The motors were centered on the participant's arm and were placed length-wise 3 centimeters apart. The distance was measured from the end-tip of each motor, starting with the first motor placed 3 centimeters from the wrist. The exact spacing was necessary for the Tactile Brush algorithm [261] to be able to produce a continuous stroking sensation at different velocities. No tattoos were used in the placement of the motors [see also 256].

The vibrotactile stroking stimuli were applied with two different intensity levels, further referred to here as high intensity (50% of motor's maximum voltage, $\pm 1.8g$ peak amplitude, 200 Hz peak frequency) and low intensity (35% of motor's maximum voltage, $\pm 0.9g$ peak amplitude, 140 Hz peak frequency). These intensity levels were chosen because, based on informal testing by the experimenters, they were found to produce comparable stroking sensations that were perceivably different in intensity. The motors were controlled by custom hardware using the Texas Instruments DRV8601 haptic processor.

10.1.3 Procedures

After the participant had signed an informed consent form the vibration motors were attached around his or her non-dominant arm. The participant was instructed to place his or her arm, with the inside facing upwards, on a foam sheet (Figure 10.1).

Next, the participant was presented with five visual-analog scales (VAS)(0-99, 10 cm in length, with labels on each end of the scale) presented on a computer screen. The VAS used were similar to rating procedures used in studies into pleasantness responses to actual stroking touches [321]. For each stimulus that a participant received, a VAS for perceived velocity, perceived continuity, perceived straightness, perceived intensity and perceived pleasantness was shown. The participant was asked to read the descriptions for each scale carefully.

After this, the participant received a test stimulus (6cm/s, 1.0g peak amplitude, 160 Hz peak frequency) and was instructed to use the VAS to log his or her response. When the procedure was clear to the participant, the participant could click an on-screen button to start the study.

The study was divided into two blocks with a one minute break between blocks. In each block the participant received 10 (5 velocities x 2 intensities) stimuli which were presented in random order. After the last stimulus had been rated, the vibration motors were removed from the participant's arm.

Finally, the participant completed a demographics questionnaire and was debriefed about the goal of the study.

10.1.4 Results

Separate two-way repeated measures ANOVAs with the independent variables velocity (5 levels), and intensity (2 levels) were conducted with the dependent variables perceived- velocity, continuity, straightness, intensity, and pleasantness. Ratings in both blocks were aggregated. Bonferroni corrections were applied for all post-hoc pairwise comparisons. Generalized Eta squared (η_G^2) and partial Eta squared (η_p^2) are reported for all F -test as measures of effect size [304].

In accordance with studies into actual stroking touch [321], regression analyses were performed to investigate a potential inverted U-curve shape for the distribution of pleasantness ratings. The independent variable velocity was log10 transformed. The curve fit of a linear regression model (reduced regression model) was tested against the fit of a quadratic regression model (full regression model), with an F -test for significant reduction of the error sum of squares in the full compared to the reduced model [88].

Effects on perceived velocity

For perceived velocity (Figure 10.2(a)) a significant main effect of velocity was found (Greenhouse-Geisser correction applied, $F(1.63, 29.32) = 72.70$, $p < .001$, $\eta_G^2 = .664$, $\eta_p^2 = .802$). No other main or interaction effects were found. Post-hoc analysis showed that vibrotactile stroking

Figure 10.2: Graphs depicting mean ratings for dependent measures of the vibrotactile stroking study. Error bars indicate ± 1 standard error.

velocities of 0.5 and 1 cm/s were significantly different from each other at $p < .05$, and all other velocities differed from each other at $p < .001$, with higher velocities being rated significantly higher on perceived velocity. These findings indicate that participants did indeed experience the vibrotactile stroking stimuli as having different velocities. Not only that, but they judged each stimulus in accordance with its actual velocity, in the sense that 0.5 cm/s was judged to be slower than 1 cm/s, which was judged to be slower than 3 cm/s et cetera.

Effects on perceived continuity

For perceived continuity (Figure 10.2(b)) no significant main or interaction effects were found. Overall, ratings for perceived continuity had a mean rating of 64.01 ($SD = 10.04$). This indicates that, overall, perceived continuity was comparable for all stimuli. The average rating for continuity was found to be significantly higher by 14.51 ($t(18) = 6.30$, $p < .001$, $d = 1.445$) than the median of the scale. Overall all of the stimuli were rated by participants as having a relatively continuous movement.

Effects on perceived straightness

For perceived straightness (Figure 10.2(c)) a significant main effect of velocity was found ($F(4, 72) = 3.22$, $p = .017$, $\eta_G^2 = .068$, $\eta_p^2 = .152$). Post-hoc analysis revealed that this effect was explained by a significant difference in perceived straightness between stimuli with a velocity of 0.5 cm/s ($M = 57.66$, $SD = 11.72$) and stimuli with a velocity of 10 cm/s ($M = 70.11$, $SD = 12.05$). These velocities had, respectively, the minimum and maximum scores for perceived straightness overall. These findings suggest that extremely slow stimuli were perceived as less straight than faster stimuli but this effect was not structural in the current study.

Effects on perceived intensity

For perceived intensity (Figure 10.2(d)) a significant main effect of velocity was found (Greenhouse-Geisser correction applied, $F(2.42, 43.52) = 24.23$, $p < .001$, $\eta_G^2 = .308$, $\eta_p^2 = .574$). Overall, stimuli with a lower velocity were rated higher on perceived intensity. Post-hoc analysis revealed a significant difference ($p < .05$) between stimuli with a velocity of 0.5 cm/s ($M = 71.87$, $SD = 11.90$) and 1 cm/s ($M = 66.28$, $SD = 12.15$), and all other velocities. Stimuli with a velocity of 3 cm/s ($M = 58.37$, $SD = 11.67$) differed significantly ($p < .05$) from all other stimuli except those of 10 cm/s ($M = 52.08$, $SD = 11.01$). Finally, the difference between stimuli with a velocity of 10 cm/s and 30 cm/s ($M = 43.32$, $SD = 19.52$) was not significant.

Figure 10.3: Mean ratings for perceived pleasantnes.

Furthermore, a significant main effect of intensity ($F(1, 18) = 28.50$, $p < .001$, $\eta_G^2 = .115$, $\eta_p^2 = .613$) was found. High intensity stimuli ($M = 63.84$, $SD = 8.66$) were rated as significantly more intense than low intensity stimuli ($M = 52.92$, $SD = 13.25$).

These findings indicate that participants did indeed perceive the high intensity stimuli as more intense than the low intensity stimuli. However, velocity also influenced perceptions of intensity. Stimuli with a lower velocity were perceived as more intense than stimuli with a higher velocity. It is plausible that an effect called ‘temporal summation’ is at work here. Temporal summation refers to the notion that the perception of the intensity of a vibrotactile stimulus is dependent upon the duration of the stimulus. Typically, vibrotactile stimuli of a longer duration will be perceived as more intense [514].

Effects on perceived pleasantness

For perceived pleasantness (Figure 10.3) a significant main effect for velocity (Greenhouse-Geisser correction applied, $F(1.78, 32.02) = 3.47$, $p = .048$, $\eta_G^2 = .074$, $\eta_p^2 = .162$) was found. Post-hoc analysis revealed a significant difference ($p < .05$) between stimuli with a velocity of 0.5 cm/s ($M = 50.76$, $SD = 21.69$) and 3 cm/s ($M = 63.03$, $SD = 13.34$).

Furthermore, a significant main effect of intensity ($F(1, 18) = 4.62$, $p = .046$, $\eta_G^2 = .018$, $\eta_p^2 = .204$) was found. Post-hoc analysis ($p < .05$) revealed that low intensity stimuli ($M = 60.52$, $SD = 11.19$) were rated as significantly more pleasant than high intensity stimuli ($M = 56.07$, $SD = 11.76$).

Finally, a significant interaction effect between velocity and intensity ($F(4, 72) = 2.62$, $p = .042$, $\eta_G^2 = .019$, $\eta_p^2 = .127$) was found. To investigate this interaction-effect further, simple-main effects analyses were performed. First, the effects of velocity for each intensity were investigated separately. A repeated measures ANOVA was performed for the different velocities for high intensity stroking. No statistically significant effect was found (Greenhouse-Geisser correction applied, $F(1.73, 31.05) = 2.28$, $p = .126$, $\eta_G^2 = .064$, $\eta_p^2 = .112$). Next, a repeated measures ANOVA was performed for the different velocities for low intensity stroking. A statistically significant effect was found for velocity ($F(2.32, 41.73) = 4.34$, $p = .015$, $\eta_G^2 = .117$, $\eta_p^2 = .194$). However, pairwise comparisons with Bonferroni correction did not reveal any statistically significant difference between individual velocities.

Second, to investigate the effect of intensity for each velocity separately, paired-samples t -tests were performed with Bonferroni correction (i.e. dividing the alpha level by the number of comparisons). However, none of these pairwise comparisons were statistically significant.

From Figure 10.3(a) it can be observed that the pleasantness ratings for low intensity vibrotactile stroking, but not for high intensity vibrotactile stroking seem to form an inverted U-curve. Indeed, an F -test comparing the fit of a linear regression model to the fit of a quadratic regression model for low intensity stimuli ($F(2, 92) = 5.44$, $p = .006$, $R^2 = .11$) showed a better fit for a negative quadratic model. This was not the case for high intensity stimuli ($F(2, 92) = 1.70$, $p = .189$, $R^2 = .04$)(Figure 10.3(b)). The peak of the fitted negative quadratic curve for low intensity vibrotactile stroking stimuli was at 6.41 cm/s.

10.2 VIBROTACTILE STROKING AND THE SOCIAL TOUCH HYPOTHESIS

What have we learned about vibrotactile stroking from the current study? First of all, the results show that the Tactile Brush algorithm [261] is quite suitable for generating vibrotactile stroking stimuli of different velocities and intensities with the 1-dimensional vibrotactile array that was used.

Participants did indeed find each stroking stimulus to differ in velocity in the expected direction (i.e. slow stimuli were rated as slower than fast stimuli). What is more, there were no clear differences in the perceived continuity of all stroking stimuli. Vibrotactile stroking at all velocities was found to be experienced by participants as relatively continuous. Non-structural differences were found for the perceived straightness of the stimuli. Although it would be expected that slow moving stimuli are perceived as less straight, based on previous research [305], such an effect did not appear consistently for all stimuli in the present study. Furthermore, the actual intensity of the vibrotactile stroking stimuli influenced perceptions of perceived intensity. High intensity stimuli were indeed perceived as more intense than low intensity stimuli. In addition, a temporal summation effect was found [514], where stimuli that involved prolonged activation of individual actuators (i.e. low velocity stimuli) resulted in higher ratings for perceived intensity. One way to further investigate this effect would be to conduct a similar study in which all stimuli are equal in duration, by repeating (i.e. backwards-forwards stroking) faster stimuli. Another possibility would be to add actuators to the array, decreasing the spatial distance between them, and thus decreasing the duration that each actuator is active. Finally, the effects of intensity could also be investigated more structurally using linear actuators for which the vibration frequency and amplitude can be independently controlled.

All in all, the results show that the vibrotactile stimuli that the participants received were indeed perceived as relatively straight, continuous movements over the arm, that differed in intensity and velocity. So the setup that was used in the study produced consistent sensations that can indeed be described as vibrotactile stroking sensations.

What is of course most interesting is the question of whether or not the pleasantness of these vibrotactile stroking sensations was judged similarly to the pleasantness of actual stroking sensations. The results show that, overall, the relation between the velocity of the vibrotactile stroking stimuli and pleasantness ratings follow an inverted U-curve. After further examination of this effect, following methods used in studies on actual stroking touches [321], a significant fit for a negative quadratic curve was found for low intensity vibrotactile stroking stimuli, but not for high intensity stimuli. This means that the ratings for pleasantness did indeed follow a velocity-dependent inverted U-curve shape similar to that found for actual stroking touches but only for low intensity vibrotactile stroking. It seems therefore that the suggestion that affective aspects of touch are most strongly related to gentle stroking touches [47, 367] also applies to vibrotactile stroking. Moreover, the peak of the fitted negative quadratic curve for low intensity vibrotactile stroking was at 6.41 cm/s, which is within the same optimum velocity range of 1-10 cm/s, which is rated most pleasant for actual stroking touches [321]. Considering the fact that vibrotactile actuators do not stimulate CT afferents [41, 47, 145] it is plausible that the velocity information of vibrotactile stroking touches through a more cognitively involved process, possibly anchored in one's own perceptual experience with actual stroking touches [353, 367], serves as an affective cue for the interpretation of the tactile sensation.

The findings from this study are the first indication that pleasantness ratings of stroking stimuli that do not stimulate CT afferents can still follow a velocity-dependent U-curve. As these are the first findings in this direction we must of course be somewhat careful with interpreting them. For example, when we look at Figure 10.3(a), we can see that the vibrotactile stroking stimulus at 10 cm/s was actually rated the most pleasant, and not the one at 3 cm/s as you might expect based on previous research into stroking touches [e.g. 321]. Thus, the inverted U-curve found in the current study does not exactly match the one that is consistently found for actual stroking touch. In the present study, the inverted U-curve is formed by the fact that vibrotactile stroking at 30 cm/s was rated as less pleasant than at 10 cm/s.

We can ask ourselves how intermittent velocities would be judged on pleasantness. Is 10 cm/s really the peak of the curve or would velocities such as 12 cm/s or 15 cm/s be rated as even more pleasant and would we only see a drop off in the rating of pleasantness after significantly faster (e.g. 20+ cm/s) vibrotactile stroking? This could of course have a significant impact on the shape of the inverted U-curve making it even less like the curve found for actual stroking touch. A study similar to the one reported here with vibrotactile stroking at additional intermittent velocities would paint a more detailed picture of the relation between vibrotactile stroking stimuli and pleasantness ratings.

Another suggestion to improve on the current study would be to look at the intensity of the stimuli in more detail. In the current study we saw that only the pleasantness ratings of low intensity vibrotactile stroking stimuli followed a velocity-dependent inverted U-curve. It would thus seem to be that the intensity of the vibrotactile stroking is actually also important in the ratings of pleasantness. However, the intensity levels in the current study were chosen based on what felt about right. A more structural investigation could look into at which intensity exactly pleasantness ratings of vibrotactile stroking tend to follow a curve similar to actual stroking. What might aid in this investigation is the use of linear resonant actuators instead of the vibration motors used in the current study, because linear actuators allow for amplitude and frequency to be independently controlled.

Despite the preliminary nature of the findings from the current study it is interesting to consider the theoretical and practical implications of these findings. First, how should the current findings be interpreted in light of the social touch hypothesis [366, 385, 386]? At the basis of the hypothesis is the unique feature of CT afferents' selective response to gentle stroking touches and the fact that pleasantness ratings of such touches follow an inverted U-curve dependent on velocity. Yet findings from the present study indicate that such velocity dependent pleasantness ratings can also be obtained using methods that do not stimulate CT afferents. It could therefore be postulated that the role of CT afferents in the formation of affective, pleasant responses to tactile stimuli is not as central as the social touch hypothesis would

suggest. Indeed, related to this, stimulation of the hand, which lacks CT afferents, can also be experienced as pleasant [171]. If anything, the current study underlines the fact that we should be mindful that affective, pleasant, and potentially socially relevant touches are not necessarily restricted to those partially coded by CT afferents.

Second, the present findings indicate that relatively simple actuators can be used to produce stroking sensations for which the subjective pleasantness ratings follow a pattern similar to subjective pleasantness ratings of actual stroking touches. This is potentially good news for the construction of social touch technology prototypes. Affordable, wearable, easy to control actuators, such as vibration motors, might be used to deliver touches that though clearly mechanical, can elicit responses in the recipient that are similar to responses to actual social touches. The TaSST, for example, could benefit from the findings presented here in order to deliver more compelling dynamic touch sensations. Investigations into social touch technology, too, could benefit from applying vibrotactile stroking touches that are optimally pleasant, for example for affective priming [448]. Based on the present findings, those working on the construction of prototypes for, and the design of studies into, social touch technology could consider vibrotactile stroking as a viable method for applying socially relevant touches that share certain characteristics with actual touch.

CHAPTER ELEVEN

SEEING IS BELIEVING: OBSERVING STROKING TOUCH

Gian Lorenzo Bernini's *Pluto and Persephone*, which can be marveled at at Villa Borghese in Rome, is one of the marvelous marble masterpieces of the Baroque period [285]. The statue is lauded for its exquisite detail in depicting a scene where the god Pluto, with the underworld's three-headed guard dog Cerberus at his heel, drags his beloved Persephone to the underworld. A feature that is most striking in this statue is Pluto's hand firmly clasped on the upper leg of Persephone [32]. Looking at the statue it seems as if the marble has turned to flesh, and it is not difficult to perceive the exact firmness of Pluto's grasp. You do not just see it, you can almost feel the way the fingers press into Persephone's yielding flesh and muscle. Indeed, for people with mirror-touch synesthesia who experience an observed touch as if they are touched themselves [30], viewing Bernini's work might be quite the experience!

While Bernini's convincing rendition of touch between two people in marble is unique as a piece of art, on an average day we observe plenty of social touching between other people going on around us. We can actually gleam quite a bit of information about the type of touch, the people applying and receiving the touch, and their relationship, from observing such social touch interactions. Indeed, several studies into actual social touch have used observational methods to gather data

and draw conclusions on the nature of the social touch interaction taking place [e.g. 226, 246].

Such observational methods might not just be useful for gathering data on social touch occurring in natural settings. Seeing a social touch occur might actually serve as a proxy for felt touch. Research has shown that when we observe touch similar areas of the brain are active, in particular the secondary somatosensory cortex (SII), to when we are actually touched ourselves [50, 139, 286]. This suggests that we automatically understand touch that we observe in the world around us through aspects of our own experience with touch [50, 139, 286]. This is not just the case for social touch, as there are indications that this same ‘mirror touch system’ is also active for observed touches between inanimate objects [139, 286], and for touches that are either accidental without clear agency (i.e. the leaves of a plant brushing against an arm) or intentional with a high level of agency (i.e. a person touching another person’s arm on purpose) [139].

These findings do not, however, mean that there are no differences in the way observed social touch and observed touch with, or between objects is processed. In one study [139] a different area of the brain, namely the primary somatosensory cortex (SI), was found to show stronger activation for observed touch that was intentional and social in nature, compared to accidental touch between objects. Additionally, observed social touch of an affective nature especially, may be differentiated in a region of the brain involved in the processing of affect (in particular the posterior insular cortex) from observed touch where a person is touched by an object [138]. In one study the posterior insular cortex showed a significant deactivation for observed social touch compared to experienced social touch and may thus be involved in differentiating social touch of others from social touch that involves the self [138].

Still, the exact velocity with which such social touches were applied, both for observed and felt touches, could be important here as well. There is other research that shows that the posterior insular cortex shows overlapping activation for both observed and experienced social touch but specifically for stroking touches of a certain velocity [365].

Stroking touches to which CT afferents, the receptors suggested to be particularly important in social touch [366, 385, 386], are sensitive resulted in increased activation in the posterior insular cortex for both felt and observed social touch. What is more, when participants were asked to rate the pleasantness of both felt and observed stroking social touches, both rating patterns showed the typical velocity-dependent inverted U-curve [365]. Indeed, in another study participants watched a video of a person's arm being stroked at different velocities [367]. When participants were asked to indicate how pleasant they thought this stroking felt to the person in the video, the pleasantness ratings showed a velocity-dependent inverted U-curve, similar to that found for pleasantness ratings of felt stroking touches [367].

Such a mirror touch system, where similar areas of the brain are active for observed and felt touch, usually operates below the level of conscious perception [50]. Moreover, it does not operate in isolation and is subject to integration with top-down cognitive processes [286]. One example of this is given in a study where cream was rubbed onto a participant's arm [349]. In addition, the participant viewed videos of another person's arm onto which cream was rubbed. Sometimes the cream was labeled 'rich moisturizing cream' (i.e. pleasant) and in sometimes it was labeled 'basic cream'. The type of label was found to influence activity in certain areas of the brain, as well as subjective ratings of observed and felt touch [349].

To summarize, studies on observed touch show that there is significant overlap between the areas of the brain that are active for observed touch in general (i.e. discriminative aspects of touch) [50, 139, 286], and for observed social touch in particular [138, 365]. The way we understand touches that we see occurring between people, then, is grounded in our own experience with touch. The way these similarities manifest themselves becomes apparent when we ask someone to watch a video of another person being touched and ask them to judge from the video, how pleasant they think the touch feels to the person in the video. The answer from the person in the video to the same question, and the answer given by the observer are likely to be remarkably similar. This may be especially the case for observed social

touches that include stroking for which both felt and observed stroking touches show a velocity-dependent inverted U-curve [365, 367]. Nevertheless, such a subjective experience of touch can be modulated by other factors, such as verbal descriptors [349].

What does all of this mean for our current interests in social touch technology? From research into mediated social touch we have already seen some indications that visual feedback of a touch can affect the believability of a mediated social touch as well as the extent to which such a mediated social touch enhances presence [220, 221, 372]. This is similar to how visual feedback can alter the subjective experience of an actual social touch [182]. The extent to which such visual feedback can affect the subjective experience of a touch, observed or felt, might depend on who or what is touched [365], and who or what is doing the touching [139]. In one study, responses to observed and felt stroking touches were only similar when a person was observed to stroke the arm of another person, and not when a person was observed stroking an object, a bowl of water in this case (if you are wondering, “why a bowl of water?”, remember that the rippling of the water makes the touch more easily visible). In social touch technology it is possible that the appearance of the toucher is different from that of an actual person. For example, in shared virtual environments, the presence of another person might be communicated by a simple dot [e.g. 33].

So, a question that is relevant when we consider the use of visual feedback of a touch in social touch technology is to what extent the appearance of the toucher can alter the subjective experience of a touch. One way to investigate this is to build on research into observed social touch which might serve as a proxy for experienced social touch. In other words, a person’s responses to an observed social touch is informative for that person’s responses to an actual experienced touch, when such a touch has characteristics (e.g. stroking velocity) similar to the observed touch. To find out to what extent the appearance of the toucher can affect the subjective experience of observed stroking touches, a video-based crowdsourcing study was conducted.

Figure 11.1: The four conditions showing different methods of applying stroking touches.

11.1 OBSERVING STROKING TOUCH FROM VIDEO

The social touch depicted in Bernini's *Pluto and Persephone* is convincing because of its extreme level of realism [32]. Nevertheless, from research into observed touch we have learned that the activation of areas of the brain involved in the processing of touch overlaps for both observed and felt touch that are either of a social nature, or feature touch between objects. Moreover, in mediated social touch research there are plenty of examples where visual feedback that does not even begin to approach the level of realism of Pluto's hand on Persephone's upper leg, can still enhance the experience of mediated social touch in a meaningful way, for example by depicting a simple 'pointer' that represents another person in a virtual environment [e.g. 33, 372]. We can ask ourselves, then, how important the lifelike representation of the toucher (i.e. the morphology) is for the subjective experience of an observed touch. If social cues are really important to the observation of social touch we might expect a touch by a human to be rated differ-

ently from a touch by an object [365]. In addition, the level of social agency of the toucher might influence the subjective experience of an observed touch [139]. Agency here is defined as the perception of the touch being applied by a social actor (e.g. a human). Differences in the subjective experience of observed touches, possibly influenced by morphology and agency, might especially manifest themselves for touches that have high social relevance, such as stroking touches [365].

Here, a study is presented in which participants watched online videos of stroking touches being applied to the forearm of a male person. Touches were applied at 0.3, 1, 3, 10, or 30 cm/s [367], by either a female human hand (Figure 11.1(a)), a female mannequin arm (Figure 11.1(b)), a Nao robot¹(Figure 11.1(c)), or a plastic tube (Figure 11.1(d)). Participants were randomly assigned to one of the four conditions and were asked to rate the perceived pleasantness of the touch on a visual analog scale (VAS).

The condition in which a human hand applied the touches was considered as the baseline, as this was the most realistic social touch condition. This condition was considered highest in morphology (i.e. an actual human hand) and highest in agency (i.e. an actual human was observed applying the touches). The mannequin arm was considered high in morphology (i.e. it looked like a human arm), but low in agency (i.e. a mannequin is not a social actor). The Nao robot was considered low in morphology (i.e. its hand does not look particularly human) and high in agency (i.e. social robots can be considered social actors that can apply touches independently [64, 287]). Finally, the plastic tube was considered low in both morphology and agency, but shared its visual material properties with both the mannequin arm and Nao robot.

First, it was hypothesized that, as for felt touch, the observation of stroking touches at different velocities would form a velocity-dependent inverted U-curve where stroking touches with a velocity of 3 cm/s would be rated as the most pleasant. A second hypothesis was that the condition with the most social cues (i.e. morphology and agency)

¹<https://www.ald.softbankrobotics.com/en/cool-robots/nao> (Last accessed 14-09-2016)

would be rated more pleasant overall: ratings for the human touch condition would be the highest, followed by the robot, mannequin arm, and plastic tube.

11.1.1 Participants

A total of 248 participants with the highest trustworthiness level was recruited via the online crowdsourcing platform CrowdFlower². Every contributor was awarded \$0.10 for participation and an additional \$0.90 if the data was considered valid.

A strict filtering procedure was used to judge whether or not a participant's responses could be considered valid. Of the 248 participants who started, 7 did not complete the survey and were excluded. Moreover, data from 55 participants was removed from the analyses because their response times for several videos were lower than the duration of the videos, which indicated that they did not watch the videos in their entirety. Data from another 2 participants was omitted because they did not answer the control question in which they had to recognize the condition they were assigned to correctly. Next, an outlier analysis on the response times per video ($> 3 SD$ different from the mean) was conducted and resulted in another 7 participants being excluded because their high response times were deemed unrepresentative.

The responses of the remaining 177 participants (71.4%) were considered valid and included in the analyses. The distribution of participants over the conditions was: Human (44), Robot (42), Mannequin (43), and Tube (48).

The mean age of these participants was 40.63, (SD : 13.36, range 19-80), and 77 were male (43.5%). Participation in the study was restricted to native English regions. Participants had either the American (70, or 39.5%), British (47, 26.6%), Canadian (41, 23.2%), or Australian (6, 3.4%) nationality, or no nationality information was provided (13, 7.3%).

²<https://www.crowdfunder.com> (Last accessed 14-09-2016)

11.1.2 Materials

For each of the four conditions a video was created in which the right arm of a Caucasian male was visible from an egocentric perspective (i.e. the camera was positioned above the right shoulder) against a neutral black background (see Figure 11.1). Each video showed the arm being stroked from the elbow towards the wrist over a distance of 10 cm.

Touches were applied by either the right hand of a Caucasian female, the left hand of a Nao robot, the right hand of a mannequin arm, or a white plastic tube (diameter 1.5 cm). A part of the robot's body was deliberately made visible in order to emphasize its social agency.

All touches, except the robot touch, were manually applied by a trained experimenter at a constant velocity (approximately 0.3 cm/s), and recorded (60 frames per second, 1280x720p resolution). The 0.3 cm/s video, the slowest stroking speed, was sped up using Adobe Premier to create videos for all the other stroking velocities. The robot touch was pre-programmed and applied by the robot itself at 1 cm/s. This was the slowest velocity at which the robot would still produce a relatively fluid motion. The video for the robot touch was slowed down for the 0.3 cm/s stroking velocity and sped up for the other velocities. For some videos some frames in which the motion was discontinuous (i.e. stuttering) were removed to make the motion in the videos as smooth as possible.

Each video began with a still frame of the start of a touch lasting for 2.5 seconds, followed by the stroking touch, and a still frame of 1.5 seconds for the end of the touch. Each video was concluded with a 2.5 seconds black frame. All videos were uploaded to YouTube with the resolution set to 640x480 pixels and with all controls and titles disabled.

The entire study sequence with embedded videos and the VAS for pleasantness ratings was programmed in Lime-Survey³. CrowdFlower contributors were redirected to the Lime-Survey from the CrowdFlower page.

³<https://www.limesurvey.org> (Last accessed 14-09-2016)

11.1.3 Procedures

When a CrowdFlower contributor clicked the link on the CrowdFlower task page he or she was redirected to the Lime-Survey and from there randomly assigned to one of the four conditions.

After a brief explanation of the task the participant was asked to enter his or her gender and age. Next, the participant was presented with an example video showing a stroking touch at 2 cm/s with the respective stimulus, and an accompanying explanation of the VAS. When the participant clicked a button the actual experimental sequence started. Videos of all velocities were presented twice in two separate blocks. The order of the videos in each block was randomized.

For each movie, playback would start automatically. The participant was asked to watch the entire movie at least once, and only to indicate the perceived pleasantness after having done so. By pressing the 'next' button, the participant could proceed to the next video. After rating the final video, the control question was presented, followed by a brief explanation of the purpose of the study. The total time to complete the study was about 5 minutes.

11.1.4 Results

To investigate whether or not there would be differences in pleasantness ratings between each of the four conditions a mixed ANOVA with the independent within-subjects variable 'velocity' (5 levels), and the independent between-subjects variable 'condition' (4 levels), and with the dependent variable 'perceived pleasantness' was conducted. Ratings in both blocks were aggregated. For the post-hoc pairwise comparisons Bonferroni corrections were applied. As measures of effect size generalized Eta squared (η_G^2) and partial Eta squared (η_p^2) are reported for all *F*-test [304].

In order to see if the pleasantness ratings for each of the four conditions would form a velocity-dependent inverted U-curve, in accordance with studies into actual stroking touch [321], and similar to the study reported in the previous chapter, regression analyses were performed. The independent variable 'velocity' was log10 transformed. For each of the conditions, the curve fit of a linear regression model (reduced

Figure 11.2: Mean pleasantness ratings for observed stroking touches.

regression model) was tested against the fit of a quadratic regression model (full regression model), with an F -test for significant reduction of the error sum of squares in the full compared to the reduced model [88]. For these analyses, R^2 is reported as a measure of effect size.

Effects of velocity

Data was aggregated over all conditions to investigate whether, overall, the pleasantness ratings would follow a velocity-dependent inverted U-curve (Figure 11.2(a)). Indeed, a quadratic, rather than a linear, regression model demonstrated a better fit for the aggregated pleasantness ratings ($F(2, 882) = 80.30$, $p < .001$, $R^2 = .154$). The peak of this fitted negative quadratic curve was at 3.48 cm/s.

The same analysis was conducted for each condition separately to investigate to what extent pleasantness ratings would follow a velocity-dependent inverted U-curve in each condition (Figure 11.2(b)). For the human touch condition a quadratic regression model showed a significantly better fit to the data than a linear model ($F(2, 217) = 30.70$, $p < .001$, $R^2 = .221$). The peak of the fitted negative quadratic curve was at 4.46 cm/s.

Similarly, for the robot touch condition a quadratic regression

model showed a significantly better fit to the data than a linear model ($F(2, 207) = 19.33, p < .001, R^2 = .157$). The peak of the fitted negative quadratic curve was at 3.33 cm/s.

For the mannequin touch condition, again, a quadratic regression model showed a significantly better fit to the data than a linear model ($F(2, 212) = 28.96, p < .001, R^2 = .215$). The peak of the fitted negative quadratic curve was at 2.99 cm/s.

As for the other conditions, for the tube condition a quadratic regression model showed a significantly better fit to the data than a linear model ($F(2, 237) = 15.48, p < .001, R^2 = .116$). The peak of the fitted negative quadratic curve was at 4.32 cm/s.

To investigate whether stroking touches at a velocity of 3 cm/s would be rated as significantly more pleasant than stroking touches at the other velocities, repeated measures ANOVA's were conducted for each of the conditions separately, using a Bonferroni correction to correct for multiple comparisons (thus statistical significance was assessed at $\alpha/4 = .013$). A 5x4 mixed ANOVA was conducted with the 5 velocities (within-subject independent variable), the 4 conditions (between-subjects independent variable), and the pleasantness scores as the dependent variable, for which the within-subject effect of velocity is reported here.

For the overall ratings a significant main effect of velocity was found (Greenhouse-Geisser correction applied, $F(2.10, 362.94) = 66.43, p < .001, \eta_G^2 = .162, \eta_p^2 = .277$). Pairwise comparisons revealed that stroking at 3 cm/s was rated as significantly more pleasant than stroking at all other velocities (all p 's $< .001$).

For the human touch condition a main effect of velocity was found (Greenhouse-Geisser correction applied, $F(1.94, 83.47) = 23.41, p < .001, \eta_G^2 = .223, \eta_p^2 = .353$). Pairwise comparisons showed that stroking at 3 cm/s was rated as significantly more pleasant than stroking at all other velocities (all p 's $< .005$), except for 10 cm/s ($p > .05$).

Similarly, for robot touch a main effect of velocity was found (Greenhouse-Geisser correction applied, $F(1.80, 73.97) = 12.99, p < .001, \eta_G^2 = .163, \eta_p^2 = .241$). Again, pairwise comparisons were conducted which showed that stroking touches at 3 cm/s were rated as

significantly more pleasant than all other velocities (all p 's < .002), except for stroking at 1 cm/s (p > .05).

For stroking with the mannequin arm, a main effect of velocity was found (Greenhouse-Geisser correction applied, $F(2.52, 105.69) = 29.01$, p < .001, $\eta_G^2 = .219$, $\eta_p^2 = .409$). Pairwise comparisons revealed that stroking at 3 cm/s was rated as significantly more pleasant than stroking at all other velocities (all p 's < .005).

Finally, for stroking touches with the tube a main effect of velocity was found (Greenhouse-Geisser correction applied, $F(2.04, 95.81) = 13.21$, p < .001, $\eta_G^2 = .116$, $\eta_p^2 = .219$). And again pairwise comparisons showed that stroking at 3 cm/s was rated as significantly more pleasant than stroking at all other velocities (all p 's < .009), except for 10 cm/s (p > .05).

Effects of stimulus type

To investigate whether the pleasantness ratings of the stroking stimuli applied in the four conditions would differ from each other, a 5x4 mixed ANOVA was conducted with the 5 velocities (within-subject independent variable), the 4 conditions (between-subjects independent variable), and the pleasantness scores as the dependent variable.

As reported in the previous section, a significant main effect of velocity was found (Greenhouse-Geisser correction applied, $F(2.10, 362.94) = 66.43$, p < .001, $\eta_G^2 = .162$, $\eta_p^2 = .277$). No significant main effect of the conditions was found ($F(1, 173) = 2.094$, $p = .103$, $\eta_G^2 = .018$, $\eta_p^2 = .035$).

However, there was a significant interaction between velocity and condition ($F(6.29, 362.94) = 2.69$, $p = .013$, $\eta_G^2 = .023$, $\eta_p^2 = .045$). To further investigate this interaction effect, pairwise comparisons between the conditions were carried out for each of the velocities. Stroking touches applied with the mannequin arm were perceived as significantly more pleasant than those applied with the tube ($p = .009$) but only for a stroking velocity of 3 cm/s. In addition, stroking with a human hand was perceived as significantly more pleasant than stroking touch by the robot at 10 cm/s ($p = .029$). All other comparisons were non-significant.

11.1.5 Conclusions and discussion

As can be experienced first hand when looking at the details of a beautiful sculpture, the mere observation of a touch activates the same areas of the brain that are also active when a touch is actually felt [50, 138, 139, 286, 365], and the subjective experience of both observed and felt touches can be remarkably similar [349, 365, 367]. With this in mind, the current study set out to investigate whether pleasantness ratings of observed stroking touches would indeed also produce a velocity-dependent inverted U-curve. Moreover, the study investigated to what extent the perceived morphology and agency of the toucher influenced such pleasantness ratings.

When we consider the notion that the subjective experience of observed touch can be similar to the subjective experience of a felt touch the findings from the current study are in line with previous research [365, 367]. The overall pleasantness ratings followed a velocity-dependent inverted U-curve, highly similar to the curve typically found for felt stroking touches [321]. The peak of the curve for the overall pleasantness ratings was at 3.48 cm/s, which is within the range of 1-10 cm/s reported for felt touches, and close to what is considered the most pleasant stroking velocity of 3 cm/s [321, 365, 367].

The pleasantness ratings for each individual condition also, followed a similar velocity dependent inverted U-curve. The peak of the fitted curve was highly similar to that for felt stroking touch, at 3.33 cm/s and 2.99 cm/s respectively, especially for the robot and mannequin touches. For stroking touch with the human hand and tube, however, the peaks of the fitted curves were respectively at 4.46 cm/s and 4.32 cm/s, which are still within the range of 1-10 cm/s reported for felt touches but different from the typical 3 cm/s peak.

These findings were further supported by analyses that showed that overall, stroking at 3 cm/s was rated as significantly more pleasant than stroking at all other velocities (see Figure 11.2(a)). This was also the case for stroking at 3 cm/s with the mannequin arm but for the other conditions differences between 3 cm/s on the one hand, and 1 cm/s and 10 cm/s on the other hand, were less clear.

Nevertheless, the current study shows that when people observe

videos of a person's arm being stroked at different velocities they are likely to rate these stroking touches in accordance with how people rate felt stroking touches applied at the same velocities. In the current study this patterns occurred for all conditions but most strongly for the condition in which the stroking touches were applied with a mannequin arm.

The results also show that there were no clear significant differences between the pleasantness ratings in each of the four conditions. It was hypothesized that the presence of social cues [365] in the form of a humanlike appearance (i.e. morphology) and social agency would positively influence pleasantness ratings but no evidence was found in support of this hypothesis. It would therefore seem that pleasantness ratings of stroking touches applied to a person's arm, irrespective of how these touches are applied, follow a pattern that is similar to felt stroking touches.

What explanation can we give for these findings based on what we have learned about observed touch? First, based on previous research [365] one would expect that stroking touches only follow a velocity dependent inverted U-curve when they are of a social nature. However, in this previous research the social and non-social conditions were based on what was touched: either a human arm or a bowl of water [365]. Conversely, in another study [138], a human arm was either touched by another person or by the leaves of a plant. In the situations where the touches by both a person and the leaves were similar (i.e. both making contact with the recipient's hand rather than a stroking touch), pleasantness ratings for the touch by the leaves were actually higher.

The manipulation of the social nature in the current study was similar to the manipulation in this last study [138] as it was based on the appearance of who or what was doing the touching rather than who or what received the touches [365]. Here, the same forearm was stroked in all conditions. The present study shows that even for stroking touches, which have been suggested to have particular relevance in social interactions [365], similar to what was found for simple touch in previous research [138] the appearance of who or what is apply-

ing the touch does not really matter. Based on the results of the study presented here we would conclude that as long as it is a human body part, or at least the forearm, being stroked, pleasantness ratings for these stroking touches will follow a velocity-dependent inverted U-curve. This would be in line with the idea that the mirror touch system, which shows overlapping activation in certain areas of the brain for observed and felt touch, is active for all kinds of observed touches, including those between people and objects [139, 286]. Of course, without actually putting people in an MRI machine, we can only speculate about the activity of the mirror touch system based on the findings from the current study. Still, it is interesting to consider that this system might also be active for observed stroking touches specifically, and that it seems to be more attuned to the stroking velocity than to the appearance of the toucher.

These explanations notwithstanding, we also need to critically consider the stimuli that were used in the current study and think about how they might have been interpreted by the participants. It is, for example, possible that participants simply perceived agency in all of the stimulus conditions, making them all social touch, either mediated by an object or not. This explanation would also mean that the robot, which was clearly observable to move of its own accord, would be perceived as a social agent. It is possible that because of the perceived social nature in all stimuli, pleasantness ratings followed the expected inverted U-curve [365]. Future research could ask participants to what extent they perceive agency in the observed toucher, in order to get a clearer picture of the differences in perceived agency between the different conditions. Another approach to make the differences in agency more clear between the conditions would be to show an automated mechanism for stroking touches applied with an object, such as the tube and the mannequin arm. This would make it more clear to the observer that touches are not applied by a human in any way, but are applied by a non-social mechanical device.

Another explanation for why the human touch was not rated as more pleasant than the other touches, as was expected, could have to do with the appearance of the human hand used in the videos. Upon

seeing the stimuli after the study was conducted, a person remarked that the hand could be perceived as a child's hand. While the person to whom the hand in the video belonged was definitely an adult, her hand being perceived as a child's hand could of course have had implications for the pleasantness ratings, especially considering the fact that it was an adult male's arm being stroked. Such a social touch might have been considered inappropriate. In relation to this, the mannequin arm might have looked both adult enough and human enough to produce the overall highest pleasantness ratings and most clearly defined inverted U-curve, in line with felt stroking touches [365]. This explanation implies that the appearance of the toucher does make a difference to some extent. However, the appearance of the human hand, as implemented in the current study, reduced the expected effect to a level similar to that of the other, non-human, touches. Future research would ideally scrutinize the appearance of the human hand more closely, possibly with the use of a manipulation check to see how people perceive the toucher (e.g. age, gender), based on the appearance of his or her hand.

We should also note that not all options for applying stroking touches have been exhausted in the present study. All conditions featured relatively pleasant and friendly looking objects with which the stroking touches were applied. It is not unthinkable that using a robot with a much less friendly appearance and a more claw-like hand would yield different results.

Finally it is important to realize that as in previous studies into observed touches, the touches in the present study were observed to be applied in a setting that was largely devoid of a clear social context. Given the fact that the same touch can communicate different signals (i.e. equipotentiality [246]), it is likely that the judgement of observed stroking touches in an actual social setting is, to some extent at least, determined by characteristics of the social setting [see also 76]. For example, if we were to observe a child's hand stroking the arm of a man, as was suggested for the human touch condition in the study reported here, knowing that the man is her father would likely make

the interpretation of the touch different, than if the observer would imagine that the man is a stranger.

Nevertheless, the study presented here demonstrates that subjective pleasantness responses of stroking touches observed from video as occurring in isolation, in accordance with earlier work on observed and physically applied touches [321, 365], follow a velocity-dependent inverted U-curve. The fact that these results were obtained from a large, heterogeneous participant pool (i.e. not just students), in an online video study, speaks for the robustness of this effect.

11.2 COMBINING SENSATION AND MODALITY

We have been introduced to ways in which our sense of touch can be tricked into feeling things that are not really there, such as a vibrotactile stroking sensation from a linear array of just four vibration motors. Not only that, but we have also seen that physical touch is not even really necessary at all to give people an impression of a touch: merely observing a touch can result in responses similar to an actual felt touch.

One question that remains is how we can integrate both of these aspects into social touch technology. If we play devil's advocate for a minute, we might even wonder if perhaps social touch technology could do away with haptic technology altogether and simply use visual representations of a touch. In one study at least, a visual-only mediated social touch seems to have elicited a sort of Midas touch effect [58]. Nevertheless, focussing solely on visual feedback would forgo a number of interesting ways in which visuo-haptic feedback can influence perception, which can be useful in social touch technology. Not only that, despite the shared circuitry for observed and felt touch, the experience is of course not completely identical [see also 286], as a felt touch might be experienced differently depending on whether it is applied by an actual person or not [300]. In addition, the perceived gender of the person applying a touch might make a difference in the experience of a touch [182].

One way to use congruent visuo-haptic feedback for social touch technology is in relation to body-ownership. In Chapter 9 we have

seen how synchronized stroking of someone's real hand and a rubber hand can result in the person experiencing the stroking sensation on the rubber hand instead of their own hand [57]. Interestingly, it has been found that this rubber hand illusion can also occur to some extent under mediated conditions where the rubber hand is replaced by a projection of a rubber hand [257] [see also 309, 342]. Note, that the rubber hand illusion may manifest itself through similar mechanisms as those active during observed social touch [see also 138]. Such congruent visuo-haptic feedback might also enhance the sensation that a virtual body a person inhabits in a shared virtual environment (SVE) is actually his or her own body. This would make touches applied to the virtual body more likely to be experienced as social touch.

Another approach is to use visual and haptic feedback to ameliorate the typically relatively sensorially poor aspects, at least compared to actual social touch, of social touch technology (see also Section 6.1). This would include the use of tactile illusions, such as apparent motion illusions to create dynamic stimuli with vibrotactile actuators, as well as congruent visual feedback, for example, seeing a hand apply a stroking touch that is felt through the vibrotactile array. Such congruent visuo-tactile feedback may be expected to enhance social presence [221, 220, 372]. Nevertheless, based on the study on observed social touch presented in this chapter, the exact appearance of the toucher may be less important than seeing a part of a human body being touched, as well as the dynamic properties of the touch. Indeed, in an SVE, congruent visuo-haptic feedback may be represented by relatively simple visualizations and still enhance social presence [e.g. 33].

Finally, haptic feedback might also be used to provide a sense of physicality to that which is virtual. Imagine how the body of a virtual character, such as those found in video games and in virtual reality applications, could be made physical by the use of haptic technology. This might allow a user to touch the virtual character, and, provided that the user is equipped with hardware such as the TaSST, can allow a virtual character to touch the user. Such *simulated social touch* would ideally feature congruent visuo-haptic feedback, based upon the

theories discussed in the previous three, to make for more compelling social touch technology interactions. In the next chapters we will see how reality and virtuality can be mixed in order to create artificial social agents that can ‘reach out of the screen’ and apply social touch to a person’s body.

PART IV

SIMULATED SOCIAL TOUCH

CHAPTER TWELVE

PLUGGED INTO THE MATRIX: SOCIAL TOUCH BY ARTIFICIAL HUMANS

It was not until thirteen years after its release that I fully grasped the central theme of the Wachowski's bleak scifi movie *The Matrix* (1999). The movie features a post-apocalyptic robot-ruled world, a fact of which humanity is kept blissfully unaware through the use of a sophisticated computer-simulated 'alternate reality'. We are transported to such alternate realities when we read a book, play a video game, or indeed watch a movie, but it was not until I tried the first developers' edition of the Oculus Rift virtual reality (VR) headset that I truly had the feeling that at some point this technology might fool me into mistaking it for reality. Like the audience's supposed reaction of shock to the Lumière brother's *L'arrivée d'un train en gare de La Ciotat* at the end of the 19th century [319], I needed to take a seat for the Rift's rollercoaster demo.

We are now living in a time where every other electronics manufacturer is releasing a VR headset that allows one to experience any number of compelling virtual realities. But perhaps we have already been one-upped, as suggested by philosopher Nick Bostrom [56]. Bostrom posits that we are currently living our lives in a complex computer simulation. Bostrom's thesis is that since computing power is expected to continue to increase in the future, it is likely that far advanced future "posthumans" will use a portion of their vast amount of available computing power to run ancestor-simulations: and many of them. Since

these simulations are likely to be highly advanced, the simulated people living inside of them will have consciousness. Supposing that this is indeed the case, the high number of simulations in which conscious people live would make it more likely that we ourselves belong to the simulated people rather than to the original biological race [56]. One rather depressing, or perhaps equally depressing, alternative is that the human race will die out before being able to run advanced ancestor-simulations. Another scenario forwarded by Bostrom is that posthumans will simply not be interested, or on ethical or legal grounds will be prohibited from running many ancestor-simulations. Bostrom, for the moment, assigns equal credence to each of these three alternatives [56].

Bostrom's thesis [56] has the intriguing consequence that perhaps we should not view what has been referred to here as actual social touch, as actual at all, but as simulated social touch. We could imagine a situation in which either our entire lives are fully computer simulated, social touch interactions included, or, like humanity in *The Matrix*, a situation in which we are simply passively laying somewhere living our lives through a simulated world controlled by malicious robots, with no actual physical contact going on beyond the simulation at all.

Given the proliferation of VR technology and its capabilities to simulate compelling virtual worlds, even with the rather limited capabilities of devices such as the Oculus Rift DK1, it might very well be the case that unless posthumans will have vastly different interests to us current humans [56], ancestor-simulations will be run in the distant future. For us mere humans at least, the drive to simulate other humans is a strong one, and one that is at the basis of numerous scientific disciplines such as efforts in neuroscience to build a simulation of the human brain [338]. If we are currently living in a computer simulation then we are also taking steps to creating a simulation within a simulation (indeed there is an argument to be made for infinite nested simulations¹).

The accurate simulation of the sense of touch might actually be very

¹For those interested in reading more about the simulation argument, visit: <http://www.simulation-argument.com> (Last accessed 19-09-2016)

important to any compelling simulation of a human if we consider the notion already put forward by the ancient Greek philosophers that the sense of touch makes real [101, 178, 280] [see also 433]. Indeed, some refer to compelling haptic sensations as ‘the holy grail’ of VR [178, 474]. Such a simulation of humans and the human sense of touch naturally also involves the simulation of social touch between the artificial humans in the simulation.

Computer science is one example of a field of research which has concerned itself with the creation of such artificial humans. A popular theory in human computer interaction (HCI) research is the Media Equation [416]. This theory states that when we perceive intelligence in a computer system we cannot help but treat this computer system as another social actor [see also 323]. This has likely to do with the fact that we have evolved in increasingly more complex social structures and are thus to some extent ‘hardwired’ to treat any perceived intelligence in an inherently social manner.

HCI, as well as human-robot interaction (HRI) research has capitalized on this notion by building computer systems that behave, look, and even move around like humans. Such computer systems can take the form of virtual agents or social robots that can, for example, use their virtual or physical bodies to express emotions during an interaction with a user [64, 200]. Along this line of reasoning, provided such artificial social agents have the capability of applying and receiving touches, it could be conceived that touch interactions with these agents are perceived as social touch. Like the simulation of other aspects of human physiology and behavior, such as those found in *The Matrix* and those that would be required for Bostrom’s simulation argument [56], such interactions constitute a form of simulated social touch.

It is important to realize that simulated social touch is different from mediated social touch. In mediated social touch at least two actual people, in as much as we can still speak of actual people, manipulate a sensor at one end to trigger a haptic sensation at the other end. The notion that sender and receiver are aware that the touches they apply and receive are applied to or felt by another person is important in me-

diated social touch. Users can be made aware of this through visual, or auditory feedback of the sender or receiver, or by simply telling a person that the sensation he or she feels is produced by another person at a distant location (see also Chapter 7). Simulated social touch, however, relies on the notion that a user perceives social agency in an artificial social agent. Thus, for a haptic sensation produced by an artificial social agent to be perceived as a form of social touch, the agent needs to provide other social cues in order to communicate a sense of social agency.

Another aspect that is important here is the relation between the artificial social agent's body and the touch sensation that is received or applied by a user. For a social robot the relation between social touches and its embodiment is direct as it can use its physical body to apply and receive touches. For a virtually embodied artificial agent the relation between an applied or received touch and the agent's embodiment is less direct as a virtual body does not afford physical touch. Thus, in the design of a touching virtual agent it is important to somehow make it apparent that the body of the agent is the source of a felt touch sensation.

Visual feedback might be especially useful in order to provide a user with a sense that the felt haptic sensation was applied by the virtual agent. Or conversely, a touch applied by the user is applied to the agent's body. Research has shown that congruent visuo-haptic feedback, even when mediated through projections or VR displays, can be used to give a person the sense of ownership of a fake rubber hand [257, 309]. It might be possible that similar congruent visuo-haptic feedback, where the haptic feedback felt by the user is synchronized to the visual feedback from the agent's embodiment, can create the illusions that the virtual body of a virtual agent feels like a real body.

With current advances in VR technology and social robotics it is highly likely that we will come into contact with artificial social agents with increasing frequency. That is, if we for the moment disregard the idea that our current reality is a simulation [56] and thus all social touch that occurs is in fact simulated. It nevertheless remains

important to study all aspects of social interactions with artificial social agents, and that includes social touch. If we are to form lasting and meaningful relationships with artificial agents [44], the addition of the sense of touch might prove beneficial for building and maintaining such relationships [508].

In the remainder of this chapter we will first take a look at research into social touch by social robots, followed by a discussion of social touch by virtual agents.

12.1 SOCIAL TOUCH AND SOCIAL ROBOTS

March 2016 marked a moment of some sadness for aficionados of the ancient Chinese game of Go. Before that date, Go players prided themselves on the fact that, unlike chess, the game of Go was still the domain of human players rather than sophisticated computers. Unfortunately, AlphaGo, powered by artificial intelligence software from Google's DeepMind, knocked Go off of its pedestal as the only game not yet fully mastered by computers, by defeating Go grandmaster Lee Sedol 4-1 in a five game series [435].

For all its Go-playing prowess, however, AlphaGo still needed a human to pick up the Go pieces and place them on the board. Evidently, the ability for an artificial intelligence system to be able to make sense of the 10^{171} possible Go board layouts - more than there are atoms in the universe, as is sometimes claimed [435] - is no guarantee for good motor skills. Indeed, it is incredibly difficult to design a robot that has a sense of touch akin to that of a human, let alone a robot with the adaptability with which a human can operate his or her extremities to move the small, smooth pieces on a Go board [429, 435]. Perhaps that is something Go players can take pride in, then, especially since the manipulation of chess pieces has already been mastered by robots [346].

The relative clumsiness of a robot's haptic abilities is part of the reason why research on tactile human-robot interaction (tactile HRI) has focussed on safety. Especially in the presence of soft, squishy, easily damaged humans - it is perhaps not without reason that the

robotic overlords in *The Matrix*, placed humans in protective womb-like pods - robots can use their sense of touch as a safety mechanism: when a robot detects that it is touching something, like a person, it can stop its operation so as to not to harm the person [22]. Nevertheless, even such accidental contact could be perceived as a form of social touch, as is the case for accidental contact between humans [272].

The focus in this section is, however, on simulated social touch as intentional applications of touches by a social robot, or the detection of intentional social touches made by a human to a social robot. It is also necessary to make a distinction between robots that are perceived as humanlike and robots that are perceived as animal-like. There are numerous examples of the latter type of robot of various levels of cuteness, from baby seals [519], to rabbit-like creatures [543]. The type of haptic feedback that such 'zoomorphic' robots provide is mainly in the realm of simulated animal behaviors, like basic head movements, breathing, and purring [519, 543]. Such haptic feedback is markedly different from the intentional social touches that are applied in human-human social touch interactions. Moreover, there are clear differences in the expectations that people have of humanlike and animal-like robots, and the social norms that are accepted for both types of robot can differ [167]. These differences in social norms may become especially relevant where simulated social touch is concerned [308], as there are obvious differences in the way people touch other people, and the way people touch animals [162, p.405] [see also 444, 521].

Based on this it could be argued that touch between a person and an animal should not be considered as social touch in the same light as human-human social touch, either mediated through, or simulated by technology, or in actual skin-to-skin contact by people in the same physical space. In line with the discussion of social touch in the rest of this book, the focus here will be on simulated social touch by social robots that are perceived as humanlike.

The physical body of a social robot affords the most direct means for making social touch interactions between humans and artificial social agents possible. In tactile HRI, a robot can detect touches made to its body through various types of soft or hard skin-type sensors,

or through sensors that can detect the position of its limbs [22]. For example, the small humanoid ‘Macra’ robot [544] is covered in a soft urethane shell, making him look a bit like the Michelin Man. The urethane shell contains touch sensors that can detect three-dimensional force distribution, which allows the robot to respond to social touches such as being picked up, or hugged. Similarly, the slightly more creepy looking ‘CB2’ is a child-sized robot that features a soft silicon skin with embedded touch sensors which allow the robot to respond to physical contact from a human [362].

There are more examples of similar robots that feature touch sensors located on their outer body (see [22] for an overview), but what is important is that a social robot can use these sensors in social touch interactions with a human in order to develop and execute certain behaviors [22]. Part of this behavior execution is the application of touch by the robot. In the next two sections we will take a look at the ways in which simulated social touch by a social robot can affect the human that is touched.

12.1.1 Touch by robots in healthcare

Social robots can use their physical bodies to communicate with people using the same non-verbal cues (such as facial expressions, hand gestures, and body postures) as people use to communicate with each other. Because of this similarity, people tend to approach social robots that use such non-verbal signals in a way that is similar to the way that they approach other people [287] [see also 416]. Social robots have been designed to capitalize on this notion in order to motivate, engage, coach, educate, monitor, and support people in various settings [65]. In health-care settings in particular, the use of social robots can be beneficial to, for example, elderly care, therapy for children with autism, and management of chronic diseases [65]. The use of simulated social touch as a way for a social robot to engage with a person in a non-verbal way is a relatively new approach [22]. This approach is, given the importance of actual social touch to well-being (see Section 4.1), a logical next step, especially for social robots that are used in health-care settings.

A first, rather explorative, direction of simulated social touch research has seen researchers use social robots that can touch and be touched in interactions with children with autism. Social robots have been found to improve engagement in social interactions of children with autism, and can elicit new social behaviors [446]. One such behavior is social touch, with which people with autism are generally uncomfortable [53]. Using a relatively non-threatening social robot has been proposed as a way to teach children with autism about social touch, in order to make them more comfortable with touch [423]. In two explorative studies, children with autism were allowed to interact freely with a child-like robot that had touch sensors embedded in its skin [422, 423]. The children were observed to touch the robot on different body locations, such as its hands, wrists, and face, and the children were found to use different types of touch, including grasping, poking, and stroking [422, 423]. These studies show, at the least, that children with autism have a propensity to touch a social robot, which in itself may be a new and useful way for them to express themselves.

In another study, children with autism were invited to play a simple cause-and-effect game with a social robot that could detect touches [424]. The robot would respond positively to gentle touches and negatively to harsh touches through vocal utterances, facial expressions, and body movement. Children were allowed to interact with the robot repeatedly, and were, with help from their teacher and an experimenter that was present, able to develop a non-aggressive touch interaction style with the social robot [424]. By using social robots as a platform it could be possible to teach children with autism about appropriate uses of social touch [see also 109], in turn helping them become more comfortable with social touch in general.

A different scenario in which social robots could be imagined to operate in a health-care setting is one where the robot acts as a nurse, charged with tasks related to the treatment of patients. An abstract humanoid robot, that actually looked rather unlike a nurse, was used in a study to investigate whether the perception of simulated social touch by such a robot would depend on the framing of the touch as either instrumental (i.e. cleaning), or affective (i.e. comforting) [91, 92].

In the study the robot applied stroking touches to the lower arm of a participant lying in a hospital bed. The touches were framed as either instrumental or affective, and were either preceded by a verbal warning from the robot, or a verbal comment after the touch. In all conditions, the touch that the robot applied was a similar stroking touch with a velocity of about 4cm/s. Participants in general responded positively to the robot-initiated touch, but participants responded less positively to the affective touch than to the instrumental touch. Touch preceded by a verbal warning was considered as less positive than touch that was not preceded by a warning.

Based on the fact that the touch that the robot applied was a stroking touch with a stroking velocity that can be considered optimal in terms of its pleasantness [e.g. 321], it is a bit surprising that the participants found this touch less pleasant when it was framed as an affective touch. A possible explanation for this lies in the fact that the robot in question had a rather unfriendly, and mechanical appearance. It could be that the more mechanical, functional appearance of the robot matched better with the functional application of touch, and less so with touches applied to communicate affect.

Finally, the researchers suggest that the sudden verbal warning most likely just startled participants [91, 92]. Perhaps with a more friendly looking, and more gently speaking robot nurse the affective touch would have been interpreted differently.

12.1.2 Touch and attitudes towards robots

If the Midas touch effect reported for actual social touch is any indication (see Section 4.4), simulated social touch by a social robot might be used to influence a person's attitude towards the robot in a positive manner. Not only that, but it may even be possible to elicit pro-social behavior in a person touched by a social robot.

Social touch that occurs between a human and a social robot might already influence attitudes towards that robot at a relatively early age. When children are first exposed to a humanoid social robot they may not always instantly accept the robot, which may have negative consequences for subsequent interactions [249]. One study found that when

a child is allowed to hold hands with the robot in the early stages of an interaction the child sees the robot as more humanlike, is less fearful of the robot, and plays more actively after having held the robot's hand [249]. Holding hands might thus be useful to pave the way for building a longer lasting relationship between the child and the robot [249].

The sight of a robot applying a touch to a person might actually already influence attitudes towards that robot [111]. A study in which participants observed a small humanoid robot aiding a computer user with computer issues showed that the perception of observed simulated social touch may depend on the robot's level of pro-activeness, as well as the observers' general attitude towards robots. The study found that a robot that was observed to be proactive and applying a touch was perceived by participants as less machine-like. A reactive robot that did not use touch was perceived as more machine-like and less dependable. Furthermore, the absence of social touch by the robot resulted in participants with a positive attitude towards robots rating it as more machine-like [111]. When used in a way consistent with the robot's overall behavior, then, simulated social touch may help in making social robots seem more humanlike [see also 287].

This does not mean that the tactile qualities of an actual touch by a social robot cannot make a difference in the perception of the touch and the robot applying the touch. A study where participants were invited to the lab to watch a horror movie together with a small humanoid robot showed that the perception of the robot was dependent on the social touch that occurred between the robot and participant [381]. The robot was found to be perceived as significantly more friendly, trustworthy, and more humanlike when participants held the robot's hand which was artificially heated, compared to a cold robot hand, or no hand-holding at all. However, simulated social touch could not attenuate the scare effects of the horror movie [381].

The Midas touch effect, which describes how a brief touch can increase the chances that the person who was touched will show pro-social behavior towards the toucher, has been investigated for both actual social touch [e.g. 114], and mediated social touch [e.g. 217].

One potential issue with the Midas touch effect is that it may in part be explained by a confederate bias, where the confederate who knows whether or not a touch is applied, also adjusts other behaviors [217]. Having a social robot as a ‘confederate’, however, would circumvent this issue as the behaviors of the robot can be preprogrammed. Using such an approach, researchers have found indications for the existence of a robotic Midas touch effect.

A first indication for a robotic Midas touch effect was found by researchers who had participants play an Ultimatum game with a small humanoid social robot [173]. In this game, one player takes on the role of proposer, and proposes a way to divide a sum of money between both players. The other player decides whether or not to accept the proposal. If the proposal is rejected, neither player receives any money. As something is better than nothing, the economically optimal way to play the game is to simply accept every offer. Yet when presented with unfair offers (e.g. 90% of the total amount of money for the proposing player and 10% for the responding player), people will often make the emotional decision to reject the offer, even though this means they will receive no money at all. To see how participants would respond to unfair offers made by a social robot that either made the offer in combination with a simulated social touch, or just made the offer, electroencephalogram (EEG) measures were taken, and special attention was paid to activation indicative of experiences of unfairness [173]. It was found that simulated social touch by the social robot attenuated the experience of unfairness during unfair offers, but that this did not affect participants’ actual behavior. Participants still rejected unfair offers, whether or not a touch was applied [173].

Evidence that points to actual changes in pro-social behavior as a result of a robotic Midas touch was found in another study where participants were asked by the same small humanoid robot as used in the previous study, to do the rather meaningless task of dragging an on-screen circle into an onscreen square using a computer mouse [371]. The robot either made the request without any touch, invited the participant to touch its hand, or invited the participant to touch its hand whereupon the robot applied a stroking touch to the participant’s hand.

The results from the study were rather remarkable in that it was found that in the condition in which the robot applied a stroking touch, participants dragged significantly more circles, and did so for a longer period of time than in both other conditions. In addition, participants rated the robot as significantly more friendly in the stroking touch condition [371]. It would thus seem that the robot's stroking touch had a strong effect on participant's tendency to comply to a request (i.e. a form of pro-social behavior). The same researchers conducted another study that followed the same general procedure as the previous one [457]. The same results for the behavioral measures were found, but this time the robot's stroking touch did not significantly affect how friendly participants thought the robot was.

The results from these last two studies are somewhat surprising given the fact that the virtual Midas touch effect can be attributed in part to the confederate adjusting other social signals (e.g. body movements, vocal utterances, facial expressions). When the confederate is blind to the condition and can thus not unconsciously adjust other social signals in accordance with the condition, the virtual Midas touch effect fails to show significant effects on pro-social behavior [217]. Given the rather basic appearance of the robot used in studies into a robotic Midas touch effect, and the rather simplistic interaction in which the touch took place [371, 457], it is unlikely that other social signals contributed strongly to the robotic Midas touch effect. Thus the effect of the robot's touch seems surprisingly strong compared to the virtual Midas touch effect. We should note though, that in the virtual Midas touch effect studies [217, 222], vibrotactile feedback was used instead of the stroking touches applied by the robot [371, 457]. What is more, the virtual Midas touch studies were carried out in the Netherlands [217, 222], while the robotic Midas touch studies were carried out in Japan [371, 457]. It could be that Japanese participants are overall more likely to show a strong pro-social response to a Midas touch in general.

12.2 SOCIAL TOUCH AND VIRTUAL AGENTS

In the classic video game *Ico* a young boy is tasked with rescuing a princess from a castle - it does not get much more classic than that - by guiding her by the hand. The hand-holding serves to make apparent the intimate relationship between the player's character and the princess, a non-player character (NPC), and underlines the NPC's reliance on the player.

Simulated social touch in video games where the player's character is touched by, or touches, an NPC is abundant, especially in story-driven games. It occurs in games that are very abstract, such as the excellent *Thomas Was Alone*, a story-driven platforming game featuring geometrically shaped characters, as well as photorealistic games such as *The Last of Us*, a story-driven action game and one of my personal all-time favorites.

In most games, this type of simulated social touch is purely visual; no haptic feedback is felt by the player as a result of a touch. Like a social robot, a virtual character, sometimes also called virtual agent, is an artificial social entity. People readily attribute human qualities to virtual agents because of their humanlike appearance and behaviors [28, 44]. This is similar to how people attribute human qualities to social robots [287]. Unlike social robots, however, virtual agents only have a virtual body and not a physical one that directly affords touch. While the visual impression of a social touch on its own has the potential to elicit responses similar to those of a felt social touch, there are still differences between the subjective experience of an observed and a felt touch and there are benefits in using multimodal feedback in social touch technology (see also Section 11.2), especially for the combination of visual and haptic feedback. The challenge, then, is to allow a virtual agent to 'reach out of the screen' to touch a person, and to allow the person to 'reach into the screen' to touch the virtual agent.

One way for a virtual agent to be able to touch a person, is to have the person wear actuators on their body. A device like the TaSST, for example, could be activated in synchrony with a visually observable social touch by a virtual agent, such as the agent reaching out its hand, to produce the sensation that the agent is applying a touch to

the person's body. The person interacting with the virtual agent can be visually represented (i.e. have an avatar) on a normal screen or, in a fully immersive VR environment, through a head-mounted display. The important thing is that the person can observe as well as feel a virtual agent's simulated social touch being applied to his or her (virtual) body.

Another approach would be for a person to use a handheld device that represents the person or, a part of the person (e.g. the hands), in the virtual world. Such a handheld device could be a controller that is tracked in actual 3D space and includes vibrotactile feedback, such as is found in the controllers for popular VR platforms like the HTC Vive. Movements of the controller in actual 3D space can be translated to movements in the virtual world. For example, when a person reaches out to touch a virtual table while holding the controller, the person's hand can be seen to move towards the surface of the table in the virtual world and can produce vibrotactile feedback when the person's hand visually makes contact with the table. Another related example is the use of a force feedback joystick that a person can manipulate in order to feel around in the virtual world. Using such a device, a person can physically interact with virtual objects, and can feel tactile or haptic sensations based on what is encountered in the virtual world. This might include the body of a virtual agent for simulated social touch.

Finally, it is also possible to physically represent the agent's body, or parts of the agent's body, and use augmented or virtual reality technology to visualize certain behaviors of the agent. Imagine, for example, a mannequin's arm (not unlike the one used in Chapter 11), that is equipped with touch sensors such as those found in the TaSST. A display positioned in such a way that the agent displayed on the screen seems to be the owner of the arm [see also 372] could be used to show behaviors of the agent, such as facial expressions. If a person touches the sensor-equipped mannequin arm, he or she would receive passive haptic feedback from the shape of the arm, and the touch detected through the sensors could be used to trigger a certain behavior in the agent. For example, if a person applies a stroking touch to the man-

nequin arm, the virtual agent could respond by smiling at such a nice social touch.

From a technical perspective then, there are several ways in which a virtual agent can touch and be touched. We have to pause, however, and consider why we might want a virtual agent to have these kinds of capabilities in the first place. One reason to allow a virtual agent to engage in simulated social touch with a person is that it gives this virtual agent an additional tool for social communication that is also available to humans. With this, virtual agents take one step closer to being able to communicate socially, with all the subtleties that humans use to communicate with each other. This same line of reasoning applies to simulated social touch for social robots.

A second reason to add social touch capabilities to a virtual agent is that the virtual agent, as well as the virtual world in which the agent resides, can be customized and controlled. The ability to minutely control the virtual agent's behaviors, such as its body movements, facial expressions, and the words it speaks, can be of great value for the study of social touch in general. By controlling the agent's behaviors, factors other than social touch that might influence an interaction between a person and the agent, can be controlled, which allows for more definite conclusions to be made on the specific role of social touch in such interactions. In addition, being able to control the environment in which the interaction takes place could also help to shed light on the role of contextual factors in the study of social touch. Normally, such factors are either very hard to control, as in studies conducted in the wild, or difficult to introduce in a convincing manner, as in lab studies. Note, though, that this approach to studying social touch, using virtual worlds and virtual agents, would require the virtual agent's touches to indeed be perceived by participants as social touch.

The malleability of virtual agents and virtual worlds is a benefit over the use of social robots in simulated social touch. While social robots have a physical body that easily affords touch, it also means that they are limited to the body that they have. This means, unlike a virtual agent, a social robot's appearance, form, and behavior, is generally much harder to customize. Moreover, the possible range of behaviors

it can show is restricted by its hardware. For example, a social robot might only be able to move its arm a certain amount at a certain speed, depending on the type of servomotor that is used to control the arm. Virtual agents do not have these hardware limitations.

In the next sections we will see that researchers have incorporated some of the ideas outlined above in order to investigate the ways in which simulated social touch by a virtual agent can affect a person interacting with the agent. It is also worthwhile noting that some of these researchers have sought to combine the strengths of social robots, such as having a physical body, with those of virtual agents.

12.2.1 Touch for emotional expressivity of virtual agents

In previous sections (Sections 4.4.1 and 7.1.1) we have seen that actual social touch, as well as mediated social touch, can be used for the communication of emotions. Similarly, researchers have investigated ways in which simulated social touch by a virtual agent can enhance the emotional expressivity of the agent in order to make it behave in a more humanlike fashion. This research aligns with work on how an agent's facial expressions can be used in order to communicate about the agent's internal state, such as the agent 'feeling' happy or sad [200].

By combining facial expressions of an emotion with simulated social touch expressions of the same emotion, it may become easier for a person interacting with a virtual agent to recognize which emotion a virtual agent is trying to bring across [55, 175]. In one experiment researchers investigated how easily participants could recognize facial expressions of an emotion made by a virtual agent, expressions of an emotion through touch by using a force feedback joystick (similar to [27]), and expressions that combined both facial and touch expressions of an emotion [175].

Results from this study showed that when facial expressions and simulated social touch expressions of the same emotion were combined the accuracy with which the expressed emotion was recognized by participants was higher, compared to recognition of either facial or touch expressions alone [175]. For the expression of most emotions, however, the recognition rate between facial expressions, and, facial and

touch expressions combined was not statistically significantly different. Thus, the addition of an expression through touch to a facial expression of the same emotion did not seem to make much of a difference for the recognizability of the emotion over just the facial expressions.

The study did find that for some participants (13% of the sample) the recognition of emotions improved with the addition of expressions through touch [175]. This is perhaps not surprising considering the individual differences in how comfortable people are in general with being touched [273, 274](see Chapter 5). People who are less comfortable with social touch in general might have had trouble to recognize the emotions that were expressed through touch. All in all, the researchers suggest that for some people the use of haptic feedback to express an emotion might help to make the expression of emotions that are similar in valence (i.e. positive or negative) but different in arousal more easy.

Based on this one study it would seem that haptic feedback does not really improve the expressivity of the agent. Indeed, the researchers also used a measure of social presence (i.e. the feeling of being together with another person [258]) and did not find any difference between the conditions [175]. The use of haptic feedback, then, did not make the virtual agent seem more humanlike, though perhaps this is not too surprising considering the relatively artificial implementation of facial and haptic feedback. First, the facial expressions were not animated and therefore not as expressive as they could have been. Second, the haptic feedback was in no way directly related to the embodiment of the virtual agent so the social touch aspect was not ideally simulated.

A more convincing implementation of social touch capabilities in a virtual agent was investigated in a study where the virtual agent could act as a health counselor [42]. Interestingly, the agent itself was composed of a physical mannequin body. The mannequin's head, however, was replaced by a computer screen on which the face of a female virtual agent was displayed. What is more, one of the agent's hands was equipped with an 'air bladder' that could be inflated using pressurized air. The idea was that if a person took hold of the agent's physical hand, the air bladder could be used to make the virtual agent squeeze

the person's hand. This approach is an interesting one in that there is a clear connection between the embodiment of the agent and the touch that the agent can apply. Moreover, by combining physical and virtual aspects, the agent has both a body that easily affords touch and a face that can be more easily used for facial and vocal expressions.

This hybrid physical/virtual agent was used to study the emotional expressivity of simulated social touch in combination with facial and vocal expressions [43]. In one study, participants wore the air bladder on their hand, which would then be used to apply a number of different haptic stimuli that represented different discrete emotions. It is important to realize that the air bladder was used in isolation, here, the rest of the agent's body was not present during the study. The researchers found that participants could not recognize discrete emotions in the squeezes that they received but they were able to associated certain types of squeezes with emotional valence and arousal. Specifically, squeezes applied with a higher force, and squeezes with a fast rhythm were perceived as high arousal, while squeezes with a fast rhythm were also perceived as positive. Squeezes of a longer duration were, however, perceived as more negative [43].

There are two likely explanations for these findings. First, the squeezes were simply not varied enough to be able to communicate different discrete emotions. This is especially likely considering the different types of touch people use to communicate emotions [245]. Second, the disembodied nature of the feedback made it more difficult to recognize specific emotions without a clear social or communicative context [43].

To provide such a context, another study was conducted, and this time, the agent's full body and face were used [43]. The agent was seated across from the participant, with the participant holding the agent's 'squeezing' hand. The participant was told to imagine that the agent was a health counselor that would try to express a number of different emotions during a counseling session. The agent would use both prosody (i.e. it pronounced a sentence in different ways), facial expressions, and touch to communicate positive, neutral, or negative emotional valence. Results from the study showed that touch had lit-

tle effect on the recognizability of the expressions overall, and, that the agent's facial expressions, in particular, dominated how people interpreted the multimodal expressions of the agent [43].

Not to be outdone by these, from the perceptive of social touch technology, somewhat disappointing findings the researchers conducted one more study using the physical/virtual agent [43]. This time, the study was not so much on the recognition of affective states but on the use of multimodal cues, including touch, in empathic communication, such as is used during health counseling sessions. The agent and the participant would have a semi-structured conversation about casual topics such as the weather and about the more difficult topic of cancer. When the participant made a scripted remark (read from a list of options) about the disease, the agent, controlled by an experimenter, would verbally give an appropriate response (e.g. "I am sorry to hear that. That must have made you feel terrible."). In one condition the agent would, in addition to the verbal remarks, also squeeze the participant's hand.

Though results were not clear cut, participants who were comfortable with being touched (measured through a 'touch receptivity' scale (see Chapter 5) showed an increase in the emotional bond with the pretend-health counselor physical/virtual agent. Such an increase was also found for people uncomfortable with social touch in general in the condition where no touch was applied.

Simulated social touch [43, 175] does not seem to be usable for the communication of emotions to the same extent as actual [245], or mediated social touch are [27]. This may have to do with the fact that it is difficult to perceive social agency in a virtual agent when the interaction itself is also artificial and devoid of a clear social and communicative context. In addition, the extent to which a person is comfortable with social touch in general, as has been discussed in Chapter 5, may actually have an impact on how this person perceives emotional expressions through simulated social touch. When receptivity to social touch is taken into account, simulated social touch might actually help to form a stronger emotional bond between a virtual agent and a person comfortable with social touch [43].

12.2.2 Touching a virtual agent

Thus far we have considered how social touch applied by a virtual agent can affect a person's perception of that agent. However, the opposite has also been investigated: how does social touch applied by a person to a virtual agent affect a person's perception of that agent? In one study participants used a head-mounted display and a force feedback joystick to interact with virtual items and virtual agents [29]. Specifically, participants were asked by the researchers to brush virtual dirt off of virtual geometric shapes as well as off of the face or torso of male and female virtual agents. Though, if the researchers in question had been even more shrewd, they would have obviously included a control condition in which participants were asked to clean up the lab while they were at it.

Nevertheless, the results from the study were interesting because they showed that participants used different amounts of force to touch virtual objects and virtual agents [29]. In particular, participants used more force to brush the dirt off of objects than off of virtual agents. Additionally, participants used more force when they touched the torso, compared to the face of a virtual agent, and applied more force when they touched male virtual agents than when they touched female virtual agents. The researchers explain these findings by suggesting that participants experienced a sufficient amount of presence, social presence in the case of the virtual agents [258], to differentiate in their touch behavior between virtual objects and virtual agents, as well as between virtual agents of different genders [29]. The idea is that in actual social touch similar differentiation occurs between genders [87].

Building on these results, other researchers have used VR and simulated social touch to investigate attitudes towards obesity [492]. In a study, participants wore a VR headset and used two haptic devices to hug several virtual characters in VR. The virtual characters were either male or female, and were either of normal weight or overweight. Results showed, that male participants hugged male virtual agents for about the same time, irrespective of their weight, while they hugged normal weight female virtual agents significantly longer than overweight female virtual agents. Conversely, female participants hugged normal weight

male virtual agents for significantly longer than they hugged overweight male virtual agents. In addition, female participants hugged female virtual agents for about the same length of time irrespective of their weight. The authors suggest that the results can be explained by views about the body image of oneself and of others, as well as stereotypical views held towards body weight [492].

Taking together the findings from the studies reported here it would seem that touch from a person to a virtual agent may shed light on that person's internal beliefs and attitudes, for example, towards gender and body image. The fact that findings in this direction have emerged also suggest that people can indeed perceive virtual agents in a way similar to the way they perceive other humans. In this sense simulated social touch could serve as a measure for the human likeness of a virtual agent. When a person touches a virtual agent in a way that he or she would normally touch an actual person this might be taken as an indication that the person touching the agent perceives the agent in a way similar to how he or she perceives an actual person as expressed through the touch behavior.

Making agents appear more humanlike could also be aided by giving the virtual agent the capability to apply social touches. However, the communication of discrete emotions does not seem to be an appropriate application of these simulated social touch capabilities. In the next section we will see some examples of how social touch, applied and received by virtual agents, can be used in applied training scenarios.

12.2.3 Touching virtual agents for medical training

Apart from purely affective communication, such as when attempting to communicate discrete emotions [245], actual social touch can also be used in settings where the touches are necessary due to the nature of a specific task [272]. In medical or therapeutic settings, such use of social touch is highly relevant [159]. We have already seen how a virtual agent could apply simulated social touch in a setting where the agent acts as a health counselor, and we have seen how such a use of

touch might affect the relationship between the agent and the person interacting with the agent [43].

Medical examinations often involve a form of touch for diagnostic purposes but at the same time such use of touch is important for forming a bond between the physician and the patient, for example, when conveying empathy [163]. Training medical staff to become proficient in the use of social touch during their daily practice may be difficult and time-consuming, given that such training likely involves hiring actors to play the part of the patient [296]. Having a virtual agent with social touch capabilities act as a patient might be useful to teach medical staff about appropriate uses of social touch, in order to improve both diagnostic, and social skills.

To this end, researchers designed a virtual agent that was visible through a VR headset but that also included a mannequin body that directly afforded touch [295, 296]. With this setup a user could see the virtual agent, its expressions, and the examination room in which the agent was situated, but could also physically touch the agent's body. The researchers in question called this a "mixed reality human", and proposed that it can be used to train medical students in conducting breast examinations. Through sensors embedded in the virtual agent's clothing and in the agent's breast, data could be gathered on the way participants used their sense of touch in interactions with the agent. Not only that, but through the detection of touches applied to the sensors, the virtual agent could also respond through speech, visual gestures (i.e. the agent's physical body did not move), and facial expressions to the touches made by participants.

In a first pilot study with the 'mixed reality' patient, a number of second year medical students was invited to perform a breast examination [295]. The study showed that participants responded empathically to expressions of pain by the simulated patient as a consequence of participants' touches to the breast. Moreover, it was found that participants touched the simulated patient in a manner similar to how physicians typically touch a real patient. These results provide some indication that a virtual agent that can be physically touched may indeed be a useful tool in the training of medical students.

How useful exactly was investigated in a follow-up study where the use of the physical/virtual agent to train medical students in the procedures of a breast examination was compared to the more typical training technique of using an actor as a patient [296]. Participants, again a group of medical students, completed a breast examination of both the virtual agent and a breast examination with a trained actor. The students rated both experiences as equally believable for a training scenario and saw the educational benefits in both approaches. Moreover, the students spent about the same time palpating the breasts of both the virtual agent and the actor. It should be noted, though, that students did not really touch the actor but touched a fake breast similar to the breasts of the virtual agent, while the actor responded to the stimulation as if it was her breast being touched. Bearing this in mind, the results indicate that a virtual patient that affords touch and that can respond to being touched in an appropriate manner is about as useful for training medical students on breast examinations as an actor who is used for the same training purposes.

In a final follow-up study the touch interaction between the medical students and the virtual agent that acted as a patient, was extended to include bidirectional touch; the virtual agent could now also physically touch the student by using one of its arms that was equipped with two servomotors [297]. The idea was that this bidirectional touch would allow the student and simulated patient to communicate nonverbally during a doctor-patient interview and subsequent breast examination.

It was found that participants not only applied touch necessary to conduct the breast examination but that they also touched the virtual agent to communicate empathy, to comfort the simulated patient, to express concern, and to get the virtual patient to comply to an instruction. These uses of social touch are similar to the way physicians typically use social touch in interactions with actual patients [297].

Prior to the actual breast examination, the virtual agent applied a single touch to the medical student's arm in order to communicate fear of the examination [297]. In one situation this touch was purely visual, and could only be observed by the medical student wearing a VR headset and could not be felt. In another condition, the virtual patient

used its servo-equipped arm to visually and physically touch the student. The medical students thought that both visual-only touch and visual-physical touch adequately communicated the virtual patient's fear but this was more so the case for the visual-physical touch. In addition, the medical students found the virtual patient to be more humanlike when it applied a visual-physical touch compared to just a visual-only touch. Based on the results the researchers concluded that physical touch was more effective for social communication in the simulated doctor-patient interaction than visual-only touch. The researchers suggest that social touch simulated through the physical/virtual agent may help to disambiguate expressions through speech, enforce social norms, and help in building rapport between the medical student and the patient [297].

The studies discussed in this section demonstrate that in at least one scenario (i.e. a breast examination), simulated social touch can be a helpful method to make a virtual agent appear more humanlike. Not only that, but a physical/virtual agent that affords touch might be a useful tool in teaching medical students about the use of touch for diagnostic purposes, as well as ways to use touch to communicate non-verbally with a patient. It is interesting to note that both the instrumental use of social touch, and the use of social touch for communicative purposes affected participants.

Finally, it is worthwhile remarking that a physical/virtual agent that can apply and receive physical touch [297] comes quite close to the capabilities of a social robot, which has a physical body with which it can apply and receive touch. Even so, the 'mixed reality' nature of the physical/virtual patient, where the visual representation of the virtual agent was still that, virtual, makes it possible to integrate more complex and dynamic facial expressions, as well as to alter the appearance of the patient [297]. This mixed reality approach, then, offers interesting opportunities for allowing simulated social touch to occur between a person and a virtual agent in situations where a touch by the virtual agent can be both seen and felt by the person.

CHAPTER THIRTEEN

HUMAN HOLOGRAMS AND TOUCHING VIRTUAL AGENTS

In the first series of *Star Trek* from 1966, Admiral Leonard H. McCoy was the chief medical officer aboard the USS Enterprise. Captain of the Enterprise - not the first captain of the Enterprise in the original series mind, that honor goes to captain Christopher Pike who starred in the unfortunately rejected pilot episode of the first ever season - James T. Kirk often jokingly referred to McCoy as “Bones”, a nickname that stuck, even in the modern movie adaptations by J.J. Abrams.

Bones is no doubt an all-time great character from the Star Trek universe. Bones’ popularity notwithstanding I would like to draw your attention to another Star Fleet medical professional for a moment. Though it is not immediately apparent when you watch a few random episodes of *Star Trek: Voyager*, but the primary physician aboard the USS Voyager is actually an emergency hologram. After the USS Voyager encounters an anomaly in a plasma field - bear with me - and suffers severe damage, as well as taking casualties among which the ship’s chief medical officer, the Emergency Medical Hologram Mark I is activated. Simply called ‘The Doctor’, an overeager medical hologram all too aware of his normally temporary status, is unpleasantly surprised when, due to a number of unforeseen circumstances, he is forced to stay on as the ship’s physician for an extended period of time.

The interesting thing about The Doctor is that, despite him being a hologram, he can physically interact with the instruments, such as

medical tricorders, needed to treat his patients, and he can touch his patients too. When The Doctor attempts to use social touch to steer captain Janeway out of the medical bay, though, we are promptly reminded of his lower rank and the fact that he is actually a holographic computer simulation that can also be turned off. The Doctor is, nevertheless, an example of a virtual agent that can physically interact with the world around him, including applying and receiving social touch.

Though it is never made apparent exactly how The Doctor is endowed with a sense of touch, we can assume that the approach is quite different from those which we have seen in the previous chapter. In the previous chapter we saw several approaches to simulated social touch for virtual agents in which some of the agent's features, including the face, were virtual, while other parts of the agent's body were physical [e.g. 43, 296]. Such an approach allows a person to touch the virtual agent's physical body while still being able to see a quite detailed representation of other important parts of the virtual agent, such as its face. Another way in which a person can touch a virtual agent is through the use of force feedback joysticks that allow a person to touch the virtual body of a virtual agent [29, 492]. A similar approach could allow a virtual agent to touch a person, for example by using a force feedback joystick to simulate a handshake with the virtual agent. Finally, a virtual agent can touch a person when that person wears actuators on his or her body that can be triggered by a behavior of the agent [43] (see Section 12.2).

Which of these approaches would be viable for creating a touching virtual agent like *Star Trek's* The Doctor? Such a touching virtual agent would need some way to move beyond the confines of a screen and be able to operate in the same physical or virtual space as the person the agent is interacting with, in order to be able to apply social touches to that person's body. This could either be achieved by moving the person into the virtual world, as would be the case with fully immersive virtual reality (VR) environments, or by moving (part of) the virtual agent to the physical world, as in the case of having an agent with a (partial) physical embodiment. A third approach, however, and one that is not

unlike the holographic *Star Trek* doctor, is the use of augmented reality (AR) technology.

AR can be considered as a variation of VR. In VR a person is fully immersed in the virtual world and cannot see the real world anymore. In contrast, in AR a person can still see the real world but with virtual elements superimposed upon it. AR supplements, rather than replaces reality, and in the ideal situation the virtual objects appear to a person to coexist in the same physical space as objects in the real world [25]. AR combines the virtual and the real in an interactive, three-dimensional fashion so that a person wearing, for example, a head-mounted display (HMD) can walk around and observe the virtual objects in 3D space [25].

Were we to replace virtual objects with virtual agents in AR, we would have a way to make these virtual agents be present in the same physical space as ourselves. If we then equip ourselves with a tactile display that is capable of making us feel touches that we see the virtual agent make to our real body, we would have a setup that approached *Star Trek's* holographic doctor. In other words, we would have a virtual agent that could visually and physically engage in simulated social touch, while being present in the same physical space as the person the agent was interacting with. A first attempt at the design of such a virtual agent is presented in the next section.

13.1 DESIGN OF A TOUCHING VIRTUAL AGENT

The use of AR technology to create a touching virtual agent does not necessarily mean that we have to create a life-sized, fully embodied agent. Depending on what technology is used and in what way it is used, it might not even be desirable to create an entire virtual agent. Unlike VR, it is by no means a given that AR operates through an HMD [25]. Anyone who has a smartphone is at some point likely to have used an AR application where the smartphone's back-camera is activated and you are able to view the world through the screen of your smartphone, but with additional information overlaid on top of the real world. A reason to use technology such as a smartphone or tablet instead of an HMD is that this technology is much more readily

Figure 13.1: Augmented reality touching virtual agent setup. The agent depicted on the computer screen can apply touches to a person's arm. The person can feel these touches through a vibrotactile sleeve and see them through the tablet.

available. An additional benefit is that it would not require a person to wear a rather cumbersome HMD [see also 25], although admittedly such technology is rapidly improving in terms of wearability and mobility (e.g. Microsoft's HoloLens).

One way to use readily available AR technology, such as smartphones and tablets, to create a touching virtual agent is to be selective about the parts of the agent that are visualized. Like a virtual Mr. Potato Head, it is possible to mix and match, picking only the components of the agent that are truly necessary to create a sensation of simulated social touch. With such an approach the question is, of course, which parts of a virtual agent should, at minimum, be visualized in an AR?

When we approach this question from the point of view that multimodal cues are important in the interpretation of a touch [178], as well as in interactions with a virtual agent [200], it stands to reason that the agent's face should at the very least be visible. The agent

can use its face to make eye contact with a person, use gaze to direct attention, and can use facial expressions to communicate about its internal state. In addition, since seeing a touch can not only result in responses similar to feeling an actual touch [e.g. 139], but can also influence the interpretation of a felt touch sensation [182](see Chapter 11), the virtual agent's hand touching the person interacting with the agent, should also be visible.

These considerations were at the basis of the creation of a first AR touching virtual agent setup (see Figure 13.1). The idea behind this touching virtual agent setup was that a person, seated at a table across from the virtual agent, could have a conversation with the agent. In addition to being able to look round, make eye-contact with the person, and talk, the virtual agent would have the capability to casually touch the person on the forearm. The touches by the virtual agent were restricted to the person's forearm on purpose, because the forearm is an appropriate body location for many different types of touch applied by a variety of people, from strangers to family members and loved ones [483]. Moreover, earlier studies with the TaSST have already shown the forearm to be an appropriate location to apply vibrotactile stimuli which could be useful as a way for the person to feel the agent's touches (see Chapter 8 and Chapter 10).

Central to the design of this AR touching virtual agent is congruent visuo-tactile feedback. In order to make it possible for a person to both see and feel a social touch applied by the virtual agent, the setup features a tablet computer positioned above the person's arm, so that the person views his or her own arm through the tablet computer. Using an AR application that runs on the tablet, the hand of the virtual agent can be made visible in the same physical space as the person's arm. The person also wears a vibrotactile display that can be activated in synchrony with the agent's hand that is visible in AR, creating visuo-tactile simulated social touch by the virtual agent.

13.1.1 Components of the touching virtual agent

The visuo-tactile simulated social touch produced by the virtual agent, was considered especially important to create the illusion that it was indeed the virtual agent that applied a touch to the person's arm. To strengthen this illusion, a number of other signals, such as the agent looking at the person's arm, were incorporated in the design of the AR touching virtual agent, such that a touch by the virtual agent occurs as follows.

The person who interacts with the touching virtual agent wears a vibrotactile sleeve around his or her left forearm. The arm is placed under a tablet that runs an AR application, so that the person sees his or her arm through the tablet. The virtual agent is displayed on a computer screen that is positioned in such a way, that the agent's shoulder and upper arm align with its outstretched hand, that appears on the tablet in AR when it applies a touch.

The touching virtual agent first looks at the location on the person's arm to which it will apply a touch, then rotates its upper body, leans forward, and stretches out its right arm to apply a touch to the person's arm. At this moment, the touching virtual agent's hand becomes visible on the tablet's screen. When the touching virtual agent's hand reaches the person's arm it stops for a brief moment and then moves downward to make visual contact with the person's arm. At the moment the touching virtual agent's hand can be observed to make contact with the person's arm, the vibrotactile actuators in the vibrotactile display worn by the person are activated, producing a congruent visuo-tactile simulated social touch.

There are four main components in the system depicted in Figure 13.1 that make this simulated social touch interaction possible: an AR program running on the tablet, a virtual agent program running on the computer that shows the virtual agent's upper-body and head on the computer screen, a vibrotactile display, and a controller program.

Each of these components communicates with the others through an Apache ActiveMQ message broker. This is in essence a program that collects messages from one program and sends them to another program in a way that the other program can understand them. For

example, when the program running the virtual agent's upper body tells the agent to apply a touch, a message is sent over the ActiveMQ broker to the tablet computer in order to notify it that the hand should be made visible. Each individual component is discussed in more detail below.

AR virtual hand

The touching virtual agent's hand is made visible on an iPad (4th Generation) that runs a Unity project. The Unity project includes the 3D render of the virtual hand, with a shadow to make it clear when the hand is above the person's arm but not touching it, and when it actually makes contact with the person's arm. In addition, the Unity project tracks two visual markers: one placed next to the person's arm, and one placed on top of it (Figure 13.2). These markers are used as reference points for the movement of the touching virtual agent's virtual hand.

Virtual agent upper body

The touching virtual agent's upper body is actually a virtual agent called Armandia, which is part of the AsapRealizer [512]. The AsapRealizer is a program that can generate, in an incremental and fluent manner, the verbal and non-verbal behavior of a virtual agent. The program uses so-called "Behavior Markup Language" (BML) scripts to define the agent's behavior. Using the AsapRealizer and BML scripts it is, for example, possible to make an agent blink, make eye contact, and move its head in a certain direction while speaking a sentence. The agent's behaviors can be changed in a convincing manner while the agent is performing another behavior. For example, when the agent looks towards the person's arm it can also be commanded to turn its upper body and stretch out its arm in order to apply a touch to the person's arm.

Vibrotactile display

To produce a tactile sensation when the touching virtual agent touches its conversation partner, a wearable vibrotactile display is used. The sleeve in question is constructed from modular elements of the Elitac Science Suit. Each element contains an eccentric mass vibration motor and the control-hardware necessary to drive the motor at four different levels of vibration intensity. Twelve such elements are linked together and attached in a line to the inside of a fleece sleeve using Velcro. The touching virtual agent can produce touches along this one-dimensional vibrotactile array.

Timing controller

Appropriate timing of the agent's movements, the movements of the hand visible on the tablet, and the activation of the vibration motors, is crucial to the illusion that the touching virtual agent actually produces the tactile sensation that is felt through the vibrotactile display. To make sure the timing of each of the components is accurate, a timing controller program is used to send commands to each of the components of the touching virtual agent. The controller is set up so that the timings of each component can be changed depending on the setup. For example, if the tablet is further away from the screen that depicts the agent, the virtual hand should take slightly longer to appear on the tablet as the agent's arm needs to cross a larger distance between the screen and the tablet. The controller program allows for the timing of each component to be adjusted accordingly.

13.1.2 Bug demonstration

A first demonstration of the touching virtual agent that showed all the components working together was one where a person experienced a bug crawling over his or her arm¹ (Figure 13.2). The bug was visible in AR on the tablet and could be felt crawling backwards and forwards over the person's arm through the vibrotactile display. The crawling

¹A video showing the bug demonstration can be seen here: <http://vimeo.com/71094353> (Last accessed 27-09-2016)

Figure 13.2: The bug demo shows the touching virtual agent responding to a bug crawling over a person's arm.

tactile sensation was generated by briefly activating individual adjacent vibration motors with a slight overlap in activation time. This did not produce a completely smooth motion over the arm (see also Chapter 10) but the overall sensation matched quite well with the movements of the bug seen in AR.

After the bug had walked on the person's arm for a little while the touching virtual agent would turn its head and look at the bug. It would exclaim "oh no! A bug! Let me squash it for you", and would promptly move its right arm, as shown on the computer screen, towards the person's arm. The touching virtual agent's hand would then become visible on the tablet above the location where the bug was at that point in time. The touching virtual agent's hand would make a quick 'slapping' motion, which was accompanied by the sound of the bug being squashed, a brief but intense localized vibration, and the agent letting the person know: "got it!".

The bug demonstration was, of course, not meant to be used for any

kind of serious investigation into the capabilities of the touching virtual agent. Nevertheless, this demonstration does show all the qualities of the touching virtual agent. First, a person sees and feels the bug crawling over his or her arm in a way where visual and tactile feedback are incorporated in a congruent fashion. This is an example of the setup being used to simulate a multimodal sensation that is related to discriminative touch (i.e. feeling the bug on the arm). Second, the setup shows the virtual agent communicating with the person through gaze, head movements, and speech. The touching virtual agent acknowledges the person, and refers to an occurrence (i.e. the bug crawling) in the physical space shared by the person and agent (i.e. the space visible on the tablet). Third, the touching virtual agent applies a social touch, albeit a relatively functional one, to the person's arm, and refers to the touch through gaze, head movements, and speech.

All in all the bug demonstration shows the capabilities of the touching virtual agent to communicate with a person through multimodal signals, most importantly, through visuo-tactile touch.

13.1.3 A simulated King Midas?

By now we have become quite well acquainted with King Midas and his ability to turn everything he touches to gold. We are also well aware that in social touch research the Midas touch effect does not refer to haptic metallurgy but to the notion that a simple social touch increases the chances that the recipient of the touch will show pro-social behavior [114]. In previous chapters we have seen several examples of the Midas touch effect in actual social touch interactions (Section 4.3), as well as a 'virtual' Midas touch effect for mediated social touch (Section 7.2). Finally, research into simulated social touch by social robots has shown that there might be a robotic Midas touch effect as well (Section 12.1.2).

It is the robotic Midas touch effect in particular that is of interest here. The robotic Midas touch effect was obtained with simulated social touch by a social robot with a rather basic appearance. Not only that, but the task which participants were asked to do was not a complex one [371, 457]. Based on the idea that an artificial social

agent with a relatively simple physical embodiment and relatively limited interaction capabilities can elicit a Midas touch effect, it might be expected that an augmented Midas touch, a Midas touch applied by the AR touching virtual agent, could result in similar positive effects on pro-social behavior.

With this in mind, the touching virtual agent was used in a pilot study to see to what extent it would be usable in studies into the Midas touch effect.

Compliance pilot study

In studies into the robotic Midas touch effect the social robot in question made a request of the participants, and this request was either accompanied by a touch or not [371, 457]. The request that the robot made was for the participant to repeatedly drag a circle, displayed on a computer screen, onto a square that was displayed on the same computer screen. This setup was based on research into the actual Midas touch effect that showed that, after a touch, participants were more willing to comply to a request to do a repetitive task, such as scoring answer sheets [395], or filling out a lengthy personality questionnaire [373].

The augmented Midas touch pilot study followed the same general procedure as that used in studies that found a positive effect of a simulated social touch by a social robot on pro-social behavior [371, 457]. The aim was to see if participants would be more likely to comply with a request made by the touching virtual agent, depending on whether or not the touching virtual agent accompanied the request by a brief touch on the participant's arm. Specifically, the agent would ask the participant if he or she would be willing to do something for the touching virtual agent. The request was either accompanied by a brief touch to the participant's arm or was made without a touch.

The task in question was the same as used in the studies into the robotic Midas touch effect [371, 457], and involved the participant repeatedly dragging a circle into a square using a computer mouse. The task was displayed on a second computer monitor positioned next to the one that showed the virtual agent. The circle was displayed on

the left side of the screen and the square on the right side. When the participant dragged the circle to the square, the circle would disappear and a new circle would appear on the left side of the screen.

The touching virtual agent would look at the second screen when making the request. The agent explained that the participant could stop the task at any time by clicking the 'stop task' button displayed at the top of the screen that displayed the task. While the participant was doing the task, the virtual agent would give a verbal encouragement every 20 seconds. Depending on the condition, the encouragement was accompanied by a touch or not.

To measure whether the agent's touches had an effect on the participant's pro-social behavior, the number of circles that was dragged into the square was recorded. In addition, the total amount of time that participants spent on the task was recorded. The same measures were used in the studies into the robotic Midas touch effect that used the same repetitive task [371, 457].

Results and conclusions In total, eight people participated in the augmented Midas touch pilot study with four participants in both the touch and non-touch conditions. In spite of the similarities between the setup of the pilot study and the setup of studies that found clear effects for a robotic Midas touch [371, 457], the results differed considerably.

The average number of circles dragged across the screen in the touch condition ($M = 51.50, SD = 95.67$) was actually lower than the average number of circles in the non-touch condition ($M = 203.50, SD = 382.56$). Related to this, the time that participants spent on the task was also lower in the touch condition ($M = 132.25, SD = 194.66$) than in the non-touch condition ($M = 317.00, SD = 556.95$).

The exceptionally high standard deviations show that there were huge individual differences in both the number of circles that participants dragged across the screen, and in the total amount of time that they spent on the task. Indeed, five of the eight participants quit the task after dragging four circles or less, while three of these participants

were in the touch condition. Two other participants in the touch condition dragged 31 and 195 circles, while one participant in the non-touch condition dragged a rather astonishing 777 circles across the screen, spending more than 20 minutes on the task.

After running the pilot study with eight participants, it became clear that the participants' tendency to drag more circles and spend more time doing the task, was in no way related to whether or not the touching virtual agent applied a touch. This idea was confirmed by participants when they were asked about how they performed on the task. Some participants were surprised by the nature of the task, and, after dragging a few circles, clicked the 'stop task' button, expecting that there was more to come. The pilot study seemed to indicate a trait in the participants to comply with how they expected the experiment to go, and in general comply with the request of the researcher to participate, rather than to comply with the actual request made by the touching virtual agent. The task, then, seemed to serve more as a measure of 'trait compliance' of the participant than a measure of an augmented Midas touch effect.

These results are in stark contrast to those obtained for the robotic Midas touch effect [371, 457]. In these studies, participants clearly dragged more circles across the screen and spent a greater amount of time on the task when they were touched by a humanoid robot, than when no touch was applied. How can we account for these differences, bearing in mind that the study reported here is only a pilot study with a few participants?

As in studies into the virtual Midas touch (i.e. mediated social touch), the touching virtual agent setup used vibrotactile feedback to generate a tactile sensation. In contrast, the robotic Midas touch studies used a stroking touch applied by the robot [371, 457]. The difference in sensation produced by these two methods of stimulation might account for the different effects on pro-social behavior. It is plausible that a Midas touch effect is more likely to occur for the types of haptic feedback that are more like an actual human social touch.

In addition, in the robotic Midas touch studies participants could easily attribute the touch that they felt to the robot because they could

see the robot applying the touch. This is similar to the way that you would attribute an actual social touch to the person applying the touch. In the pilot study presented here though, despite efforts to make the simulated social touch by the touching virtual agent as compelling as possible, it could be that participants simply did not attribute the sensation that they felt to the touching virtual agent to the same extent as you would attribute a simulated social touch to a robot. The touching virtual agent's touch might therefore not have been considered a social touch at all, nullifying any effects on pro-social behavior. This issue might also be present in studies into the virtual Midas touch effect because these studies used mediated social touch where participants were only told by the experimenter that another person would touch them at a distance [217]. No feedback regarding the touch, other than the vibrotactile sensation itself, was provided to participants, possibly limiting potential effects on pro-social behavior. In other words, for both mediated social touch and simulated social touch by the touching virtual agent, if you do not have the feeling that a felt touch was applied by another social entity it is unlikely that the felt touch can produce a Midas touch effect.

A final explanation might have to do with the culture in which the studies were conducted. Like studies into the virtual Midas touch [217], the pilot study reported here was conducted with participants from Europe, with a majority of participants from the Netherlands. The studies into the robotic Midas touch effect, on the other hand, were conducted with participants from Japan [371, 457]. An explanation could therefore be that people from Japan are overall more likely to comply to a request than Europeans are. Indeed, Japanese individuals specifically have an interdependent view of the self in which an individual's behavior is organized by what the individual perceives to be the thoughts, feelings, and actions of others in the relationship [339, p.227]. A social touch could serve as an especially strong signal of such interdependence, considering Japan can be described as a low contact culture in which the touches that do occur have strong social significance (see also Section 2.2). This is in contrast to Western views of the self in which the notion of independence from others is character-

istic [339]. Thus, to someone from Japan, a touch might seem to be a clear signal of interdependence that is directly relevant to the self leading to increased pro-social behavior, whereas the same touch to someone with an independent view of the self might not as readily be interpreted as relevant to that person which might reduce chances of this person showing pro-social behavior.

As there have been no studies to date that have investigated the actual or virtual Midas touch effect with participants from Japan, this cultural explanation remains speculative for now. Nevertheless, we might take into account this cultural perspective in suggesting improvements to the design of the pilot study. For one, it might be a good idea to employ a measure that could be used to interpret how likely someone is in the first place to show pro-social behavior, whether or not a social touch is applied. A measure of a person's personality traits, especially the Big Five personality inventory's 'Agreeableness' scale [351], might be useful here. In addition, using a measure of touch avoidance [14, 16] or touch receptivity [43] might provide insights into how strongly a touch is likely to affect a person in a positive or negative way. Most importantly for the design of the task, using a more realistic task that is repetitive yet still has some meaning (e.g. filling out a lengthy personality questionnaire [373]) would minimize the chances that participants quit the task after only a few attempts. Finally, it is advisable to embed such a task in a broader scenario where the participant interacts with the agent for a longer period of time. Having the participant and the agent hold a conversation and discuss the task might help the participant get used to the agent and possibly build rapport between the agent and the participant [44]. This may help make the agent seem more humanlike and consequently make the agent's touch more likely to be interpreted by the participant as a form of social touch.

Despite the fact that the touching virtual agent could use facial expressions, body postures, and speech to communicate with a person, as well as being able to apply simulated social touch through congruent visuo-tactile stimulation, the pilot study did not show the results expected based on earlier studies into simulated social touch. The

touching virtual agent setup and the pilot study did however provide insights into how to improve upon the design of the setup and the design of future studies. In the next section we will be introduced to a study that was inspired by the touching virtual agent setup and pilot study.

13.2 FRIEND OR FOE: SIMULATED SOCIAL TOUCH IN AN AR GAME

The grey sky over the stadium continues to release a slight drizzle, befitting of the events that have just occurred as you walk off of the pitch with your head bowed low. A drop of rain mixes with a tear running down your nose, disguising your sadness while you stare at the tips of your football boots and contemplate the dramatic 0-5 defeat you just suffered in front of your own fans. You try to come to grips with the penalty you missed in the first half, and try against your better judgement to forget about the own goal that sealed your team's fate in the second half, as you slowly make your way towards the dressing rooms. Just before the spikes on your boots touch the first step of the stairs leading down to the catacombs of the stadium, you see someone walking up to you smiling. He congenially puts his arm around your shoulder and takes in your sad expression while he pets your chest, apparently as a show of support, as if to say 'cheer up, there will be other matches', as any good teammate would.

Now imagine this person being the opponent that you just lost to in a spectacular fashion. Rather than make you feel better about the lost match, the exact same touches as described above, but applied by your opponent, would probably make you want to knock a few teeth out of that stupid smile of his. Indeed, as we discussed in Section 4.4 the interpretation of an actual social touch depends strongly on the context in which such a touch takes place. The same touch can have a very different meaning (i.e. the concept of equipotentiality [246]) so whether someone is a teammate or a rival can therefore strongly influence the way you interpret a touch. For the most part we have considered positive effects of social touch but in the right - or wrong, if you will - circumstances social touch can also have negative consequences [131, 164, 334].

The impact of the circumstances in which a social touch takes place was investigated in two studies in which participants were invited into the lab to play a game either against, or together with, a confederate [76]. In a first experiment participants were randomly assigned to a touch or non-touch condition. The participant and the confederate, who acted as another participant, were instructed to complete a maze as quickly as possible (i.e. competitively). After completing the maze, in the touch condition, the confederate would pat the participant's shoulder three times, smile, and wish them luck with the next part of the experiment. In the non-touch condition, the confederate simply did not apply the three patting touches while keeping his or her behavior comparable to that in the touch condition. The final part of the experiment consisted of a task in which the participant had to divide credits between him or herself and the confederate.

The results of this experiment showed that participants in the touch condition donated significantly fewer credits to the confederate [76]. In the somewhat competitive condition of the experiment, a social touch negatively affected a person's tendency to show pro-social behavior. In a sense, the situation in which the touch occurred resulted in a reverse Midas touch effect.

In a second experiment by the same researchers, participants were randomly assigned to either a collaborative or competitive condition that either featured touch or did not feature touch (i.e. there were four conditions in total) [76]. In the collaborative condition the participant worked together with a confederate to solve a puzzle. Solving the puzzle as quickly as possible increased the participant's chances of winning a movie ticket. In the competitive condition, the participant was told he or she would compete with the confederate, and that winning would increase the chances of winning a movie ticket. The confederate would leave the room for a second experiment and would either pat the participant on the shoulder three times, or would not touch the participant. Similar to the first experiment, the participant then had to divide a number of credits between him or herself and the confederate.

The results of this experiment showed that the setting in which a social touch takes place can determine whether such a touch will have a

positive or negative effect on pro-social behavior [76]. In the competitive condition, participants donated fewer credits to the confederate when they were touched compared to when they received no touch. Conversely, participants in the collaborative condition donated more credits to the confederate when they were touched as compared to when they were not touched. The explanation provided by the researchers is that participants perceived the touches from the competitor as a way to assert dominance [76] [see also 334] and that this act of showing dominance made participants less willing to share the credits that were provided.

What is of interest is that related results have been obtained for mediated social touch in a study where participants navigated a maze and were either helped or deceived by an ostensible other participant [63]. In the situation where participants were told they were competing with another participant that might deceive them in the maze navigation task, participants experienced a higher sense of control when they used a force feedback joystick that allowed them to push back against the deceiver's feedback. Put differently, the participant could assert his or her dominance and this affected the way the participant felt about the interaction depending on whether it was collaborative or competitive.

Why are these studies important to our current inquiry into simulated social touch? Well, the research efforts discussed so far regarding simulated social touch by social robots and virtual agents have only considered the benefits of social touch. In fact, the adage seems to be 'the more touch the better!' However, this does not seem to be the case if we consider how a social touch in a competitive setting can negatively impact someone's tendency to show pro-social behavior.

With this in mind we need to consider whether the perception of a touch by a virtual agent is also dependent on the situation in which the touch occurs. A touch applied by a virtual agent in the wrong setting, or at the wrong moment, will probably make one dislike the agent rather than build rapport with it. In certain settings, then, an agent that does not apply a touch might be perceived differently from an agent that does apply a touch. Based on the study discussed above [76], it might be expected that a touching virtual agent is perceived more favorably in

(a) The two virtual agents in augmented reality. The agent on the left can be seen to apply a touch to a person's left arm. (b) A person playing the game with the two virtual agents.

Figure 13.3: Two virtual agents that can apply social touches, are visible on a tablet in augmented reality.

a collaborative settings, while a non-touching virtual agent is perceived more favorably in competitive settings. To figure out if this would be the case, a study was conducted that featured two virtual agents in a collaboratively or competitively framed AR game.

13.2.1 AR game with touching agents

A study was conducted to investigate in what way a simulated social touch by a touching virtual agent could affect a person's perception of this agent depending on the situation in which the touch occurred. In the study, participants looked at a tablet computer running an AR application, and would be able to see two female virtual agents, named Anna and Belle, standing in the room in which the study took place (Figure 13.3(a)). Both agents were female because research on actual social touch shows that both men and women are relatively comfortable with being touched by a woman, whereas men are quite uncomfortable with being touched by another man [131, 248, 534].

Depending on the experimental condition, participants would either play a collaborative game with the virtual agents, or play a competitive game against the virtual agents (Figure 13.3(b)). During the interactions with the virtual agents prior to and after playing the game, participants would be touched by one of the virtual agents. The touches

could be seen to be applied through the tablet computer and could be felt through a vibrotactile display worn on the upper arm that was activated in synchrony with the visual feedback.

It is important to note that this setup differs from the one of the touching virtual agent presented in the previous section. In the study presented here, a participant held a tablet in both hands and could move around the room relatively freely. The tablet would detect visual markers placed on the wall, which determined the position of the two virtual agents in the room. When a participant looked at the tablet he or she would see two fully embodied virtual agents, rather than a part of a virtual agent as was the case in the touching virtual agent setup presented in Section 13.1.

In the AR setup presented here, when an agent touched the participant, the agent's movement would be visible on the tablet, but the actual moment of contact could not be observed because of the angle at which the participant viewed the agents on the tablet (Figure 13.3). The focus of the present study, however, was on casual touches during a more elaborate interaction with the two virtual agents rather than on completely accurate visuo-tactile feedback of the agent's touch such as in the previous touching virtual agent setup. What is more, the setup used in the current study allowed participants to see both of the virtual agents and the game, presented in a way that people are familiar with from AR applications on their smartphones and tablets. The setup thus provided a convenient way to present all relevant information during the study.

The scenario in which participants interacted with the touching virtual agents centered around a simple game implemented in AR. In the game, a three-dimensional grid of coins was shown hovering in the room. The participant could move the tablet around to aim, and could press an on-screen button to 'shoot' at the coins to collect them. To make this simple game a bit more challenging, a block moved in front of the coins blocking the participant's aim.

Depending on the experimental condition that a participant was assigned to, the game would either be framed as a collaborative game or as a competitive game. In the collaborative game, the participant would

play together with the two virtual agents present in the room in order to increase a shared score by shooting as many coins as possible. In the competitive game, the participant would play against the two virtual agents and each player (i.e. the participant and both of the virtual agents) had an individual score that could be increased by shooting the coins.

The instructions about how to play the game made it clear that the game was either played together with (i.e. collaborative condition), or against (i.e. competitive conditions) the two virtual agents. In addition, while the participant was playing the game, both virtual agents would make verbal remarks that matched the condition. For example, in the collaborative condition the virtual agents would exclaim: "Let's work together!; Good job!; We can do it!", whereas in the competitive condition they would let the participant know: "I was quicker than you!; These coins are mine!; Only one of us can win!" The game was designed so that it would be impossible to collect all coins during the game's duration (i.e. 40 seconds). The time was shown counting down at the top of the screen. After the time ran out the participant received feedback about his or her performance compared to the agents' performances. For all participants in both conditions, participants were told that they performed slightly better than both agents.

In essence, the game served as an excuse for the participant to interact with the two virtual agents. Both virtual agents would use gaze, body postures, gestures, and speech to communicate with the participant. During a single experimental session, one of the two agents would also touch the participant, once prior to, and twice after playing the game. In addition, one of the virtual agents would always start the interaction by speaking first. Speaking first could be seen as a form of assertiveness, which could potentially influence the participant's perception of the agent [490]. To control for this in the study, for half of the participants the agent that applied the touch was also the assertive agent, whereas for the other half of the participants the virtual agent that did not touch was the assertive agent (i.e. the one that started all interactions). Thus there would be an equal number of participants that had a touching or non-touching assertive agent.

With this study setup it was expected that the participant would have a more positive opinion of the virtual agent that applied the touch, but only in the collaborative condition. For the competitive condition it was expected that this effect would be significantly weaker or even reversed (i.e. the participant would have a less positive opinion of the touching virtual agent) [see also 76].

Two measures were used to assess the participant's opinion of the agent. First, after the game was completed, both virtual agents would sit down on an actual chair of which there were four in the room. The participant was also asked to sit down next to one of the two agents. If the participant really liked one of the agents more than the other, it might be expected that the participant would sit next to this agent, rather than next to the agent that they liked less. Second, participants completed a questionnaire about both of the virtual agents. The questionnaire consisted of fourteen items, such as honest, friendly, modest [29], and polite [490]. For each virtual agent the participant indicated his or her agreement with statements like "I thought Anna was likable" on a 7-point Likert scale, ranging from "strongly disagree" to "strongly agree".

As we have seen throughout the previous chapters, a person's general attitude towards social touch might influence his or her perception of a person that applies a touch. Therefore, after the study, the participant also completed a questionnaire that measured touch receptivity [43]. The participant indicated his or her agreement with statements such as "I feel uncomfortable when someone casually touches me" on a 7-point Likert scale, ranging from "strongly disagree" to "strongly agree".

So, let us summarize: participants played an AR game either with, or against two virtual agents. One of these virtual agents would apply touches that could be felt by the participant through a vibrotactile display. After playing the game, both virtual agents and the participant would sit down on chairs, and the participant was asked to indicate what he or she thought of each virtual agent. It was hypothesized that the participant would judge the touching virtual agent more positively on a number of personality items, but only in the collaborative con-

dition. Conversely, in the competitive condition it was expected that the non-touching virtual agent would be judged more positively on the same personality items.

Participants

In total 42 people participated in the study. There were 29 male participants and 13 female participants. The average age was 21.5 ($SD = 2.54$). Participants were all students or employees of a university.

Materials

The tablet that was used by participants to interact with the two virtual agents and play the game, was a Google Nexus 10. The tablet ran a Unity 3D application that used Qualcomm's Vuforia plug-in, and visual markers attached to the back wall of the room (see Figure 13.3) to determine the position of both of the virtual agents and the game elements in the room. The Unity Multipurpose Avatar plug-in was used to create the two virtual agents which could be controlled using Unity's Mecanim animation system. The agents' speech was prerecorded using Microsoft Windows 8 Hazel and Zira speech synthesizers. Basic scripts were used for synchronizing the agents' lip movements to speech parameters (i.e. amplitude), and randomized blinking behavior was implemented.

A newer version of the Elitac Science Suit, a previous version of which was used in the touching virtual agent setup discussed in the previous section, was used here. Three pancake-style eccentric mass vibration motors were attached in a triangular position with approximately 10 centimeters spacing between each motor, to a stretchable sleeve using Velcro. The participant wore one of these sleeves on each upper arm. The motors on the upper arm were activated in synchrony with a virtual agent's touch.

An additional six vibration motors (two rows of three, with approximately 10 centimeter spacing between them vertically, and approximately 20 centimeter spacing between them horizontally) were placed on the participant's abdomen using a similar stretchable fabric as the sleeves worn on the upper arm. The vibration motors on the abdomen

were activated when a participant aimed to shoot a coin but missed it. Each of the motors was activated briefly in succession to produce a kind of 'buzzing' sensation. The idea behind implementing this feedback was that it would make the virtual agent's touches stand out less during the interaction.

Procedures

After obtaining written consent, the experimenter explained the study's general procedure. Next, the vibrotactile displays were attached to the participant's body, and the participant received the tablet. Instructions on how to hold and use the tablet were given by the experimenter. The principle of the coin-collecting game was introduced for both conditions. Next, the working of the tactile display was tested in a trial version of the game. All further instructions were given on the tablet.

When the study started both virtual agents would greet the participant, introduce themselves, and ask the participant to read to game's instructions that would appear on the tablet's screen. When the participant indicated that he or she had understood the instructions, the virtual agents would wish the participant luck, and one of the agents would accompany this verbal utterance with a touch.

After completing the game, the touching virtual agents would congratulate the participant on his or her performance and accompany this remark with a touch. Finally, the touching virtual agent suggested that another game should be played at a different time, and again accompanied this remark with a touch. Next, the participant was asked to sit down on one of the four chairs to fill out the agent perception questionnaire, single-item questions regarding the game and the agent's touches during the game, demographics questions, and the touch receptivity questionnaire using the tablet. The touch receptivity questionnaire was given at the end of the session so as not to prime the participant to the agents' touches. After completing all questionnaires the participant was debriefed about the aim of the study. The total duration of the study was about 20 minutes.

Table 13.1: Principal component analysis with oblique rotation for the 14 personality items.

Component	Item	Component loading
Trustworthiness ($\alpha = .835$)	Honest	.812
	Competent	.767
	Informed	.765
	Sincere	.677
	Trustworthy	.667
	Credible	.603
	Interesting	.488
Politeness ($\alpha = .686$)	Polite	.833
	Modest	.792
Warmth ($\alpha = .807$)	Confident	.780
	Approachable	.757
	Warm	.746
	Friendly	.621
	Likeable	.546

Results

To get a workable set of variables that reflected the underlying constructs of the agent personality questionnaire [29, 490] and the touch receptivity questionnaire [43], a dimension reduction technique was used.

Principal component analysis (PCA) with oblique rotation for the 14 adjectives of the virtual agent personality questionnaire revealed a structure with three components that explained 59.54% of the total variance. Table 13.1 shows the components, items, and component loadings. The first component describes the trustworthiness of the agent, which consists of items such as trustworthy and competent. The second component describes the agent's politeness, with the items polite and modest. Finally, the third component, warmth, concerns affective interpersonal aspects of the agent, such as its friendliness and how approachable it is. All factors had relatively high internal

consistency. PCA component scores, which are the summed individual scores of each participant for each item, weighted by the appropriate component loading from the PCA, were calculated for each of the three factors, and were used for all analyses.

The touch receptivity questionnaire was adapted from previous research on touching virtual agents [43]. Two items specific to the medical context of that research were not used (i.e. items 5 and 7 from [43]). For one item the wording was considered confusing for non-native English speakers, and thus the wording was changed (i.e. "I go out of my way to interact with people who casually touch a lot" [43]). The confusing nature of the wording of this item was underlined when, after the study was completed, it turned out the actual meaning of the item was also reversed in the changed version. Nevertheless, the changed item was maintained, as a reliability analysis showed adequate internal consistency for all eight items that were used (Cronbach's $\alpha = .736$). A PCA was used to obtain a single component score for touch receptivity, and that score was used for all participants in the analyses.

As measures of effect size generalized Eta squared (η_G^2) and partial Eta squared (η_p^2) are reported for all F -tests, and Hedges' g_s is reported as a measure of the effect size for all t -tests [304].

Game experience and agent's touch Participants enjoyed playing the game more in the collaborative condition ($M = 5.65$, $SD = .81$) than they did in the competitive condition ($M = 5.05$, $SD = 1.00$). This difference was statistically significant ($t(40) = 2.138$, $p = .039$, $g_s = .648$). Participants thought the game was more challenging in the collaborative condition ($M = 4.25$, $SD = 1.55$) than in the competitive condition ($M = 3.95$, $SD = 1.53$), and indicated that they felt that they performed better in the competitive condition ($M = 4.41$, $SD = 1.84$) compared to the collaborative condition ($M = 4.00$, $SD = 1.45$). Neither of these differences were statistically significant, however, (both p 's $> .05$).

In addition to questions about the game, participants also answered a number of questions about the touches by the touching virtual agent. Participants rated the touches as more pleasant in the collaborative condition ($M = 4.47$, $SD = 1.23$) than in the competitive condition ($M =$

4.05, $SD = 1.23$). In addition, participants rated the touches in the collaborative condition ($M = 5.18$, $SD = 1.29$) as better timed with the touching virtual agent's vocal expressions, than in the competitive condition ($M = 4.55$, $SD = 1.40$). Finally, there was only a small mean difference between the ratings for the question whether participants experienced the touching virtual agent as the source of the felt touch sensation in the collaborative ($M = 4.12$, $SD = 1.42$) and competitive condition ($M = 4.35$, $SD = 1.69$). Despite these mean differences, none were statistically significant (all p 's $> .05$). Overall, participants rated the touching virtual agent's touches as moderately pleasant, well timed, and as originating from the agent.

Finally, participants indicated to what extent they felt that the touching and non-touching virtual agents were present in the same room (i.e. a combination of physical and social presence also called co-presence [258]). To investigate whether there would be differences in perceived presence between the touching and non-touching agents depending on the condition, first, a mixed model ANOVA (Analysis of Variance) was conducted with *touch* as the within-subjects variable (i.e. touching and non-touching virtual agent) and *condition* as the between-subjects variable (i.e. collaborative and competitive). Next, a mixed model ANCOVA (Analysis of Covariance) was conducted with *touch* as the within-subjects variable, *condition* as the between-subjects variable, and *touch receptivity* as the covariate. Including the covariate in the analysis can suppress the main effect of the repeated measure. Therefore, main effects of the between-subject variable *touch* are reported for the ANOVA while main effects of the within-subject variable *condition* are reported for the ANCOVA (see also [19] for an example of this and see [20, 191, 505] for a more detailed discussion on the complexities of mixed model ANCOVA's).

The analysis revealed a main effect for touch ($F(1, 40) = 9.363$, $p = .004$, $\eta_G^2 = .034$, $\eta_p^2 = .190$) The touching virtual agent ($M = 4.11$, $SD = 1.61$) was rated significantly higher on presence than the non-touching virtual agent ($M = 3.55$, $SD = 1.47$). There were no other main or interaction effects.

(a) Mean component scores for ratings of the agent's trustworthiness for the collaborative and competitive condition. (b) Mean component scores for ratings of the agent's politeness for the collaborative and competitive condition.

Figure 13.4: Component scores for trustworthiness and politeness for both conditions.

Sitting down next to the agents During the study, four chairs were present in the experiment room. After the game was completed the agents would sit down on two of the four chairs that were farthest away from the participant. Participants were asked to sit down too in order to fill out the questionnaires, and it was recorded whether they sat down next to the touching agent or the non-touching agent.

First, it is interesting to note that only two out of the 42 participants sat down on a chair that could be observed through the tablet computer to be occupied by a virtual agent. It could be that participants really did perceive the chairs to be occupied, although, of course, it is also quite possible that participants simply sat down on one of the two chairs closest to them.

In the collaborative condition exactly half (10 out of 20) of the participants sat next to the touching agent. In the competitive condition, 9 participants sat next to the touching virtual agent, while the remaining 13 participants chose to sit down next to the non-touching agent. However, the difference between participants' tendency to sit next to a touching agent in the collaborative and competitive condition was not statistically significant ($\chi^2(1) = .349$, $p = .554$, Cramer's $V = .091$).

Figure 13.5: Mean component scores for ratings of the agent’s warmth for the collaborative and competitive condition.

Perception of agents' personalities Separate analyses were performed for each of the dependent variables related to the agent’s personalities, that is trustworthiness, politeness, and warmth,. The procedure was identical to that followed for the analyses of the presence measure. First, mixed model ANOVAs were conducted with *touch* as the within-subjects variable (i.e. touching and non-touching virtual agent), and *condition* as the between-subjects variable (i.e. collaborative and competitive). Main effects of the within-subjects variable are reported for this analysis. Next, mixed model ANCOVAs were conducted with *touch* as the within-subjects variable, *condition* as the between-subjects variable, and *touch receptivity* as the covariate. Main effects of the between-subjects variable are reported from this analysis.

For trustworthiness, no significant main or interaction effects were found (all *p*’s > .05). Yet when we look at Figure 13.4(a), we can see that overall the agents were judged higher on trustworthiness in the com-

petitive condition than in the collaborative condition. It is also noteworthy that the touching virtual agent was rated as more trustworthy than the non-touching virtual agent in the competitive condition especially. Bear in mind though that these differences were not statistically significant.

For politeness there were no significant main or interaction effects (all p 's $> .05$). From Figure 13.4(b) it can be observed that both agents in the collaborative condition were rated as more polite than in the competitive condition. In both conditions, the touching virtual agent was rated as more polite than the non-touching virtual agent. Again, these differences were not statistically significant.

For warmth, a significant main effect of *touch* ($F(1, 40) = 21.81, p < .001, \eta_G^2 = .150, \eta_p^2 = .353$), and a significant effect of *touch receptivity* ($F(1, 39) = 6.78, p = .013, \eta_p^2 = .148$) were found. No main effect of condition was found. From Figure 13.5 we can observe that the touching virtual agent was rated higher on warmth than the non-touching virtual agent in both conditions. The size of the difference between the ratings for the touching virtual agent and the non-touching virtual agent was dependent on the level of touch receptivity (adjusted $R^2 = .124$). The difference between ratings for the touching and non-touching agent increased with increases in touch receptivity (standardized $B = .381$), which indicates that participants that scored higher on touch receptivity rated the touching agent higher on warmth than the non-touching agent. For participants lower in touch receptivity this difference was less pronounced.

Conclusions and discussion

Being touched by another person can positively affect how you feel about that person and can make you more inclined to act in a pro-social manner towards the toucher (i.e. the Midas touch effect described in Section 4.4). However, such positive effects of social touch might be reduced or even reversed when the touches are applied in a competitive setting [76]. Think again of the example of the lost football match described at the beginning of this section, and the opponent coming over to touch you; such a touch is likely to be met with

adversity. Research into social touch has shown that touches in a collaborative setting engender pro-social behavior, while touches applied in a competitive setting by a competitor can have negative effects on pro-social behavior [76].

The notion that social touch might affect the recipient of the touch differently depending on the setting in which the touch takes place was the starting point of the present study in which simulated social touch by virtual agents in AR was investigated in both a collaborative and competitive setting. It was hypothesized that participants would judge a touching virtual agent more positively on a number of personality items, compared to a non-touching agent, but only when the agent applied the touches in a collaborative setting. Conversely, it was expected that in a competitive setting the non-touching virtual agent would be regarded more positively by participants than the touching virtual agent.

Results from the study showed that the condition in which the simulated social touch took place did not influence participant's judgement of the virtual agent's. The condition (i.e. collaborative or competitive) only had an effect on the extent to which participant enjoyed the game, as it was found that participants enjoyed the game more in the collaborative condition. For all of the other dependent measures, most importantly the perceived trustworthiness, politeness, and warmth of the touching and non-touching virtual agents, the condition in which the touches were applied had no effect.

Nevertheless, the results did show differences in judgements for the touching virtual agent compared to the non-touching virtual agent. First, the virtual agent that applied a simulated social touch was rated by participants as being more clearly present in the same room as the participant, compared to the virtual agent that did not apply a touch. This effect of simulated social touch on presence is interesting as it suggest that touch by a virtual agent could be used to create more compelling interactions between people and virtual agents that are present in the same virtual (in VR) or physical (in AR) space [see also 29]. The notion that 'touch makes real' [101, 178, 280, 433] also seems to apply here to some extent to virtual agents. Be mindful though, that in

the current study presence was only measured as a single-item measure. Additional research will have to provide evidence for the extent to which touch by a touching virtual agent can enhance feelings of social presence, in a more robust fashion.

Second, the touching virtual agent's personality was judged by participants as warmer than the personality of the non-touching virtual agent. Note, though, that this effect was not strong enough to make participants sit next to the touching agent more than next to the non-touching agent. Nevertheless, this finding suggests that touch, like specific facial and vocal expressions [200], can be perceived as a social cue that says something about the personality of the virtual agent 'sending' the signal, in this case, the agent applying the touch. The fact that in the current study simulated social touch had an effect on perceived warmth and not on perceived trustworthiness, or politeness, is perhaps not surprising given that actual social touch is often related to feelings of intimacy [21], which could be seen as a form of interpersonal warmth. Moreover, this finding matches with findings from studies into the ways that actual social touch can affect perceptions of the toucher. Several studies have found that social touch can positively influence a person's attitude towards the toucher, in particular, how much they like the toucher [71, 146, 163]. Note, that likability is part of the construct of warmth in the present study.

The findings from the present study thus suggest that, as for actual social touch by an actual person, simulated social touch by a virtual agent positively affects a person's perception of that virtual agent's personality. This effect, however, was not the same for everyone. Some people are more comfortable with social touch than others, a concept referred to as touch avoidance [14, 16, 210, 211] or touch receptivity [43]. In the current study, participants' judgements of the touching and non-touching virtual agents were found to be related to participants' trait touch receptivity. In particular, participants who scored higher on touch receptivity, and who were thus more comfortable with social touch in general, rated the touching virtual agent relative to the non-touching virtual agent, higher on warmth than those participants who scored lower on touch receptivity. That is, participants who were

more comfortable with social touch in general, rated the touching virtual agent as warmer than the non-touching virtual agent to a greater extent than participants who were less comfortable with social touch in general.

This finding is all the more interesting in the sense that it provides credence to the notion that participants did indeed perceive the touches by the virtual agent, implemented in the present study as an arm movement by the agent with synchronized vibrotactile feedback, as social touch. Had participants not perceived the agent's actions as social touch, to at least some extent, it is unlikely that participants' trait touch receptivity would have had any effect on ratings for warmth for the touching virtual agent. The fact that no such effect was found for trustworthiness and politeness might indicate that these constructs are less well communicated through touch [see also 148].

To summarize, the present study did not find support for the notion that simulated social touch is perceived differently in a collaborative or competitive context. However, it was found that a touching virtual agent was rated higher on the personality attribute *warmth*, than a non-touching virtual agent, and that this rating was dependent on participants' trait touch receptivity.

The present study is the first to find such effects of simulated social touch by a virtual agent. On the one hand this means that simulated social touch can be a potentially useful way to make a virtual agent seem to have a warmer personality. This could be especially useful in situations where it is important that a virtual agent has the capability to communicate interpersonal warmth, for example, to provide emotional support during a therapy or counseling session [e.g. 43]. On the other hand, the fact that this study is the first to find such a result also means that we should take care in interpreting this result as follow-up studies will need to provide further evidence for its robustness. Some suggestions for these follow-up studies can be provided.

With future studies in mind, let us first consider why the setting in which the touches took place did not have an effect in the present study, when previous research into actual social touch showed that the setting can indeed influence the perception of a touch and per-

son applying the touch [76]. One explanation for why the condition to which a participant was assigned (i.e. collaborative or competitive) did not influence the participant's judgements of the virtual agents is that the manipulation of competitiveness in the present study was not strong enough. We could take the fact that participants enjoyed the competitive game less than the collaborative game as evidence that indeed the implementation of competitiveness was less than optimal. We should also consider some important differences in the implementation of competitiveness in the present study and in that of previous research on actual social touch [76].

First, in the present study participants were made aware, through the score being visible on the screen, that they had actually won the game in the competitive condition. Maybe participants felt rather good about their performance in the game, reducing any negative effect of touch in the competitive condition.

Second, winning or losing the competitive game against the virtual agents did not have any real consequences. In previous research on actual social touch participants were led to believe that in order to win a movie ticket they would have to beat their opponent at the experimental task [76, p. 242]. This made the game more high-stakes and likely enhanced feelings of competitiveness in the participant.

A suggestion for future research into simulated social touch by virtual agents in a game scenario, would be to make the game more high-stakes. One way to do this would be to tie the participant's performance in the game to their chances of winning a prize, such as a movie ticket. A follow-up study might contain three conditions, one collaborative and two competitive, where in one competitive condition participants are told that they won the game against the touching virtual agent, while in the other competitive condition participants are told they lost the game. This way, it could be investigated how simulated social touch affects perceptions of the agent in a high-stakes game that is either won or lost by the participant. We might expect that, especially in the condition where the participant loses to the virtual agent, the effects of simulated social touch on the participant's perception of the agent will be negative.

Another explanation of why there was no difference between the conditions in the present study has not so much to do with the game but with the fact that the interaction involved virtual agents rather than real people. Previous research suggests that the negative effects of actual social touch in a competitive setting have to do with perceptions of dominance [76]. It was suggested that participants perceived the confederate as someone who was trying to exert dominance in order to manipulate the participant into sharing more credits. There are two reasons why this explanation does not hold for the current study.

First, the dominance explanation is related to the measurement that was used, namely, the participant dividing credits between him or herself and the opponent [76]. Such a measurement is not possible with virtual agents because it is highly unlikely that the participant will share any credits with the virtual agent, given that the agent, being a virtual character, has no need for such rewards as movie tickets. In other words, the participant would not consider it rude, or socially unwanted behavior to keep all of the credits. A more elaborate game scenario involving the participant and the virtual agent playing together for a longer period of time where they share in-game resources relevant to their survival in the virtual world might be an interesting direction for future research.

Second, it might be more difficult in general to perceive dominant or manipulative behavior in a virtual agent [e.g. 62], compared to in an actual person. This might have been especially the case for the virtual agents in the present study whose behavior was entirely scripted. If actual social touch in a competitive setting is indeed perceived as dominant, and if such expressions of dominance are difficult to communicate through simulated social touch by the virtual agents, as well as in the type of competitive condition used in the present study, it is likely that participants did not interpret the touching virtual agent's touches in the competitive condition as an expression of dominance. Thus, these touches did not have a negative effect on the way participants judged the touching agent.

Finally, we might also consider an alternate explanation for why participants rated the touching virtual agent higher on warmth than

the non-touching virtual agent. As this finding from the study was obtained through a within-subjects measure (i.e. each participant rated both the touching and the non-touching virtual agent), it is possible that participants guessed the aim of the study and adjusted their ratings accordingly in order to please the researcher. This explanation, however, would involve a rather elaborate rating strategy by participants in which first, the participant conjectures that the agent's actions are indeed a form of social touch, and that such a social touch is more strongly related to personality attributes of the agent that have to do with a warm personality; participants did not simply rate the touching virtual agent higher on all attributes. While it is unlikely that participants did indeed use such an elaborate rating strategy, it cannot be ruled out completely with the experiment design that was used in the current study. A between-subjects design, in which in one condition there is a virtual agent that touches, while in the other condition there is a virtual agent that does not touch, could shed further light on this issue.

Despite the fact that there is room for improvement, the study presented here does bring together all of the elements related to simulated social touch that we have been introduced to in the previous chapters. The study showed that social touch, even when it is applied by a virtual character, can affect a person's perception of the toucher. This was done using wearable actuators, like the ones found in the TaSST, that were activated in synchrony with congruent visual feedback of the touch in order to create a more compelling simulated social touch. All of this was presented in plausible contexts in which social touch can take place. From this we can conclude that the use of AR or VR technology might indeed be highly useful for the study of social touch technology, as well as social touch in general.

13.3 SIMULATED SOCIAL TOUCH IN THE NEAR FUTURE

In the previous chapters we have been made to doubt the reality of our own existence, and have been introduced to the existence, at least in the minds of science fiction writers and moviemakers, of sophisticated artificial worlds and the artificial social entities that inhabit these

worlds. For the sake of everyone's sanity, let us conclude this chapter by considering the wider implications of the two previously discussed touching virtual agent setups and the accompanying studies for simulated social touch in the here and now - and perhaps the not *too* distant future.

Both touching virtual agent setups that were presented in this chapter were based on the idea of combining congruent visual and tactile feedback to create the illusion of social touch from a virtual agent in AR. The approach taken for both setups differs, however. The first touching virtual agent setup (Section 13.1) featured a computer screen on which a virtual agent's head and shoulders were visible and which was used to show the virtual agent's head movements, gaze, speech, and facial expressions. A tablet running an AR application was used to show the virtual agent's hand touching a person's arm, which was positioned under the tablet. Vibrotactile actuators worn on the forearm by the recipient of the touch were activated in synchrony with the visual feedback of the touch.

For scenarios that are focussed on the quality of the simulated social touch itself, such a stationary setup might be particularly beneficial. One example would be a study in which repeated congruent visuohaptic simulated social touch by a virtual agent (e.g. stroking touches, maybe rendered using air jet stimulation [463, 496]), would be applied to a participant's arm. It would be interesting to see if such stimulation would lead a participant to experience the agent's touches as more physically present, almost like a 'virtual rubber hand illusion' [see also 257]. Variations on this scenario could involve different types of haptic feedback, different types of touch, and changing the appearance of the touching virtual agent and the appearance of the agent's hand (e.g. old or young, healthy or ill, realistic or abstract). A host of interesting research could be conducted into which elements make for the most compelling simulated social touch experience. Not only that but this setup could possibly also be used for therapeutic applications, for example, for treating hypertactility [53], issues related to one's body image (e.g. anorexia nervosa [82] [see also 492]), and phantom limb pain [85] [see also 388].

For this to be possible, the physical space shared by the person interacting with the virtual agent and the virtual agent itself (i.e. the tablet computer) might have to be expanded. One possibility would be to cover the area of a desk where the person's hands would be located with a horizontally oriented opaque screen, with a wide-angle camera attached to the bottom of the screen. A projector could then project the image of the camera onto the opaque screen, thereby expanding the visible AR area [see also 378, 379]. Adding a mannequin arm, equipped with sensors similar to those found in the TaSST, might make for interesting bi-directional touch interactions in AR space (see also Section 12.2).

The touching virtual agent setup presented in Section 13.2.1 differs from the one described above in that a person holds a tablet in their hands and can walk around freely to see virtual agents in AR space. This setup is not necessarily stationary and might be less suitable for scenarios, such as the ones described above, that focus on the touch itself. As we have seen in the 'Friend or Foe' study, a mobile AR setup in which virtual agents are present that, through wearable actuators, can touch a participant, might be particularly useful in studies where the simulated social touches are more casual and occur in a specific context. Think, for example, of a Midas touch study where a virtual agent casually touches the participant to see if it can elicit pro-social behavior. Using AR, it might even be possible to have a scenario in which both actual humans and virtual humans are present that can touch the participant in order to be able to make a direct comparison between actual and simulated social touch in the same scenario. The use of a head-mounted display, such as Microsoft's HoloLens rather than a handheld tablet, might make for even more compelling simulated social touch interactions.

Enough possibilities, then, to expand the two AR touching virtual agent setups described in this chapter. We can not only use expanded versions of these two setups for interesting follow-up research, but we can also use them as examples to consider the boundaries of simulated social touch. For example, what if the touching virtual agents are not controlled by a computer program but by another person? This would

make the agent, from the perspective of the person controlling it, an avatar; a virtual representation of that person. From the perspective of the other person in AR or VR space interacting with this 'avatar', however, the interpretation of the agency of this virtual agent depends on what this person believes about the agent, perhaps based on what he or she was told by the experimenter, when taking part in a study. If someone told this person that the touching virtual agent is controlled by another, remotely located person, then we are looking at a situation in which the avatar's touches are a form of mediated social touch [e.g. 58]. If someone told the person interacting with the touching virtual agent that the agent's behavior is computer generated, as in the two studies discussed in this chapter, we are dealing with simulated social touch. However, situations in between these two are also possible. What if someone told this person that the touching virtual agent could either be controlled by another person, or, by a computer program? Here, we would have a situation in which we could conduct a 'tactual Turing-test', in which we could investigate whether certain social touch behaviors by the touching virtual agent make it seem more or less humanlike. The task of the recipient of the touches would be to judge, based on the touch behavior, whether or not the touching virtual agent was an actual person or a computer program. This might be very helpful for evaluating simulated social touch behavior on believability while controlling for other behaviors such as facial expressions.

Based on such tactual Turing-test research, we could end up with a set of computer-generated simulated social touch behaviors that would make a virtual agent seem more humanlike. Such evaluated behaviors could then be implemented in computer-controlled touching virtual agents. Nevertheless, we could also conceive of a hybrid approach where the virtual agent is indeed an avatar of another person but of a person that has only partial or indirect control over the avatar. This is often the case in video games where a player simply pushes a control stick forward to make the on-screen avatar walk forward without the player actually having to control each limb individually², let alone con-

²To anyone who wonders what such a game would be like, I can highly recommend the game QWOP: <https://www.foddy.net/Athletics.html> (Last accessed 30-10-2016).

trol gaze, and facial expressions. Here, the computer decides when to move the avatar's limbs based on simple input from the player. It is also possible, however, to have the computer decide, based on certain parameters, to automatically execute certain behaviors. When such parameters are related to social situations, and social signals, a player's avatar could, for example, be made to smile when encountering another player in a social online game. In a similar fashion, we could also think of a situation where the computer decides that the avatar should not just smile at the other player but also shake the other player's hand (felt by the user as feedback through the game controller, for example). With this we would have a hybrid approach where the avatar would mediate certain actions by the person (e.g. general movement) while other actions were computer generated (e.g. shaking hands). It would be very interesting indeed to see such an approach implemented in a social video game and to see how such hybrid mediated/simulated social touch would be experienced by the recipients.

These rather novel directions for simulated social touch all build on the notion put forward in Chapter 12, that simulated social touches ideally involve congruent multimodal feedback related to the artificial social entity's embodiment. What if we ignore this notion for a second and think of situations where an artificial social entity does not have a body but still might want to apply or receive a simulated social touch? Spike Jonze's movie *Her* (2013) provides an interesting case for such a form of simulated social touch.

The desire to touch becomes all too clear in this movie in which a professional romantic letter-writer - apparently such a job will exist in the near future - Theodore, becomes romantically involved with his purely voice-based operating system, named Samantha. While a healthy dose of imagination combined with Samantha's extremely life-like voice and humanlike intelligence make for a compelling social experience even when intimate social touch interactions are imagined and verbalized, the desire to touch through an actual body runs as a theme throughout the entire movie. An interesting question is: would the relationship between Theodore and Samantha have been better if Samantha had had, not a visual body like the virtual agents described

in this chapter per se, but the capability of applying haptic feedback to Theodore's body? Would this combination of voice and touch be enough to create a compelling experience of simulated social touch?

While *Her* is still in the realm of science fiction, current technological developments include virtual agents that primarily consist of a voice and the ability to understand natural human speech. Examples of such agents, like Samantha, often carry female names such as Siri, Alexa, and Cortana, stressing their human qualities. Exactly how simulated social touch could be embedded in such voice assistant systems remains an open question. But we can, nonetheless, imagine a situation in which these systems could become more context aware and more proactive, and could prompt a person to pay attention to certain information, like the presence of a landmark while walking through a city. Such a prompt could occur through both a vocal utterance ("Hey, I think you'll find this interesting"), as well as haptic feedback, for example, a 'tap' delivered through a smartwatch, like the type of haptic feedback implemented in the Apple Watch.

It is likely that the human likeness of the voices of these agents, as well as their ability to understand natural language, and thus the extent to which they seem humanlike, impacts the interpretation of haptic feedback applied by these voice assistant systems. In the case of Samantha, the voice-based interactions are so realistic that any touch applied by her through haptic technology, would probably come close to what has been described here as mediated social touch. In other words, as becomes clear from *Her*, the distinction between a simulated voice-based virtual agent and remote communication with an actual person can be blurred, and with it, the lines between simulated and mediated social touch.

For virtual agents, those with and those without a body, the decision to allow them to touch a person, and the decision to allow a person to touch them, rests with the designer of the agent. This is quite different from social robots which by definition have a physical embodiment, and a physical embodiment inevitably affords touch. For a social robot, then, considering its embodiment in light of simulated social touch is not a question of 'if' but a question of 'how'. It has already been ar-

gued in Section 12.1 that for a social robot's touch to be experienced as simulated social touch, the social robot needs to have humanlike, rather than animal-like, qualities. This distinction is, however, not black-and-white as there are robots that have a rather animal-like appearance (e.g. a trunk, green fur) but can still show humanlike behaviors (e.g. talking, facial expressions) [e.g. 437]. An interesting research question, then, is which aspects of the design of a social robot make it more or less suited for simulated social touch. It could be argued that social robots with more animal-like qualities afford touch more easily but to what extent such touch interactions are comparable to actual social touch between people remains to be investigated.

With what we have learned about simulated social touch by virtual agents in AR in this chapter, we could ask ourselves to what extent research on touching virtual agents can provide insights into simulated social touch by social robots. To answer this question we first need to be aware of some key differences between the touching virtual agents that have been discussed in this chapter and social robots in general. First, the touches applied by the virtual agents were all generated using vibrotactile feedback while a simulated social touch by a social robot is likely to involve physical contact applied through the robot's arm, the sensation of which is markedly different from vibrotactile feedback, and which may influence the way a person experiences such a touch (see the discussion of the augmented and robotic Midas touch effect in Section 12.1.2). Second, given the state of current technology, the agent's facial expressions, body movements, and general movement is likely to be much more humanlike than that of even the best social robot. Think for example of the 'Friend or Foe' study in which both virtual agents sat down on a chair; such an action would be extremely complex for a social robot to execute.

As the sensory quality of haptic stimulation in AR and VR improves, and as social robots become capable of showing more sophisticated facial expressions and body movements, it is likely that findings from simulated social touch research will carry over more easily between virtual agents and social robots. Though it is likely that observations such as the one from the 'Friend or Foe' study, showing that simulated so-

cial touch can make a virtual agent seem to have a warmer personality, also apply to simulated social touch by social robots [111, 249, 381], for now at least, we need to be mindful of the fact that there are still clear differences between virtual agents and social robots [e.g. 308].

Perhaps, simulated social touch is not a question of *either* social robots *or* virtual agents, though. It is possible to combine AR with a social robot to provide the best of both worlds [358], such as having detailed animated facial expressions visible in AR, and a physical body that directly affords touch [see also 297]. Such an artificial social entity would be able to share the same physical space as an actual person, could show subtle facial expression, and indeed, apply and receive social touches. *Star Trek's* The Doctor might not be science fiction for long.

PART V

CONCLUSIONS AND DISCUSSION

CHAPTER FOURTEEN

WHEN I GET THAT FEELING: ETHICS OF SOCIAL TOUCH TECHNOLOGY

Until now, the elephant in the room has only been regarded with sidelong glances. Yet when we think about social touch it is perhaps the first thing that springs to mind, and it is something that is often accompanied by a slight blush and a furtive giggle. Perhaps even more so than the topic of love (see Chapter 7), it is a favorite topic of many a writer and singer, not least among whom Marvin Gaye. The name of the elephant in the room, is sex.

Why, when the topic of sex has thus far only received cursory attention, devote space to it right before the end? The reason is that the ethics of social touch, and by extension the ethics of social touch technology, are ultimately about the appropriateness or inappropriateness of touch. Where inappropriateness can relate to a social or cultural faux pas (is it two or three kisses; do we shake hands or bow?), inappropriate touch is inextricably intertwined with sexual touch. Consensual sexual touch is undeniably a very important form of social touch in adult romantic relationships [246, 272], yet sexual touch is also a topic that requires careful consideration of the ethical issues surrounding such uses of touch. For one, there is concern that the use of social touch in certain settings, such as the workplace, as well as in education, and psychotherapy [12, 252], brings with it the risk of sexual intimidation or abuse [112, 412]. This is exemplified in legislation that largely prevents touch occurring between a teacher and a pupil,

a development that some argue is detrimental to the development of children [159, 337].

A complete discussion of the functions of sexual touch, for example, what can be gleaned from the organization of erogenous zones in both men and women [499], let alone a discussion of the causes and consequences of inappropriate uses of touch, is beyond the scope of this chapter (see [112, 412] for reviews). Nonetheless, with changing sexual norms and the role that technology plays in such changes [180, 442], it is important to consider, here, the impact that social touch technology could have on sex and sexual behavior, and the ethical questions that might surround the introduction of social touch technology into society in general.

Perhaps even more so than for actual social touch, for which people can readily come up with examples such as shaking hands and hugging, the mention of the combination of social touch and technology seems almost inevitably to conjure up images in people's minds of all kinds of exotic sex toys. Woody Allen's 'orgasmatron' from the movie *Sleeper* (1973) gives you some kind of idea. The intrinsic connection that people seem to make between social touch technology and sex is perhaps not surprising given the fact that some of the earliest examples of technology for mediated social touch were aimed at sexual touch. While the Telephonic arm wrestling installation [530] was the first *working* device for mediated social touch (see Section 6.3), in 1973, How Wachspress¹ presented a prototype of a device which he called the 'Auditac Sonic Stimulator', or as described on the leaflet: "Beethoven between the legs" [404, p. 36]. The device in question featured a hose like that of a vacuum cleaner, connected to a fire-engine-red, square amplifier. The other end of the hose was connected to a hand-held device that looked somewhat like an ultrasound machine and that made it possible for the sounds produced by the amplifier, possibly including Beethoven, to be felt as vibrations on the body. Wachspress himself describes to conception of this device:

¹Have a look at his decidedly 'retro' website for more background on his inventions: <http://www.auditac.com> (Last accessed 14-11-2016).

"It was a wild time, people were trying anything. I got into all the senses. I was inventing atomizers - I still have a scent library. And it was at that time that I got the original acid flash of multimedia. The idea of two-way tactile communication over a distance. Carrying it to its most outrageous extension, a fuck-by-phone machine" [404, p. 36].

Wachspress was reluctant to focus too much on the sexual applications of his invention - he called it a 'tactile communication device' - and proposed interaction possibilities such as shaking hands with the people at home when you have just landed on the moon (it was still very much the space age), as well as a form of tactile television.

Inadvertently or not, Wachspress was the first to conceive of a device that would now be recognized under the term 'teledildonics'. The term itself is attributed to the media-artist Stelarc [see also 178], but it was likely derived from an earlier description of Wachspress' invention as "psycho-acoustic dildonics" [376, p.dm9]. Etymological questions aside, if we paraphrase Wachspress, teledildonics concerns the use of haptic technology for engaging in sexual acts at a distance, usually through the Internet. While this type of technology has received some attention from the academic community [e.g. 31, 312, 324, 330], it has been of most profound interest to the 'adult entertainment' industry, for obvious reasons. There are now countless examples of devices on the market that promise to deliver a mediated sexual experience that approximates the sensory qualities of 'the real deal' [see also 324]. To give a specific example, *Kiiroo*² features a set of sex toys, one for men and one for women, that are connected to each other through the Internet. Stroking motions on the female sex toy, which looks like a vibrator, are detected through embedded capacitive touch sensors, and are translated to up-and-down motions of a ring in the male sex toy, which is placed over the erect penis.

One objection that could be raised against the use of such teledildonics technology is that it degrades the intimate act of sexual intercourse to a 'cheap' thrill, and is largely devoid of any of the courtship

²See <https://www.kiiroo.com> (Last accessed 15-11-2016).

behavior that might precede sexual intercourse in a romantic relationship. Additionally, it is not unthinkable that the use of teledildonics technology outside romantic relationships, especially when connected to pornography (e.g. a performer manipulating the female sex toy), can have negative effects comparable to those of other cybersex activities, such as stimulating addictive behaviors, and promoting objectification of women [108, 132, 450]. Moreover, it is quite possible that engaging in a sexual act through teledildonics technology with another person, professional performer or not, could be viewed by a spouse as cheating [330, 545]. Easy access to sexual interactions through teledildonics could thus potentially make cheating more easy, with obvious negative consequences for romantic relationships [545]. Additional issues that can be raised relate to the fact that it is not necessarily clear with whom you would be engaged in a sexual act through teledildonics, so legality, age representation, and consent are relevant concerns [132, 330].

The negative aspects of cybersex have been relatively well-researched [108, 132, 450] - though note that few research efforts have focussed on potential positive effect [132] - but such research is currently lacking for teledildonics technology. For the time being, we might keep a more open-minded perspective, and consider the potential beneficial uses of teledildonics technology as well.

It is undeniable that sexual intercourse plays an important role in romantic relationships [170, 357]. Yet, increasing mobility, changing work requirements, such as traveling and working abroad, and an increasing number of people focussing on their career, offer new challenges to those in a romantic relationship, especially those in a long-distance relationship [470]. Teledildonics technology could be used by those in a long-distance relationship to have the possibility of some form of physical intimacy, while being physically separated from each other. Teledildonics might not be a replacement for actual physical intimacy in this scenario, but it might at least offer those in a long-distance relationship an additional aid for maintaining such a relationship under less than ideal circumstances. In relation to this, and with regard to cheating behavior using teledildonics technology, we could also wonder the opposite: could teledildonics help reduce cheating due

to easier access to one's sexual partner despite a physical distance separating both partners? Although, if a device is the only thing that is preventing a person from cheating, relationship issues probably run deeper.

Another potentially beneficial use of teledildonics could be for people who have restricted access to sexual partners, due to mental or physical disabilities [125]. While it should be remarked that it is, again, no substitute for an actual romantic relationship, teledildonics technology might offer a more easily accessible form of sexual relief for people with disabilities.

The exact impact, positive or negative, of teledildonics technology on views of sexuality, romantic relationships, and addictive behaviors, among other things, remains an area of future study. Nevertheless, there are certain inherent risks to the use of teledildonics technology, irrespective of potential effects. As for any form of Internet-based communication, including social touch technology of a non-sexual nature, as discussed in the previous chapters, privacy is a concern. The amount of data that social media platforms such as Facebook gather is astounding, and with the collection of such an amount of often highly personal data, it is inescapable that questions surrounding privacy should arise [546]. Considering that social touch technology could operate over the Internet, perhaps even connected to one or more social media platforms, similar privacy risks as those that are relevant to the use of Facebook, are relevant to social touch technology. This makes one wonder what it would feel like if data regarding the use of social touch technology, for example used to communicate one-on-one with a romantic partner, let alone data regarding the use of social touch technology for sexual touches, were recorded, logged, and analyzed. How comfortable would you be with, for example Facebook, knowing when, where, for how long, and with what intensity you applied a mediated social touch, sexual or otherwise, to your significant other? As described in Chapter 2 in the excerpt from Orwell's *1984*, even in Orwell's surveillance state dystopia, touch, unlike other forms of communication, is still private.

Evidence that these privacy concerns regarding social touch tech-

nology are very real has recently made the news. A manufacturer of a women's sex toy that connects via Bluetooth to a smartphone in order to provide personalized stimulation, was caught logging the data about the usage of the sex toy, including the number of uses, the time of use, and the most used intensity setting³. The company behind the sex toy is now being sued by a woman who felt that the gathering of highly sensitive and personal information regarding her use of the sex toy was a severe invasion of privacy.

Another issue regarding social touch technology, that is related to privacy concerns, is the issue of security. Like all other Internet-connected devices, from smart fridges, to smart lighting, social touch technology, teledildonics included, can potentially be hacked by people trying to gain unsolicited access to the device. Especially in situations where you might not be immediately aware of such a hack, the fact that you are not being touched by the person who you think is applying the touches might be considered a severe invasion of personal space, if not a form of sexual harassment, or in the most extreme cases, where teledildonics are involved, digital rape. With the introduction of social touch technology into society these security issues will need to be considered very carefully.

Still, one advantage that social touch technology has over its actual, interpersonal counterpart, is that technology can be switched off. Social touch technology for remote communication purposes ultimately requires actuators, such as the vibration motors found in the TaSST, to be placed on the body in order to make it possible for the receiver of a touch to feel the touches. Compared to actual social touch, it is much easier to remove oneself from unwanted social touches through technology, as any wearable device can be removed, leaving the toucher to apply touches to thin air. Social touch technology therefore affords more control to the recipient of a touch than is typically the case for actual social touch. It could even be that the recipient has ultimate control over how a touch by a sender is felt on the body. In Section 8.4, with regard to the use of the TaSST in the communication be-

³For a report of the sex toy company's data logging practices see: <https://goo.gl/uJKRYy> (Last accessed 15-11-2016).

tween caregivers and people with deafblindness, the idea of adding a 'volume knob' to a touch-based communication device, was considered a must-have feature. Such a volume knob, or a similar control mechanism, would allow the recipient of a touch to have control over, for example, the intensity and location of a touch. Such a control mechanism does, however, introduce a mismatch into the communication, between what type of touch the sender thinks he or she is applying, and the type of touch the recipient actually feels. This mismatch makes it more difficult for the sender of a touch to apply an appropriate touch, which could lead to undesirable mediated social touch interactions (e.g. touching, when the recipient has his or her device dialed all the way up, could produce a disproportionately strong touch sensation). Of course, the recipient of a mediated social touch could also place the device on an area of the body that is considered inappropriate, potentially forcing a sender to apply an inappropriate touch, irrespective of the sender's intentions.

An interesting example of a clear mismatch between touch input and touch output is found in a Durex commercial which features a kind of teledildonic underwear (referred to in the commercial as the slightly cringe inducing "Fundawear"⁴). Couples can use a smartphone app to activate vibration motors in the underwear of their partner, with the idea of providing sexual stimulation to erogenous zones. As becomes apparent from watching the commercial, there is a clear disconnect between the output (i.e. providing sexual stimulation), and the input (i.e. pressing a few onscreen buttons). In the case of the underwear in this Durex commercial, this leads to the interaction being clearly a gimmick, rather than a meaningful intimate, erotic exchange.

A mismatch between input and output in social touch technology can have more severe implications than a not entirely convincing promotional gimmick, however. In the case that the input lacks the same level of intimacy as the output (e.g. touching the screen on a smartphone, compared to stimulation of erogenous zones), there is the danger that the person applying the touches can more easily ignore conven-

⁴The Durex Fundawear commercial can be viewed here: <https://www.youtube.com/watch?v=qb7DN3kp12o> (Last accessed 15-11-2016).

tional social norms regarding the use of more intimate forms of touch and engage, consciously or unconsciously, in inappropriate touch behaviors. Such effects are likely to be exacerbated when multimodal cues are lacking (e.g. seeing the toucher apply a touch), and are even more extreme when the toucher can remain completely anonymous.

A recent account by a woman playing an online virtual reality (VR) game, where other players could also be virtually present, illustrates the consequences of the anonymity that an online environment provides⁵. In the game in question, the player is endowed with virtual hands, and a faceless virtual helmet that hovers over the player's virtual hands. Players can hear each other's voices, but other than that, the visual appearance of the player's avatar affords complete anonymity. The goal of the game is to use a bow-and-arrow to shoot zombies but, as the woman playing the game experienced, there are few restrictions in the game to prevent other behaviors.

The woman in question describes, in some detail, how the other player faced her and used his disembodied, virtual hands to make rubbing-motions near where her chest would have been. After repeatedly telling the other player to stop, even running away from him (although, strictly speaking, it could have been a female player as well), the other player chased her down, and started making rubbing-motions near where her crotch would have been. The woman recounting this experience tries to impress upon the reader that, even though she could not physically feel the touches she saw, just seeing them being applied to her virtual body was a harrowing experience. This should not come as a surprise when we take into account the research described in Chapter 11, that seeing a touch can activate similar parts of the brain as experiencing a touch, and the subjective ratings of an observed and felt touch can be quite similar. No wonder, then, that the woman in question felt violated by the obscene behavior of the other player. We can only assume that, had the game featured realistic, full-body haptic feedback, allowing for mediated social touch, the experience would have been an even more traumatic one.

⁵For the entire account, visit: <https://goo.gl/VHrzCh> (Last accessed 15-11-2016).

The reason that people think they can get away with this type of obscene behavior probably has to do with the level of anonymity that is afforded by the game. Making efforts to reduce the level of anonymity might be one way to prevent inappropriate uses of social touch technology. Another solution would be to define strict ‘no-touch’ areas on a person’s avatar, like the chest or crotch. If a person present in VR attempts to touch these areas on another player’s avatar, he or she will be penalized, and might even be temporarily, or permanently suspended from the virtual world. Using this approach, it might even be possible to tailor the areas on a person’s avatar that are available for touch, to the relationship between the people engaging in the social touch interaction. For example, one’s spouse is likely to be allowed to touch a larger area of one’s body than a complete stranger [483].

These technical solutions are, of course, no guarantee for the prevention of inappropriate social touch behavior in VR, but they do at least offer some options for control on the side of the receiver of a touch. Such control options are mostly not available in actual social touch interactions, and are also likely to be less easily implemented in other forms of social touch technology. This applies in particular to social robots that might take on a humanlike appearance, and engage in social touch similar to how an actual human would engage in social touch. This is a major theme in a book that was previously discussed in relation to the TaSST, namely Dick’s *Do Androids Dream of Electric Sheep*. The novel features ‘replicants’, artificial humans (i.e. androids) that are nearly indistinguishable from actual humans. Rick Deckard, the novel’s protagonist, is a bounty hunter tasked with identifying, and ‘retiring’, deviant androids. During his travels, however, he meets a young woman of whom he is not sure whether she is an android or not, and when he starts to develop romantic feelings for her, he struggles with this doubt all the more. The question of whether we are supposed to feel empathy, love, or sexual desire towards, in the case of Dick’s novel, highly advanced humanoid robots is an especially interesting one from the perspective of social touch technology.

Decidedly more low-tech versions of Dick’s androids are found in the adult entertainment industry in the form of life-sized dolls, that

are supposed to emulate the look and feel of an actual woman [see also 324, 330]. The purpose of these so called ‘real dolls’ leaves little to the imagination, and a rightful criticism is that they continue the objectification of woman as mere objects of sexual desire (although note that male versions of these dolls do now also exist [330]). Less directed at sexual intercourse are computer programs that provide an ‘artificial girlfriend experience’, and that feature a virtual character that simulates the experience of being in a romantic relationship [see also 324].

Combining these two examples would result in something like a social robot that has physical qualities like an actual person, and whose behavior is designed to simulate the experience of being in a romantic relationship [479]. The realism of both the haptic sensations related to such a robot’s body, not to mention the simulated social touch capabilities of such a social robot (e.g. being able to apply convincing stroking touches), as well as its social intelligence (e.g. being able to respond appropriately to receiving various forms of touch, as well as to other social cues) are likely to determine the success of such robots. For now, a robot that fully integrates all of these aspects is science fiction, yet we can already observe all of the components slowly emerging, from automatic touch recognition, to socially intelligent voice-assistants. And with an international academic conference dedicated to the topic of love and sex with robots, it is likely that these developments will continue in the future⁶.

A potential use of this type of robot, is hinted at in research into VR, and is not without controversy⁷. There are research efforts, in the form of VR-supported behavioral therapy [38, 419], that investigate the use of VR technology in the treatment of sex addicts or even sex offenders. Touch-capable social robots could be imagined to fulfill a similar role, although, as for VR, the use of this type of technology for treating sex offenders will have to be investigated with the utmost care, and under strict supervision of professional therapists.

⁶More information about the conference on ‘love and sex with robots’, which, incidentally, was forbidden from being organized in Malaysia, can be found here: <http://loveandsexwithrobots.org> (Last accessed 15-11-2016).

⁷There was an event at the MIT Medialab on “forbidden research” such as the use of VR and robots to treat sex offenders. Transcripts of the event can be found here: <https://goo.gl/nNgYNH> (Last accessed 15-11-2016).

A final, intriguing future perspective on the use of the type of social robot described above, is social robots as sex workers [541]. In light of the current spread of sexually transmitted diseases, as well as cases of abuse, and human trafficking, having technology, such as social robots, replace sex workers might be one potential solution to these problems [541]. But, like Rick Deckard, we might wonder about the ethical implications of treating such future, possibly sentient, artificial humans in this way. Perhaps they will share our desire for intimate physical contact, but will, like we do for most of our most intimate social touch interactions, reserve such contact for those that are most close to them.

CHAPTER FIFTEEN

THE ALTERNATE FIRST DAY OF SCHOOL

I was a happy boy on my first day of school. My father, wearing a t-shirt, a pair of jeans, and sneakers, an outfit similar to the one I had seen him wear during the weekend - apparently his boss very much agreed with his style of clothing - helped me into my jacket as we walked down the hallway towards the front door. Just as I stepped over the threshold, I felt a sensation as if I was hugged, as special compartments in my jacket inflated. I quickly pulled my small tablet computer out of my pocket, and saw a message from my mother, who was abroad on a business trip, appear on the screen. Eagerly, I jabbed my finger at the video chat icon, until my mother's face was visible on my tablet.

'You'll do great today! Have fun!' she said encouragingly, and I could feel a stroking motion on my upper arm, produced by small vibration motors embedded in the sleeve.

'Sure mom!' I said hastily, and squeezed my sleeve, which I knew would make my mother's bracelet contract to produce a squeezing sensation on her arm.

'But I have to go now, my spaceship is almost done and I need to check up on the astronauts!'

My mother laughed, gave me one last hug through my jacket, and said 'Alright little rocket scientist, but let me know how things are going today will you?'

I nodded, squeezed my sleeve one last time, and quickly opened the application that housed my space ship and astronauts who, by the looks on their animated faces, were eagerly awaiting my finishing touches on their craft, ready to go into space.

Slightly distracted by the act of placing the final thruster nozzle on my spaceship, I walked towards the car, while my father pulled the front door closed behind us, and, with one hand, tapped a few icons on his smartphone to turn off the lights, set the alarm, and lock the doors, as he used his other hand to open the rear door of our car.

I clambered into the back seat, my eyes still trained on the screen of my tablet, and heard the familiar faint humming noise as our car backed out of the drive way on auto-pilot, while my father checked his e-mail on the on-board screen, humming a tune from the eighties.

After what must have been a brief drive, too brief for me to finish all of the pre-launch procedures anyway, the car pulled up to a building that reminded me of something I had previously seen in Google Streetview; a low building with what looked like a solar panel roof, just like the one our house had. Unlike our house, though, the building stretched around the edges of a square that featured some kind of strange orange arc I had never seen before, and something I recognized to be a digital football goal, with automatic score counter and everything. I had seen such a place before. No doubt, this is what they called a 'school'.

I stowed my tablet in my jacket pocket, climbed out of the car, and grabbed hold of my father's hand. Together, we walked towards the school building, through a small wooden fence that ran along the square, and we stopped close to where the orange arc stood. I glanced around the square and saw plenty of other children of my age holding onto their parents, and looking around warily, obviously impressed by these new surroundings. Just as I considered investigating the strange orange arc, a tall woman walked towards us and exchanged pleasantries with my father. At that moment I felt a brief hugging sensation through my jacket again, but I was so entranced by this peculiar woman, that I only responded by briefly squeezing the sleeve of my jacket, thrice in quick succession.

Obviously the tall woman had noticed my staring, and promptly turned towards me.

'You must be Gijs! Your father just told me you are building a spaceship, I would love to see it!'

I nodded slowly, aghast that someone could be interested in my interplanetary endeavors. I pulled out my tablet, and switched to an augmented reality view. There they were, my three brave astronauts, standing on the square in front of the school, as I looked at them through the camera of my tablet. I stretched out my hand, and as I did so, one of the astronauts stretched out his, and we shook, right there on the school grounds. Then, all three astronauts turned around, climbed up the ladder leading to the crew pod of the spacecraft, and I could see a timer beginning to count down.

Ten, nine, eight, seven.

I briefly glanced over to my father and the woman, who had crouched down beside me to watch the launch. I could not help but feel a sense of pride in having an audience.

Six, five, four, three.

My tablet started to vibrate, as the rocket's engines started up, and I held on to my tablet tighter, focussing my eyes on the screen.

Two, one, launch.

The tablet shook violently as the blast expelled from the thruster nozzle I had just a few moments ago installed, lifted the rocket up from off of the square and moved it upwards ever faster. I tilted my tablet upwards to keep the rocket in view as it sped towards the atmosphere.

'That was great!' The woman said enthusiastically, as the rocket disappeared from sight, and was now only visible as an icon on my control panel screen.

'Gijs, this is your teacher.' My father informed me as I monitored the rocket's progress on my tablet.

'I have to go to work now, but you can go with her, and she will show you around the school and classroom. I have been told they have some pretty cool stuff in there!'

With a questioning look on my face, I looked up from my tablet to the woman. What cool stuff could my father possibly be talking about?

‘That’s right!’ the woman said in what I now assumed was her regular, enthusiastic voice.

‘My favorite is Oscar, he is my robotic teaching assistant. I am sure he is looking forward to welcoming you with open arms.’

I looked up at my father, intrigued, as if to verify what my new teacher had said was true.

My father bent down towards me, gave me a kiss on the forehead, and ruffled my hair.

‘You hear that? A robot! You are so lucky! Have fun on your first day of school!’ He said encouragingly.

My teacher gently took my hand, and, as my father walked towards the gate we had just passed through, my teacher and I started walking towards the school. I walked along slowly, holding her hand, all the while pondering ‘A robot? I wonder if it will shake my hand like one of my astronauts?’

15.1 APPLICATIONS AND FUTURE RESEARCH

The decidedly utopian depiction of the near future and the impact of technology, including social touch technology, on everyday life in that future, described in the previous section, could be how a child that goes to school for the first time in a few years will experience that day. In contrast to the story in Chapter 1, which was a slightly dramatized account of my own first day of school, the story from the previous section is one that features many kinds of technology for remote communication, entertainment and education which may, in the near future, indeed feature social touch capabilities. At the same time, we might wonder what the impact of such technology, with both adults and children being constantly absorbed in it, will be on daily life. In the previous chapter we have already seen some examples of potential ethical issues regarding social touch technology.

Despite the fact that this utopian depiction of the near future raises some questions about the proliferation of technology in everyday life, it also outlines examples of useful applications of social touch technology, that could potentially be beneficial. A mother, due to work unable to be present during her son’s first day of school, can now be remotely

present and provide some much needed support. A game, with educational value, in which a person can interact with virtual characters in augmented reality. And a social robot that supports a teacher, and can walk, talk, and touch.

These are just a few examples of how social touch technology could play a role in our daily lives in the near future. But what other uses can we foresee? And what kind of research would be necessary to make such potential uses a reality? For starters, we might consider how social touch technology, mediated social touch specifically, could fulfill the role that actual social touch plays in helping to maintain and strengthen social relationships (see also Section 4.2). Especially in those situations where people are unable to physically touch each other, mediated social touch could be used to the same effect as actual social touch. Think, for example, of people in a long-distance relationship who may feel a need for physical intimacy which cannot be gratified due to the distance separating them. Or of elderly people who, due to age related health issues, might be restricted in their access to satisfactory social relationships. Think also of a soldier, who is dispatched to a war-zone, and spends a considerable amount of time away from his or her family. An even more extreme example would be an astronaut sent to the international space station, or perhaps sent on a trip to Mars, who would be away from home for a long time, possibly indefinitely. It is not unthinkable that mediated social touch could help such a person, in the isolation that space travel involves, to better cope with being away from home.

An indication that being away from loved ones, or lacking satisfactory social relationships altogether, is a serious issue is found in research on loneliness [232], and some researchers even argue that the adverse effects of loneliness on health are comparable to those of smoking [289]. Thus, the prevention of loneliness might be a worthwhile endeavor. Although it should be noted that the most effective way to treat loneliness is through behavioral therapy [232], we could still argue that providing easier, and more complete access to exciting social relationships might reduce the chances that a person that

spends time in isolation, for whatever reason, will develop feelings of loneliness.

The application of social touch technology for these purposes, however, rests on the notion that people are affected by social touch technology in a way that is similar to how they are affected by actual social touch. In Chapter 7 we saw examples of research that has found similarities in the way that people respond to actual, and mediated social touch. The fact that people's hedonic responses to touch through technology (Chapter 10), or even observed touch through technology (Chapter 11), are quite similar to their responses to actual social touch can be taken as another indication that responses to social touch technology and actual social touch can overlap.

Still, there are also quite a few studies that have failed to find such overlap so, for now, we need to take some care with proposing social touch technology as a stand-in for actual social touch, for example to combat loneliness. A clear difference between social touch technology and actual social touch is that people, especially those in a romantic relationship, are exposed to actual social touch all the time, and may have even developed their own style of interaction through touch. Think, for example, of pinching someone's side as a sign of playful affection, or squeezing someone's hand twice to say 'I love you'. Such personal uses of social touch could be the ones that are most meaningful, and the ones with the biggest impact. This is hypothetical, because, as was outlined in Chapter 4, it is difficult to obtain insights into such uses of social touch (though see [226, 272] for questionnaire and observation based approaches). What is more, as social touch technology is not widely available, at least not yet, people have not had any chance to develop similar styles of interaction through, for example, mediated social touch. It could be that effects of mediated social touch rely on people's familiarity with this type of technology, obtained through prolonged use of the technology in daily situations. Such situations are difficult, if not impossible, to convincingly reproduce in a lab setting. It would thus be necessary to conduct longitudinal research in which participants get the opportunity to incorporate mediated social touch into their daily routines, and to develop their own style of in-

teraction. Some insightful studies in this direction have already been conducted [392, 393] but it remains difficult to generalize these findings given the very specific, structured use cases (i.e. the moments during which mediated social touch was possible were pre-planned) and hardware used in these studies.

It would be interesting to follow up on these studies with research using more standardized hardware for mediated social touch that can be freely and spontaneously used by participants in day-to-day situations. Technology such as that developed for the TaSST (Chapter 8) could be of use here. Not only could such longitudinal research provide insights into how mediated social touch could, perhaps in a way similar to actual social touch [213, 214], support people in a romantic relationship, it could also be followed up by lab studies, in which the specific uses of mediated social touch by a couple could be investigated for potential effects of such touches.

One potential effect that could be particularly interesting to study is stress reduction through social touch technology. Studies in actual social touch have shown that being touched, especially being touched by one's partner, can have stress reducing effects. While this may already be beneficial in day-to-day communication, for example, providing support to someone prior to a job interview, the potentially most interesting applications are in health care. In health-care settings, mixed results have been obtained for the positive effects of touch on stress reduction and pain reduction, possibly due to the fact that the touches were applied by a nurse or doctor, rather than by someone the patient was really close to (see Section 4.1). Mediated social touch could be used for supportive social touch interactions in situations where it is not possible for a relative or spouse to be physically present, such as when a patient is quarantined or in an intensive care unit. Being able to reduce stress or even pain in such circumstances using a non-pharmacological method (i.e. without the need for medication), could be highly beneficial for preparing a patient for surgery, or helping a patient recover from surgery.

Nevertheless, research to date has shown mixed results of mediated social touch on stress reduction (see Section 7.1). There are two likely

causes for this that would need to be addressed in future research. First, there have been clear differences between the type of haptic stimuli that were applied in different studies. If we look at results for actual social touch it seems that massage therapy, especially, can have quite a strong positive impact on stress reduction [127]. Thus, mediated social touch that provides a type of stimulation similar to a massage might have a higher chance of reducing stress than, for example, a squeeze to the hand [148]. Systematic investigations into which types of haptic feedback to use in mediated social touch for stress reduction, such as thermal stimulation, forces exerted on the skin, or movement over the skin, would be an interesting line of future research.

A second issue that this line of research would need to address, however, is how mediated social touch affects a person's physiological responses. Studies into the stress reducing effects of mediated social touch have used several methods of measuring psychophysiological parameters related to stress (e.g. heart rate) but some of these studies had a number of methodological issues (see Section 7.1). What is more, it is not yet entirely clear what sort of physiological responses can be expected as a result of actual social touch [532]. Therefore, future studies into potential stress reducing qualities of mediated social touch using psychophysiological measures should ideally, in tandem, also investigate such responses to actual social touch.

Thus far we have considered potential applications from a primarily haptic perspective. However, research on social touch technology (see Chapter 7 and Chapter 12), the studies discussed in Chapter 10, Chapter 11, and Chapter 13, included, has shown that congruent feedback from other modalities, especially the visual, can make social touch technology more compelling. It is possible that potential effects of social touch technology can be enhanced when haptic feedback is supplemented by appropriate visual feedback.

A particularly interesting application area that could make optimal use of congruent visuo-haptic feedback is that of social augmented reality (AR) or virtual reality (VR). Companies like Facebook and Microsoft are investigating ways in which we might interact with each other in the future through AR and VR technology. The addition of realistic touch

capabilities to such systems is only a matter of time as in fact most VR systems available on the market today feature haptic feedback in the controllers that are bundled with the system. Given the availability of such haptic technology, in AR or VR, it is inevitable that it will be used for social touch applications, as the example of sexual harassment in social VR in the previous chapter illustrates. Nevertheless, we can also imagine how being able to interact with a loved one through social AR or VR, especially when it incorporates social touch technology, would make for social interactions at a distance that approach face-to-face interactions in terms of the modalities that are available for communication.

In social AR or VR we may encounter others with whom we can interact but it is quite likely that we will also encounter artificial social agents. In fact, many gaming applications that are available for VR platforms feature interactions with virtual agents. The step from the current type of interactions with these agents to the integration of social touch technology in the way we interact with virtual agents in VR and AR is a relatively small one. We might expect that the ability to touch and be touched by these virtual agents can enhance the sense of social presence, and make these agent seem like actual social actors (see Section 12.2). Not only that, but, as the study in Chapter 13 has shown, simulated social touch by a virtual agent might also influence the way that people perceive the personality of the agent. Simulated social touch could thus be a way for game developers to make the computer-controlled characters that inhabit a virtual world more life-like, and to use touch as a way for these characters to express their personality.

Beyond entertainment-focussed applications of simulated social touch, social touch by virtual agents could also be useful in scenarios in which virtual agents are currently often studied, namely for coaching, training, and therapy purposes [44]. The idea behind these types of social agents is that they can support people in maintaining certain routines, for example, the intake of medication or support in adopting healthy eating patterns, by providing encouraging feedback. In another application area, virtual agents can be used by people to train

certain skills. In Section 12.2.3 we have already seen how a virtual agent can be used to train medical students, but applications extend to other forms of training, such as training police officers to become more proficient at interrogating suspects [476]. Finally, virtual agents might be used for therapeutic purposes, such as behavioral therapies [44], in which the agent takes on the role of therapist. The addition of simulated social touch to virtual agents in these scenarios might enhance feelings of social presence which would make the agent a more adequate substitute for an actual human being. Not only that, but it is imaginable that an agent could use a Midas touch to convince people to, for example, adhere to their medicine intake. Though as we have seen in Section 13.1.3, a Midas touch effect for virtual agents has yet to be found. What is more, the use of simulated social touch by virtual agents for certain applications will have to be investigated carefully as, in for example, psychotherapy, the use of touch is not recommended [12, 252].

The applications that are now viable for virtual agents might also be possible with social robots in the near future. It is likely that in this near future social robots will walk among us and engage in all kinds of tasks that are currently being undertaken by people, and because of their physical bodies, we will inevitably come into contact with social robots, if only by accident. Their physical body also makes them inherently suited for simulated social touch applications, especially when social robots are equipped with the ability to detect and understand social touch [277, 278]. The sex robots discussed in the previous chapter are an interesting, albeit futuristic and perhaps unethical use of a robot's touch capabilities. Another area of application that, like mediated social touch, shows particular promise is the use of social robots in health care. Such robots might support doctors and nurses in their daily practice, and could apply social touches for the same reason that people would apply them, such as for diagnosis or comforting a patient [e.g. 91, 92]. It is even possible that with increasing demands on health care and a reduced work force, social robots will stand in for human doctors and nurses in some instances. The use of social touch

by these robots might be an important way for them to engage with their patients.

As was already made clear in the discussion of the relevant literature in Chapter 12, the use of simulated social touch by both virtual agents and social robots is an area of research that is still very much in its infancy. Not much is known about how and when such artificial social agents should touch us, and what aspects of these agents, such as their humanlike appearance, the capabilities of their bodies in general (e.g. Can they walk? Touch and be touched?), and their apparent artificial intelligence will impact the way in which we will experience touches by such artificial social entities. That we will experience touches by artificial social entities, either in AR or VR, or by social robots, is practically a given. The examples of applications discussed here offer a glimpse into the future where social touch technology might be integrated into the devices that we use to communicate with others, and into the devices that are designed to interact with us in the most humanlike way possible.

That being said, the technology that we use on a daily basis, to some extent at least, is also designed to tap into our tendency to behave in an inherently social manner towards technology [416]. This is most obvious in the design of digital voice assistants which are available on every modern smartphone, and are making their way into the household through dedicated voice-activated speakers which can be used to command a digital assistant to do any number of tasks, from dimming the lights, to ordering new washing powder. Developments in consumer electronics that run parallel to the development of these types of digital assistants are wearable technology, such as smart watches and fitness trackers, and the so-called 'Internet of Things' (IOT) - Internet-connected physical products. What these two types of technology have in common is that they blend digital information and communication with physical products and if we add the social design of modern technology we can brew up a rather fascinating question: can we use what we have learned from social touch technology research in the design of haptic feedback for systems that are not necessarily social actors?

Imagine, for example, your calendar application wanting to notify

you of an urgent upcoming business meeting through a haptic wearable. One way for a person to get your attention through social touch might be to tap you on the shoulder. Your calendar application, too, could apply haptic feedback to your shoulder to notify you of the meeting. Such feedback is more appropriate given the function of your calendar app and the content of the event (i.e. a business meeting), than to apply, say, a stroking touch. Should the event in question be a romantic rendezvous, your calendar app could perhaps apply a stroking touch in combination with thermal feedback, to a more intimate area of the body, such as the stomach [218], to notify you of the upcoming amorous encounter.

Similarly, your fitness app might support and coach you to maintain a healthy fitness routine. In order to get you to adhere to such a routine, the app could apply haptic feedback to notify you. It is tempting to think about such haptic feedback in terms of the Midas touch effect, where a combination of motivational text and ‘touches’ from the app could help to convince you to go for a run. Another function of the same fitness app might be to get you to relax during certain moments of a busy working day. Applying calming, massaging haptic feedback in combination with doing a breathing exercise could be a way for such an app to use ‘social touch’.

These examples all include an application that is not necessarily perceived by a person as a social actor. Of course, the interpretation of the haptic feedback applied by these apps might be more readily interpreted as social if such applications *are* designed as social actors, for example, in combination with voice assistants (see Section 13.3). If current efforts by major technology companies are any indication, we may indeed see such uses of social touch technology. For the moment, however, it is too early to provide formal guidelines for the use of social touch technology in the design of haptic feedback. Nevertheless, developers and designers working on technology that can incorporate haptic feedback might do well to inform themselves about research on social touch technology.

15.2 ALMOST BUT NOT QUITE

Colin, a small, seemingly insignificant robot from the last part in Douglas Adams' 'trilogy of five' of *The Hitchhiker's Guide to the Galaxy*, is perhaps not the most well-known character from the Guide's universe. Colin is a melon-sized, hovering security robot, who vigilantly patrols the Hitchhiker's Guide's main office building. That is, until he gets hacked by Ford Prefect and taken on a wild chase through the building. Colin, however, is ecstatic about everything he encounters, from large heavily armed aliens, to ceilings, and security doors. You see, Ford cleverly bypassed a chip on the robot's logic board that governed whether or not Colin would feel happy about a particular stimulus, this bypass inadvertently resulting in the fact that Colin now responds to every incoming stimulus in a positively delighted and gleeful manner.

One might say that the view on social touch technology that has been put forward here has been somewhat Colinesque, and focussed on the possibilities, rather than the impossibilities of the technology. Given that social touch technology research is in essence still in a pre-Aristotelian age (see also Sections 2.1 and 3.1), it can be argued that it is rather more constructive to think about what such technology might bring to the table, than ways in which it could fail to do so. Nevertheless, it is good to practice a bit of Marvinism (a term derived from the much more famous Hitchhiker's Guide robot, Marvin the paranoid android) every now and again, too, and we should recognize that there is still a long way to go, and a lot of work to be done. A sizable portion of the work that has been done thus far has been described here, and a number of contributions to the field of social touch technology have been discussed in the previous chapters.

The design process of the TaSST has demonstrated that coupling touch input to vibrotactile output might be a way to communicate different types of touch at a distance. Important to this is the notion that the sensor that detects touch input should be able to detect different types of touch as well, especially in terms of the amount of force exerted on the sensor. A wearable, modular design, where discrete sensor and actuator units can be linked together and placed anywhere on the body, was found to be a particularly useful way to use the technology

developed for the TaSST for different purposes. Future work on social touch technology might learn from the development of the TaSST and adopt a similar modular design. An exciting possibility would be to develop the TaSST hardware in a collaborative open-source fashion in order to foster research into social touch technology, that, due to the use of similar hardware, is more easily comparable across studies.

Nevertheless, vibrotactile feedback, such as that produced by the vibration motors found in the TaSST, is only one way to apply haptic stimulation, and, arguably, a way that produces a more artificial feeling than other forms of stimulation (e.g. warmth, or force-feedback). Looking for novel ways of applying haptic stimuli to a person's body, preferably using actuators that allow for the design of wearable devices that are suitable for everyday use (see also the discussion in the previous section), is a useful research endeavor. Such efforts notwithstanding, an alternative approach was explored in Chapter 10, in which the use of simple vibration motors to generate richer tactile sensations, specifically stroking sensations, was investigated. The study showed that stroking sensations of different velocities generated using a vibrotactile array are rated similarly on pleasantness to actual stroking sensations. Follow-up studies to further investigate this finding would be highly valuable and could shed further light on the appropriateness of relatively simple actuator technology for social touch technology.

In addition to studying 'sensory depth' (i.e. making the touch sensation more realistic), social touch technology research should also study 'sensory breadth' [see also 323]. In particular the study of visual feedback that is presented in a congruent manner with haptic feedback might help a person to attribute a felt haptic sensation to the sender and could enhance feelings of social presence. The study presented in Chapter 11 has demonstrated that pleasantness responses to observed stroking touches can be similar to pleasantness responses of actually felt stroking touches. What is more, these pleasantness judgements seem more dependent on the velocity of stroking than on the way the stroking touches are applied. This finding is interesting in that it might afford researchers some freedom in how exactly they provide congruent visual feedback in conjunction with haptic feedback. It might not

be necessary to have photorealistic depictions of human touches *per se*.

An additional contribution of the study into observed stroking touches is that it shows that the use of videos can be a viable way to study certain aspects of social touch. Moreover, such videos can be presented to participants through crowdsourcing platforms to quickly gather responses. Crowdsourcing is a very cost and time effective way of getting enough participants for ample statistical power, something which further aids the development of social touch technology research into a more mature field of research.

Finally, Chapter 13 has shown two different ways in which visual feedback and haptic feedback can be integrated in a congruent manner in order to produce a virtual agent that can interact with a person through various modalities. The AR touching virtual agent study has shown that this type of simulated social touch can influence perceptions of presence and the way a person perceives the virtual agent that applies a social touch. What is more, this study has shown that AR, and likely also VR, are useful ways to investigate social touch technology by allowing for more elaborate scenarios in which interactions with virtual agents can be integrated, as well as offering control over congruently presented multimodal signals and the environment in which touches take place.

Social touch technology as a field of research is still in full development and the work presented here contributes suggestions for the design of hardware, the use of multimodal feedback, and novel ways of integrating social touch capabilities in interactions with computer systems. Not only that, but the literature discussed in the previous chapters shows that the combined research efforts to date have, in some ways, brought social touch technology close to actual social touch. Social touch technology might come close, but is in other ways -, for example, the mechanical nature of certain types of haptic stimulation or virtual characters - also rather far removed from actual social touch. Perhaps for now it best, then, to borrow once more from Douglas Adams and characterize social touch technology as almost, but not quite, entirely unlike social touch.

PUBLICATIONS BY THE AUTHOR

CONTRIBUTING TO CHAPTERS

G. Huisman. Social Touch Technology: A Survey of Haptic Technology for Social Touch. *IEEE Transactions on Haptics*, in press, 2017.
Contributes to Chapters 2, 3, 6, 7, and 12.

C. J. A. M. Willemse, **G. Huisman**, M. M. Jung, J. B. F. van Erp, and D. K. J. Heylen. Observing Touch from Video: The Influence of Social Cues on Pleasantness Perceptions. In *International Conference on Human Haptic Sensing and Touch Enabled Computer Applications*, pages 196-205, 2016, Springer.
Contributes to Chapter 11

G. Huisman, G., A. Darriba Frederiks, J. B. F. van Erp, and D. K. J. Heylen. Simulating Affective Touch: Using a Vibrotactile Array to Generate Pleasant Stroking Sensations. In *International Conference on Human Haptic Sensing and Touch Enabled Computer Applications*, pages 240-250, 2016, Springer.
Contributes to Chapters 9 and 10

G. Huisman, J. Kolkmeier, and D. K. J. Heylen. With us or against us: simulated social touch by virtual agents in a cooperative or competitive setting. In *Proceedings of the International Conference on Intelligent Virtual Agents*, pages 204-213, 2014, Springer.

Contributes to Chapter 13

G. Huisman, J. Kolkmeier, and D. K. J. Heylen. Simulated social touch in a collaborative game. In *Proceedings of the International Conference on Human Haptic Sensing and Touch Enabled Computer Applications*, pages 248-256, 2014, Springer.

Contributes to Chapter 13

A. Darriba Frederiks, D. K. J. Heylen, and **G. Huisman**. TaSST: affective mediated touch. In *Proceedings of the International Conference on Multimodal Interaction*, pages 315-316, 2014, ACM.

Contributes to Chapter 8

G. Huisman, A. Darriba Frederiks, and D. K. J. Heylen. Affective touch at a distance. In *Proceedings of Affective Computing and Intelligent Interaction*, pages 701-702, 2013, IEEE.

Contributes to Chapter 8

G. Huisman., M. Bruijnes, J. Kolkmeier, M.M Jung, A. Darriba Frederiks and Y. Rybarczyk. Touching virtual agents: embodiment and mind. In *Proceedings of the International Summer Workshop on Multimodal Interfaces*, pages 114-138, 2013, Springer.

Contributes to Chapter 13

G. Huisman and A. Darriba Frederiks. Towards tactile expressions of emotion through mediated touch. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems*, pages 1575-1580, ACM.

Contributes to Chapter 8

G. Huisman, A. Darriba Frederiks, E. M. A. G. van Dijk, D. K. J. Heylen, and B. J. A. Kröse. The TaSST: Tactile sleeve for social touch. In *Proceedings of World Haptics Conference*, pages 211-216, 2013, IEEE.

Contributes to Chapter 8

G. Huisman, A. Darriba Frederiks, E. M. A. G. van Dijk, B. J. A. Kröse, B., and D. K. J. Heylen. Self touch to touch others: designing the tactile sleeve for social touch. in *Online proceedings of TEI'13*, 2013.

Contributes to Chapter 8

G. Huisman. A touch of affect: mediated social touch and affect. In *Proceedings of the International Conference on Multimodal Interaction*, pages 317-320, 2012, ACM.

Contributes to Chapter 8

OTHER PUBLICATIONS

M. Bruijnes, **G. Huisman**, and D. K. J. Heylen. Tasty Tech: human-food interaction and multimodal interfaces. In *Proceedings of ICMI 2016 workshop on Multi-sensorial Approaches to Human-food Interaction*, 2016, ACM Digital Library.

G. Huisman, M. Bruijnes, and D. K. J. Heylen. A Moving Feast: Effects of Color, Shape and Animation on Taste Associations and Taste Perceptions. In *Proceedings of the International Conference on Advances in Computer Entertainment Technology*, ACM Digital Library.

A. Darriba Frederiks, B. J. A. Kröse and **G. Huisman**. Internet of touch: analysis and synthesis of touch across wearable and mobile devices. In *Proceedings of the International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*, pages 273-276, ACM.

M. M. Jung, R.W. Boensma, **G. Huisman**, and E. M. A. G. van Dijk. Touched by the storyteller: the influence of remote touch in the context of storytelling. In *Proceedings of Affective Computing and Intelligent Interaction*, pages 792-797, 2013, IEEE.

G. Huisman, M. van Hout, E. M. A. G. van Dijk, T. van der Geest, and D. K. J. Heylen. LEMtool: measuring emotions in visual interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 351-360, 2013, ACM.

T. Beelen, R. Blaauboer, N. Bovenmars, B. Loos, L. Zielonka, R. W. van Delden, R., **G. Huisman**, and D. Reidsma. The art of tug of war: investigating the influence of remote touch on social presence in a distributed rope pulling game. In *Proceedings of Advances in Computer Entertainment*, pages 246-257, Springer.

A. Minuto, **G. Huisman**, and A. Nijholt. Follow the grass: A smart material interactive pervasive display. In *Proceedings of International Conference on Entertainment Computing*, pages 144-157, Springer.

G. Huisman, and M. van Hout. The development of a graphical emotion measurement instrument using caricatured expressions: the LEMtool. In *Proceedings of the International Workshop on emotion in HCI*, pages 5-8, 2010.

BIBLIOGRAPHY

- [1] International Society for the Study of Affective Touch (ISSAT). https://www.ucl.ac.uk/psychoanalysis/01_psychoanalysis_other/Association-for-the-study-of-Affective-Touch-Inaugural-Conference, 16-02-2015.
- [2] The Aye-Ayes or Cheiromys of Madagascar. *Science*, 2(76):574–576, 1881.
- [3] R. Ackerley, H. B. Wasling, J. Liljencrantz, H. Olausson, R. D. Johnson, and J. Wessberg. Human C-tactile afferents are tuned to the temperature of a skin-stroking caress. *The Journal of Neuroscience*, 34(8):2879–2883, 2014.
- [4] L. B. Adamson and J. E. Frick. The still face: A history of a shared experimental paradigm. *Infancy*, 4(4):451–473, 2003.
- [5] C. Addams. The New Yorker. Cartoon, November 10 1945.
- [6] C. Addams. The New Yorker. Cartoon, March 20 1954.
- [7] M. D. S. Ainsworth. Object relations, dependency, and attachment: A theoretical review of the infant-mother relationship. *Child Development*, 40(4):969–1025, 1969.
- [8] R. D. Albert and I. A. Ha. Latino/Anglo-American differences in attributions to situations involving touch and silence. *International Journal of Intercultural Relations*, 28:253 – 280, 2004.
- [9] M. Alhalabi and S. Horiguchi. Tele-Handshake: A Cooperative Shared Haptic Virtual Environment. In *Proceedings of EuroHaptics 2001*, Birmingham, UK, July 2001.
- [10] D. S. Alles. Information transmission by phantom sensations. *IEEE Transactions on Man-Machine Systems*, 1(11):85–91, 1970.

- [11] T. B. Altuglu and K. Altun. Recognizing touch gestures for social human-robot interaction. In *Proceedings of ICMI 2015*, pages 407–413, 2015.
- [12] J. H. Alyn. The politics of touch in therapy: A response to Willison and Masson. *Journal of Counseling & Development*, 66(9):432–433, 1988.
- [13] T. Amemiya, H. Ando, and T. Maeda. Virtual force display: Direction guidance using asymmetric acceleration via periodic translational motion. In *Proceedings of World Haptics Conference 2005*, pages 619–622. IEEE, 2005.
- [14] J. F. Andersen, P. A. Andersen, and M. W. Lustig. Opposite sex touch avoidance: A national replication and extension. *Journal of Nonverbal Behavior*, 11(2):89–109, 1987.
- [15] P. A. Andersen and L. K. Guerrero. Haptic behavior in social interaction. In M. Grunwald, editor, *Human haptic perception: basics and applications*, chapter 12, pages 155 – 163. Birkhäuser, 2008.
- [16] P. A. Andersen and K. Leibowitz. The development and nature of the construct of touch avoidance. *Environmental Psychology and Nonverbal Behavior*, 3(2):89 – 106, 1978.
- [17] P. A. Andersen, M. W. Lustig, and J. F. Andersen. Changes in latitude, changes in attitude: The relationship between climate and interpersonal communication predispositions. *Communication Quarterly*, 38(4):291 – 311, 1990.
- [18] E. Anisfeld, V. Casper, M. Nozyce, and N. Cunningham. Does Infant Carrying Promote Attachment? An Experimental Study of the Effects of Increased Physical Contact on the Development of Attachment. *Child Development*, 61(5):1617–1627, 1990.
- [19] D. Annaz, A. Karmiloff-Smith, M. H. Johnson, and M. S. Thomas. A cross-syndrome study of the development of holistic face recognition in children with autism, Down syndrome, and Williams syndrome. *Journal of Experimental Child Psychology*, 102(4):456–486, 2009.
- [20] K. J. Anstey, A. Salim, S. R. Lord, M. Hennessey, P. Mitchell, K. Mill, and C. Von Sanden. Our correct use of ANCOVA yields acceptable results. *Journal of the International Neuropsychological Society*, 13(2):371, 2007.
- [21] B. App, D. N. McIntosh, C. L. Reed, and M. J. Hertenstein. Nonverbal channel use in communication of emotion: How may depend on why. *Emotion*, 11(3):603 – 617, 2011.
- [22] B. D. Argall and A. G. Billard. A survey of tactile human–robot interactions. *Robotics and Autonomous Systems*, 58(10):1159 – 1176, 2010.
- [23] J. Atkinson and O. Braddick. Sensory and perceptual capacities of the neonate. In *Psychobiology of the human newborn*, pages 191–220. John Wiley, 1982.

- [24] M. Auvray, E. Myin, and C. Spence. The sensory-discriminative and affective-motivational aspects of pain. *Neuroscience and Biobehavioral Reviews*, 34:214–223, 2010.
- [25] R. T. Azuma. A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, 6(4):355, 385 1997.
- [26] P. Bach-y Rita and S. W. Kercel. Sensory substitution and the human-machine interface. *Perception*, 7(12):541–546, 2003.
- [27] J. Bailenson, N. Yee, S. Brave, D. Merget, and D. Koslow. Virtual interpersonal touch: Expressing and recognizing emotions through haptic devices. *Human-Computer Interaction*, 22(3):325–353, 2007.
- [28] J. N. Bailenson and N. Yee. Digital chameleons automatic assimilation of nonverbal gestures in immersive virtual environments. *Psychological Science*, 16(10):814–819, 2005.
- [29] J. N. Bailenson and N. Yee. Virtual interpersonal touch: Haptic interaction and co-presence in collaborative virtual environments. *Multimedia Tools and Applications*, 37(1):5–14, 2008.
- [30] M. J. Banissy, R. C. Kadosh, G. W. Maus, V. Walsh, and J. Ward. Prevalence, characteristics and a neurocognitive model of mirror-touch synaesthesia. *Experimental Brain Research*, 198(2-3):261–272, 2009.
- [31] J. Bardzell and S. Bardzell. “Pleasure is Your Birthright”: Digitally Enabled Designer Sex Toys as a Case of Third-Wave HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 257–266. ACM, 2011.
- [32] P. Barolsky. Bernini and Ovid. *Notes in the History of Art*, 1(1996):29–31, 16.
- [33] C. Basdogan, C.-H. Ho, M. A. Srinivasan, and M. Slater. An experimental study on the role of touch in shared virtual environments. *ACM Trans. Comput.-Hum. Interact.*, 7(4):443–460, Dec. 2000.
- [34] R. F. Baumeister and M. R. Leary. The need to belong: desire for interpersonal attachments as a fundamental human motivation. *Psychological Bulletin*, 117(3):497–529, 1995.
- [35] C. Beckett, B. Maughan, M. Rutter, J. Castle, E. Colvert, C. Groothues, J. Kreppner, S. Stevens, T. G. O’Connor, and E. J. S. Sonuga-Barke. Do the Effects of Early Severe Deprivation on Cognition Persist Into Early Adolescence? Findings From the English and Romanian Adoptees Study. *Child Development*, 77(3):696–711, 2006.
- [36] T. Beelen, R. Blaauboer, N. Bovenmars, B. Loos, L. Zielonka, R. Delden, G. Huisman, and D. Reidsma. The art of tug of war: Investigating the influence of remote touch on social presence in a distributed rope pulling game. In D. Reidsma,

- H. Katayose, and A. Nijholt, editors, *Advances in Computer Entertainment*, volume 8253 of *Lecture Notes in Computer Science*, pages 246–257. Springer International Publishing, 2013.
- [37] C. V. Bellieni, D. M. Cordelli, S. Marchi, S. Ceccarelli, S. Perrone, M. Maffei, and G. Buonocore. Sensorial saturation for neonatal analgesia. *The Clinical Journal of Pain*, 23(3):219–221, 2007.
 - [38] M. Benbouriche. Virtual reality applications in forensic psychiatry. In *Proceedings of the 2014 Virtual Reality International Conference*, pages 7–10. ACM, 2014.
 - [39] K. J. Berkley and C. H. Hubscher. Are there separate central nervous system pathways for touch and pain? *Nature Medicine*, 1(8):766 – 773, 1995.
 - [40] L. Bernstein. A note on Christie’s: ”Experimental naivet and experiential naivet.”. *Psychological Bulletin*, 49(1):38–40, 1952.
 - [41] P. Bessou, P. R. Burgess, E. R. Perl, and C. B. Taylor. Dynamic properties of mechanoreceptors with unmyelinated (C) fibers. *Journal of Neurophysiology*, 34(1):116–131, 1971.
 - [42] T. Bickmore and R. Fernando. Towards empathic touch by relational agents. In *Proceedings of Autonomous Agents and Multiagent Systems*, 2009.
 - [43] T. W. Bickmore, R. Fernando, L. Ring, and D. Schulman. Empathic Touch by Relational Agents. *IEEE Transactions on Affective Computing*, 1(1):60–71, 2010.
 - [44] T. W. Bickmore and R. W. Picard. Establishing and maintaining long-term human-computer relationships. *Transactions on Computer-Human Interaction*, 12(2):293–327, June 2005.
 - [45] S. Biggs and M. Srinivasan. Haptic interfaces. In K. Stanney, editor, *Handbook of Virtual Environments: Design, Implementation, and Applications*, pages 93–115. Lawrence Erlbaum, London, 2002.
 - [46] G. Bishop. Neural mechanisms of cutaneous sense. *Physiological Reviews*, 26(1):77–102, 1946.
 - [47] M. Bjrnsdotter, L. Lken, H. Olausson, . Vallbo, and J. Wessberg. Somatotopic organization of gentle touch processing in the posterior insular cortex. *The Journal of Neuroscience*, 29(29):9314–9320, 2009.
 - [48] M. Bjrnsdotter, I. Morrison, and H. Olausson. Feeling good: on the role of C fiber mediated touch in interoception. *Experimental Brain Research*, 207(3-4):149–155, 2010.
 - [49] M. Blagrove, S.-J. Blakemore, and B. R. Thayer. The ability to self-tickle following rapid eye movement sleep dreaming. *Consciousness and Cognition*, 15:285–294, 2006.

- [50] S.-J. Blakemore, D. Bristow, G. Bird, C. Frith, and J. Ward. Somatosensory activations during the observation of touch and a case of vision-touch synaesthesia. *Brain*, 128(7):1571–1583, 2005.
- [51] S. J. Blakemore, D. M. Wolpert, and C. D. Frith. Central cancellation of self-produced tickle sensation. *Nature Neuroscience*, 1(7):635–640, 1998.
- [52] C. Boesch and H. Boesch. Tool use and tool making in wild chimpanzees. *Folia Primatologica*, 54(1-2):86–99, 1990.
- [53] O. Bogdashina. *Sensory perceptual issues in autism and Asperger Syndrome: different sensory experiences, different perceptual worlds*. Jessica Kingsley Publishers, 2003.
- [54] S. Bolanowski, R. Verrillo, and F. McGlone. Passive, active and intra-active (self) touch. *Behavioral Brain Research*, 148:41–45, 2004.
- [55] D. Bonnet, M. Ammi, and J.-C. Martin. Improvement of the recognition of facial expressions with haptic feedback. In *Haptic Audio Visual Environments and Games (HAVE), 2011 IEEE International Workshop on*, pages 81–87, Oct 2011.
- [56] N. Bostrom. Are we living in a computer simulation? *The Philosophical Quarterly*, 53(211):243–255, 2003.
- [57] M. Botvinick and J. Cohen. Rubber hands ‘feel’ touch that eyes see. *Nature*, 391(6669):756, 1998.
- [58] P. Bourdin, J. M. T. Sanahuja, C. C. Moya, P. Haggard, and M. Slater. Persuading people in a remote destination to sing by beaming there. In *Proceedings of the 19th ACM Symposium on Virtual Reality Software and Technology, VRST '13*, pages 123–132, New York, NY, USA, 2013. ACM.
- [59] J. Bowlby. The nature of the child’s tie to his mother. *The International Journal of Psycho-Analysis*, 39:350–373, 1958.
- [60] J. Bowlby. Attachment and loss: Retrospect and prospect. *American Journal of Orthopsychiatry*, 52(4):664–678, 1982.
- [61] S. Brave and A. Dahley. inTouch: a medium for haptic interpersonal communication. In *Proceedings of CHI '97*, pages 363–364. ACM, 1997.
- [62] S. Brave, C. Nass, and K. Hutchinson. Computers that care: investigating the effects of orientation of emotion exhibited by an embodied computer agent. *International Journal of Human-Computer Studies*, 62(2):161–178, 2005.
- [63] S. Brave, C. Nass, and E. Sirinian. Force-feedback in computer-mediated communication. In C. Stephanidis, editor, *Universal access in HCI: towards an information society for all*, volume 3, pages 145–149. Lawrence Erlbaum, 2001.

- [64] C. Breazeal. Emotion and sociable humanoid robots. *International Journal of Human-Computer Studies*, 59(1–2):119 – 155, 2003.
- [65] C. Breazeal. Social robots for health applications. In *Proceedings of IEEE Engineering in Medicine and Biology Society.*, pages 5368–5371, 2011.
- [66] I. Bretherton. The origins of attachment theory: John Bowlby and Mary Ainsworth. *Developmental Psychology*, 28(5):759 – 775, 1992.
- [67] A.-M. Brouwer, N. van Wouwe, C. Mühl, J. van Erp, and A. Toet. Perceiving blocks of emotional pictures and sounds: effects on physiological variables. *Frontiers in Human Neuroscience*, 2013.
- [68] L. Brown, S. Brewster, and H. Purchase. A first investigation into the effectiveness of tactons. In *Proceedings of World Haptics 2005*, pages 167–176, March 2005.
- [69] M. Brunet, F. Guy, D. Pilbeam, H. T. Mackaye, A. Likius, D. Ahounta, A. Beauvilain, C. B. H. Bocherensk, J.-R. Boisserie, L. D. Bonis, Y. Coppens, J. Dejax, C. Denys, P. Düringer, V. Eisenmann, G. Fanone, P. Fronty, D. Geraads, T. Lehmann, F. Lihoreau, A. Louchart, A. Mahamat, G. Merceron, G. Mouchelin, O. Otero, P. P. Campomanes, M. P. D. Leon, J.-C. Rage, M. Sapanetkk, M. Schusterq, J. Sudrek, P. Tassy, X. Valentin, P. Vignaud, L. Viriot, A. Zazzo, and C. Zollikofer. A new hominid from the Upper Miocene of Chad, Central Africa. *Nature*, 418:145–151, 2002.
- [70] G. Buckingham. Getting a grip on heaviness perception: a review of weight illusions and their probable causes. *Experimental Brain Research*, 232:1623–1629, 2014.
- [71] J. K. Burgoon, J. B. Walther, and E. J. Baesler. Interpretations, evaluations, and consequences of interpersonal touch. *Human Communication Research*, 19(2):237–263, 1992.
- [72] H. E. Burt. Tactual illusions of movement. *Journal of Experimental Psychology*, 2(5):371, 1917.
- [73] F. Busch, H. Nagera, and J. McKnight. Primary transitional objects. *Journal of the American Academy of Child Psychiatry*, 12(2):193–214, 1973.
- [74] J.-J. Cabibihan and S. Chauhan. Physiological responses to affective tele-touch during induced emotional stimuli. *Transactions on Affective Computing*, PP(99):1–1, 2016.
- [75] J.-J. Cabibihan, L. Zheng, and C. Cher. Affective tele-touch. In S. Ge, O. Khatib, J.-J. Cabibihan, R. Simmons, and M.-A. Williams, editors, *Social Robotics*, volume 7621 of *Lecture Notes in Computer Science*, pages 348–356. Springer Berlin Heidelberg, 2012.

- [76] J. Camps, C. Tuteleers, J. Stouten, and J. Nelissen. A situational touch: How touch affects people's decision behavior. *Social Influence*, 8(4):237, 250 2013. Article published online.
- [77] M. Carlson and F. Earls. Psychological and Neuroendocrinological Sequelae of Early Social Deprivation in Institutionalized Children in Romania. *Annals of the New York Academy of Sciences*, 807(1):419–428, 1997.
- [78] D. Carney. My position on “power poses”. http://faculty.haas.berkeley.edu/dana_carney/pdf_My%20position%20on%20power%20poses.pdf, 2016.
- [79] D. R. Carney, A. J. Cuddy, and A. J. Yap. Power posing brief nonverbal displays affect neuroendocrine levels and risk tolerance. *Psychological Science*, 21(10):1363–1368, 2010.
- [80] C. S. Carter. Neuroendocrine perspectives on social attachment and love. *Psychoneuroendocrinology*, 23(8):779 – 818, 1998.
- [81] C. J. Cascio. Somatosensory processing in neurodevelopmental disorders. *Journal of Neurodevelopmental Disorders*, 2(2):62–69, 2010.
- [82] T. F. Cash and E. A. Deagle. The nature and extent of body-image disturbances in anorexia nervosa and bulimia nervosa: A meta-analysis. *International Journal of Eating Disorders*, 22(2):107–126, 1997.
- [83] W. Caudill and H. Weinstein. Maternal Care and Infant Behavior in Japan and America. *Psychiatry: Interpersonal and Biological Processes*, 32(1):12–43, 1969.
- [84] N. Cauna. Nature and functions of the papillary ridges of the digital skin. *The Anatomical Record*, 119(4):449–468, 1954.
- [85] B. L. Chan, R. Witt, A. P. Charrow, A. Magee, R. Howard, P. F. Pasquina, and J. W. Tsao. Mirror therapy for phantom limb pain. *New England Journal of Medicine*, 357(21):2206–2207, 2007.
- [86] A. Chang, S. O'Modhrain, R. Jacob, E. Gunther, and H. Ishii. Comtouch: design of a vibrotactile communication device. In *Proceedings of DIS '02*, pages 312–320. ACM, 2002.
- [87] W. F. Chaplin, J. B. Phillips, J. D. Brown, N. R. Clanton, and J. L. Stein. Hand-shaking, gender, personality, and first impressions. *Journal of Personality and Social Psychology*, 79(1):110 – 117, 2000.
- [88] S. Chatterjee and A. Hadi. *Regression analysis by example*. John Wiley & Sons, Ltd., 2006.
- [89] A. Chellali, C. Dumas, and I. Milleville-Pennel. Influences of haptic communication on a shared manual task. *Interacting with Computers*, 23(4):317 – 328, 2011.

- [90] L. M. Chen, R. M. Friedman, and A. Roe. Optical imaging of a tactile illusion in area 3b of the primary somatosensory cortex. *Science*, 302(5646):881–885, 2003.
- [91] T. Chen, C.-H. King, A. Thomaz, and C. Kemp. An investigation of responses to robot-initiated touch in a nursing context. *International Journal of Social Robotics*, 6(1):141–161, 2014.
- [92] T. L. Chen, C.-H. King, A. L. Thomaz, and C. C. Kemp. Touched by a robot: An investigation of subjective responses to robot-initiated touch. In *Proceedings of the 6th International Conference on Human-robot Interaction, HRI '11*, pages 457–464, New York, NY, USA, 2011. ACM.
- [93] R. Cholewiak and A. Collins. The generation of vibrotactile patterns on a linear array: Influences of body site, time, and presentation mode. *Perception & Psychophysics*, 62(6):1220–1235, 2000.
- [94] R. Cholewiak and A. Collins. Vibrotactile localization on the arm: Effects of place, space, and age. *Attention, Perception, & Psychophysics*, 65:1058–1077, 2003.
- [95] W. J. Chopik, R. S. Edelstein, S. M. van Anders, B. M. Wardecker, E. L. Shipman, and C. R. Samples-Steele. Too close for comfort? adult attachment and cuddling in romantic and parent-child relationships. *Personality and Individual Differences*, 69(0):212 – 216, 2014.
- [96] V. G. Chouvardas, A. N. Miliou, and M. K. Hatalis. Tactile displays: a short overview and recent developments. In *Proceedings of the 5th International Conference on Technology and Automation*, pages 246–251, 2005.
- [97] R. Christie. Experimental naïveté and experiential naïveté. *Psychological Bulletin*, 48(4):327–339, 1951.
- [98] H. T. Chugani, M. E. Behen, O. Muzik, C. Juhász, F. Nagy, and D. C. Chugani. Local brain functional activity following early deprivation: A study of postinstitutionalized romanian orphans. *NeuroImage*, 14(6):1290 – 1301, 2001.
- [99] K. Chung, C. Chiu, X. Xiao, and P.-Y. P. Chi. Stress outsourced: a haptic social network via crowdsourcing. In *Proceedings of CHI '09*, pages 2439–2448. ACM, 2009.
- [100] R. Clarke. Approved school boy absconders and corporal punishment. *The British Journal of Criminology*, 6(4):364–375, 1966.
- [101] C. Classen. *The Deepest Sense: A Cultural History of Touch*. University of Illinois Press, 2012.
- [102] J. A. Coan, H. S. Schaefer, and R. J. Davidson. Lending a Hand: Social Regulation of the Neural Response to Threat. *Psychological Science*, 17(12):1032–1039, 2006.

- [103] T. J.Coderre, J. Katz, A. L. Vaccarino, and R. Melzack. Contribution of central neuroplasticity to pathological pain: review of clinical and experimental evidence. *Pain*, 52:259–285, 1993.
- [104] J. Cohen. *Statistical power analysis for the behavioral sciences*. Psychology Press, 1988.
- [105] S. Cohen, D. Janicki-Deverts, R. B. Turner, and W. J. Doyle. Does Hugging Provide Stress-Buffering Social Support? A Study of Susceptibility to Upper Respiratory Infection and Illness. *Psychological Science*, 2014.
- [106] J. Cole. The neuroscience and phenomenology of sensory loss. In M. Grunwald, editor, *Human haptic perception: basics and applications*, pages 295 – 301. Birkhäuser, 2008.
- [107] J. Cole. Intimacy; views from impairment and neuroscience. *Emotion, Space and Society*, 13:87–94, 2014.
- [108] A. Cooper, D. L. Delmonico, and R. Burg. Cybersex users, abusers, and compulsives: New findings and implications. *Sexual Addiction & Compulsivity*, 7(1-2):5–29, 2000.
- [109] S. Costa, H. Lehmann, K. Dautenhahn, B. Robins, and F. Soares. Using a humanoid robot to elicit body awareness and appropriate physical interaction in children with autism. *International Journal of Social Robotics*, pages 1–14, 2014.
- [110] A. Craig and M. Bushnell. The thermal grillillusion: Unmasking the burn of cold pain. *Science*, 265(5169):252–255, 1994.
- [111] H. Cramer, N. Kemper, A. Amin, B. Wielinga, and V. Evers. ‘Give me a hug’: the effects of touch and autonomy on people’s responses to embodied social agents. *Computer Animation and Virtual Worlds*, 20(2-3):437–445, 2009.
- [112] S. Craven, S. Brown, and E. Gilchrist. Sexual grooming of children: Review of literature and theoretical considerations. *Journal of Sexual Aggression*, 12(3):287–299, 2006.
- [113] L. Crucianelli, N. Metcalf, A. Fotopoulou, and P. Jenkinson. Bodily pleasure matters: velocity of touch modulates body ownership during the rubber hand illusion. *Frontiers in Psychology*, 4:703, 2013.
- [114] A. H. Crusco and C. G. Wetzal. The Midas Touch: The Effects of Interpersonal Touch on Restaurant Tipping. *Personality and Social Psychology Bulletin*, 10(4):512–517, 1984.
- [115] R. S. Dahiya, G. Metta, M. Valle, and G. Sandini. Tactile sensing—from humans to humanoids. *Transactions on Robotics*, 26(1):1–20, 2010.

- [116] D. M. Dalby, J. P. Hirdes, P. Stolee, J. G. Strong, J. Poss, E. Y. Tjam, L. Bowman, and M. Ashworth. Characteristics of individuals with congenital and acquired deaf-blindness. *Journal of Visual Impairment & Blindness*, 103(2):93–102, 2009.
- [117] K. M. Dallenbach. Some new apparatus. *The American Journal of Psychology*, 34(1):90–95, 1923.
- [118] J. Dammeyer. Mental and behavioral disorders among people with congenital deafblindness. *Research in Developmental Disabilities*, 32(2):571–575, 2011.
- [119] I. Darian-Smith. The sense of touch: performance and peripheral neural processes. In J. Brookhart, V. Mountcastle, I. Darian-Smith, and S. Geiger, editors, *Handbook of Physiology*, pages 739–788. American Physiological Society, 1984.
- [120] K. Dautenhahn, S. Woods, C. Kaouri, M. L. Walters, K. L. Koay, and I. Werry. What is a robot companion – friend, assistant or butler? In *IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 1192–1197. IEEE, 2005.
- [121] A. Debrot, D. Schoebi, M. Perrez, and A. B. Horn. Touch as an interpersonal emotion regulation process in couples’ daily lives: The mediating role of psychological intimacy. *Personality and Social Psychology Bulletin*, 2013.
- [122] N. Dechev, W. Cleghorn, and S. Naumann. Multiple finger, passive adaptive grasp prosthetic hand. *Mechanism and Machine Theory*, 36(10):1157–1173, 2001.
- [123] J. F. Deethardt and D. G. Hines. Tactile communication and personality differences. *Journal of Nonverbal Behavior*, 8(2):143–156, 1983.
- [124] R. D. Deidiker. Accidental ligature strangulation due to a roller-type massage device. *The American Journal of Forensic Medicine and Pathology*, 20(4):354–356, 1999.
- [125] G. Di Giulio. Sexuality and people living with physical or developmental disabilities: a review of key issues. *The Canadian Journal of Human Sexuality*, 12(1):53–68, 2003.
- [126] C. DiSalvo, F. Gemperle, J. Forlizzi, and E. Montgomery. The hug: an exploration of robotic form for intimate communication. In *Proceedings of International Workshop on Robot and Human Interactive Communication. ROMAN 2003.*, pages 403–408, Oct 2003.
- [127] B. Ditzen, I. D. Neumann, G. Bodenmann, B. von Dawans, R. A. Turner, U. Ehlert, and M. Heinrichs. Effects of different kinds of couple interaction on cortisol and heart rate responses to stress in women. *Psychoneuroendocrinology*, 32(5):565 – 574, 2007.
- [128] K. Dobson, D. Boyd, W. Ju, J. Donath, and H. Ishii. Creating visceral personal and social interactions in mediated spaces. In *Proceedings of CHI ’01*, pages 151–152. ACM, 2001.

- [129] C. Dodge. The bed: A medium for intimate communication. In *CHI '97 Extended Abstracts on Human Factors in Computing Systems*, pages 371–372, New York, NY, USA, 1997. ACM.
- [130] G. Dölen, A. Darvishzadeh, K. W. Huang, and R. C. Malenka. Social reward requires coordinated activity of nucleus accumbens oxytocin and serotonin. *Nature*, 501(7466):179–184, 2013.
- [131] D. Dolinski. Touch, compliance, and homophobia. *Journal of Nonverbal Behavior*, 34(3):179–192, 2010.
- [132] N. M. Döring. The Internet’s impact on sexuality: A critical review of 15 years of research. *Computers in Human Behavior*, 25(5):1089–1101, 2009.
- [133] S. Dorros, A. Hanzala, and C. Segrin. The big five personality traits and perceptions of touch to intimate and nonintimate body regions. *Journal of Research in Personality*, 42(4):1067–1073, 2008.
- [134] W. Douglas and J. Ritchie. Non-medullated fibres in the saphenous nerve which signal touch. *The Journal of Physiology*, 139(3):385–399, 1957.
- [135] V. M. Drescher, W. H. Gantt, and W. E. Whitehead. Heart rate response to touch. *Psychosomatic Medicine*, 42(6):559–65, 1980.
- [136] M. Drouin, D. H. Kaiser, and D. A. Miller. Phantom vibrations among undergraduates: Prevalence and associated psychological characteristics. *Computers in Human Behavior*, 28(4):1490–1496, 2012.
- [137] M. Eaton, I. L. Mitchell-bonair, and E. Friedmann. The effect of touch on nutritional intake of chronic organic brain syndrome patients. *Journal of Gerontology*, 41(5):611–616, 1986.
- [138] S. J. H. Ebisch, F. Ferri, A. Salone, M. G. Perrucci, L. D’Amico, F. M. Ferro, G. L. Romani, and V. Gallese. Differential involvement of somatosensory and interoceptive cortices during the observation of affective touch. *Journal of Cognitive Neuroscience*, 7(1808-1822), 23.
- [139] S. J. H. Ebisch, M. G. Perrucci, A. Ferretti, C. D. Gratta, G. L. Romani, and V. Gallese. The sense of touch: Embodied simulation in a visuotactile mirroring mechanism for observed animate or inanimate touch. *Journal of Cognitive Neuroscience*, 20(9):1611–1623, 2008.
- [140] H. H. Ehrsson, N. P. Holmes, and R. E. Passingham. Touching a rubber hand: Feeling of body ownership is associated with activity in multisensory brain areas. *The Journal of Neuroscience*, 25(45):10564–10573, 2005.
- [141] E. Eichhorn, R. Wettach, and E. Hornecker. A stroking device for spatially separated couples. In *Proceedings of the 10th International Conference on Human Computer Interaction with Mobile Devices and Services*, pages 303–306, New York, NY, USA, 2008. ACM.

- [142] P. Ekman and E. L. Rosenberg. *What the face reveals: Basic and applied studies of spontaneous expression using the Facial Action Coding System (FACS)*. Oxford University Press, 1997.
- [143] H. A. Elfenbein and N. Ambady. On the universality and cultural specificity of emotion recognition: A meta-analysis. *Psychological Bulletin*, 128(2):203–235, 2002.
- [144] N. Elias. *The Civilizing Process: Sociogenetic and Psychogenetic Investigations*. Blackwell Publishing, 2000.
- [145] D.-M. Ellingsen, J. Wessberg, O. Chelnokova, H. Olausson, B. Laeng, and S. Leknes. In touch with your emotions: Oxytocin and touch change social impressions while others’ facial expressions can alter touch. *Psychoneuroendocrinology*, 39:11 – 20, 2014.
- [146] D. Erceau and N. Guéguen. Tactile contact and evaluation of the toucher. *The Journal of Social Psychology*, 147(4):441–444, 2007.
- [147] C. J. Erickson. Percussive foraging in the aye-aye, *Daubentonia madagascariensis*. *Animal Behavior*, 41(5):793–801, 1991.
- [148] S. M. Erk, A. Toet, and J. B. Van Erp. Effects of mediated social touch on affective experiences and trust. *PeerJ*, 3:e1297, 2015.
- [149] E. Ernst. The safety of massage therapy. *Rheumatology*, 42(9):1101–1106, 2003.
- [150] A. Escalona, T. Field, R. Singer-Strunck, C. Cullen, and K. Hartshorn. Brief report: Improvements in the behavior of children with autism following massage therapy. *Journal of Autism and Developmental Disorders*, 31(5):513–516, 2001.
- [151] G. Essick, A. James, and F. McGlone. Psychophysical assessment of the affective components of non-painful touch. *NeuroReport*, 10(10):2083 – 2087, 1999.
- [152] G. K. Essick, F. McGlone, C. Dancer, D. Fabricant, Y. Ragin, N. Phillips, T. Jones, and S. Guest. Quantitative assessment of pleasant touch. *Neuroscience & Biobehavioral Reviews*, 34(2):192 – 203, 2010.
- [153] R. Etzi, C. Spence, and A. Gallace. Textures that we like to touch: An experimental study of aesthetic preferences for tactile stimuli. *Consciousness and Cognition*, 29(0):178 – 188, 2014.
- [154] European Space Agency. Historic handshake between space and earth. http://www.esa.int/Our_Activities/Human_Spaceflight/Historic_handshake_between_space_and_Earth, June 2015.
- [155] M. T. Fairhurst, L. Löken, and T. Grossmann. Physiological and behavioral responses reveal 9-month-old infants’ sensitivity to pleasant touch. *Psychological Science*, 25(5):1124–1131, 2014.

- [156] R. Feldman. Oxytocin and social affiliation in humans. *Hormones and Behavior*, 61(3):380 – 391, 2012. Oxytocin, Vasopressin and Social Behavior.
- [157] R. Feldman, M. Singer, and O. Zagoory. Touch attenuates infants' physiological reactivity to stress. *Developmental Science*, 13(2):271–278, 2010.
- [158] S. G. Ferber, R. Feldman, and I. R. Makhoul. The development of maternal touch across the first year of life. *Early Human Development*, 84(6):363–370, 2008.
- [159] T. Field. *Touch*. MIT Press, 2001.
- [160] T. Field, M. Diego, and M. Hernandez-Reif. Massage therapy research. *Developmental Review*, 27(1):75 – 89, 2007.
- [161] T. M. Field. Massage therapy effects. *American Psychologist*, 53(12):1270–1283, 1998.
- [162] A. Fine. *Handbook on Animal-Assisted Therapy: Theoretical Foundations and Guidelines for Practice*. Academic Press, 2010.
- [163] J. D. Fisher, M. Rytting, and R. Heslin. Hands touching hands: Affective and evaluative effects of an interpersonal touch. *Sociometry*, 39(4):pp. 416–421, 1976.
- [164] K. Floyd. All touches are not created equal: Effects of form and duration on observers' interpretations of an embrace. *Journal of Nonverbal Behavior*, 23(4):283–299, 1999.
- [165] B. Fogg, L. D. Cutler, P. Arnold, and C. Eisbach. Handjive: A device for interpersonal haptic entertainment. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '98, pages 57–64, New York, NY, USA, 1998. ACM Press/Addison-Wesley Publishing Co.
- [166] P. Fonagy, H. Steele, and M. Steele. Maternal representations of attachment during pregnancy predict the organization of infant-mother attachment at one year of age. *Child Development*, 62(5):891–905, 1991.
- [167] T. Fong, I. Nourbakhsh, and K. Dautenhahn. A survey of socially interactive robots. *Robotics and Autonomous Systems*, 42(3–4):143 – 166, 2003. Socially Interactive Robots.
- [168] R. Forget and Y. Lamarre. Postural adjustments associated with different unloadings of the forearm: effects of proprioceptive and cutaneous afferent deprivation. *Canadian Journal of Physiology and Pharmacology*, 73(2):285–294, 1995.
- [169] K. Fortuna, L. Baor, S. Israel, A. Abadi, and A. Knafo. Attachment to inanimate objects and early childcare: A twin study. *Frontiers in Psychology*, 5:1–7, 2014.
- [170] R. C. Fraley and P. R. Shaver. Adult romantic attachment: Theoretical developments, emerging controversies, and unanswered questions. *Review of General Psychology*, 4(2):132 – 154, 2000.

- [171] S. Francis, E. Rolls, R. Bowtell, F. McGlone, J. O'Doherty, A. Browning, S. Clare, and E. Smith. The representation of pleasant touch in the brain and its relationship with taste and olfactory areas. *Neuro Report*, 10(3):453–459, 1999.
- [172] D. K. Fromme, W. E. Jaynes, D. K. Taylor, E. G. Hanold, J. Daniell, J. R. Rountree, and M. L. Fromme. Nonverbal behavior and attitudes toward touch. *Journal of Nonverbal Behavior*, 13(1):3–14, 1989.
- [173] H. Fukuda, M. Shiomi, K. Nakagawa, and K. Ueda. 'Midas touch' in human-robot interaction: Evidence from event-related potentials during the ultimatum game. In *Proceedings of International Conference on Human-Robot Interaction 2012*, pages 131–132, 2012.
- [174] M. Furukawa, H. Kajimoto, and S. Tachi. Kusuguri: A shared tactile interface for bidirectional tickling. In *Proceedings of the 3rd Augmented Human International Conference*, AH '12, pages 9:1–9:8, New York, NY, USA, 2012. ACM.
- [175] Y. Gaffary, V. Eyharabide, J.-C. Martin, and M. Ammi. The impact of combining kinesthetic and facial expression displays on emotion recognition by users. *International Journal of Human-Computer Interaction*, 30(11):904–920, 2014.
- [176] A. Gallace and C. Spence. The science of interpersonal touch: an overview. *Neuroscience and Biobehavioral Reviews*, 34(2):246–59, 2010.
- [177] A. Gallace and C. Spence. To what extent do gestalt grouping principles influence tactile perception? *Psychological Bulletin*, 137(4):538–561, 2011.
- [178] A. Gallace and C. Spence. *In Touch With the Future: The sense of touch from cognitive neuroscience to virtual reality*. Oxford University Press, 2014.
- [179] A. Gallace, H. Z. Tan, and C. Spence. The Body Surface as a Communication System: The State of the Art after 50 Years. *Presence: Teleoperators and Virtual Environments*, 16(6):655–676, 2007.
- [180] J. R. Garcia, C. Reiber, S. G. Massey, and A. M. Merriwether. Sexual hookup culture: A review. *Review of General Psychology*, 16(2):161–176, 2012.
- [181] Y. F. A. Gaus, T. Olugbade, A. Jan, R. Qin, J. Liu, F. Zhang, H. Meng, and N. Bianchi-Berthouze. Social touch gesture recognition using random forest and boosting on distinct feature sets. In *Proceedings of ICMI 2015*, pages 399–406, 2015.
- [182] V. Gazzola, M. L. Spezio, J. A. Etzel, F. Castelli, R. Adolphs, and C. Keysers. Primary somatosensory cortex discriminates affective significance in social touch. *Proceedings of the National Academy of Sciences*, 109(25):E1657–E1666, 2012.
- [183] F. A. Geldard. Adventures in tactile literacy. *American Psychologist*, 12(3):115–124, 1957.

- [184] F. A. Geldard. Saltation in somesthesia. *Psychological Bulletin*, 92(1):136 – 175, 1982.
- [185] F. A. Geldard and C. E. Sherrick. The cutaneous “rabbit”: A perceptual illusion. *Science*, 178(4057):178–179, 1972.
- [186] F. Gemperle, C. Kasabach, J. Stivoric, M. Bauer, and R. Martin. Design for wearability. In *Proceedings of the Second International Symposium on Wearable Computers*, pages 116–122. IEEE, 1998.
- [187] J. R. Georgiadis, M. L. Kringelbach, and J. G. Pfaus. Sex for fun: a synthesis of human and animal neurobiology. *Nature Reviews Urology*, 9(9):486–498, 2012.
- [188] E. T. Gershoff. Corporal punishment by parents and associated child behaviors and experiences: A meta-analytic and theoretical review. *Psychological Bulletin*, 128(4):539–579, 2002.
- [189] E. Giannopoulos, V. Eslava, M. Oyarzabal, T. Hierro, L. González, M. Ferre, and M. Slater. The effect of haptic feedback on basic social interaction within shared virtual environments. In M. Ferre, editor, *Haptics: Perception, Devices and Scenarios*, Lecture Notes in Computer Science, pages 301–307. Springer Berlin Heidelberg, 2008.
- [190] J. J. Gibson. Observations on active touch. *Psychological Review*, 69(6):477–491, 1962.
- [191] G. C. Gilmore. Inappropriate use of covariate analysis renders meaningless results. *Journal of the International Neuropsychological Society*, 13(2):370, 2007.
- [192] G. Gioberto, J. Coughlin, K. Bibeau, and L. E. Dunne. Detecting bends and fabric folds using stitched sensors. In *Proceedings of the 2013 International Symposium on Wearable Computers*, ISWC ’13, pages 53–56, New York, NY, USA, 2013. ACM.
- [193] M. Gleeson and F. Timmins. A review of the use and clinical effectiveness of touch as a nursing intervention. *Clinical Effectiveness in Nursing*, 9(1):69–77, 2005.
- [194] M. Goldman, O. Kiyohara, and D. A. Pfannensteil. Interpersonal touch, social labeling, and the foot-in-the-door effect. *The Journal of Social Psychology*, 125(2):143–147, 1985.
- [195] H. Goldsmith and J. A. Alansky. Maternal and infant temperamental predictors of attachment: A meta-analytic review. *Journal of Consulting and Clinical Psychology*, 55(6):805–816, 1987.
- [196] D. Gooch and L. Watts. Communicating social presence through thermal hugs. In *Proceedings of 1st Workshop on Social Interaction in Spatially Separated Environments*, UbiComp ’10, pages 11–19, 2010.

- [197] D. Gooch and L. Watts. Yourgloves, hothands and hotmits: Devices to hold hands at a distance. In *Proceedings of the 25th Annual ACM Symposium on User Interface Software and Technology*, UIST '12, pages 157–166, New York, NY, USA, 2012. ACM.
- [198] I. Gordon, A. C. Voos, R. H. Bennett, D. Z. Bolling, K. A. Pelphrey, and M. D. Kaiser. Brain mechanisms for processing affective touch. *Human Brain Mapping*, 34(4):914–922, 2013.
- [199] G. Gottlieb. Ontogenesis of sensory function in birds and mammals. In E. Tobach, L. Aronson, and E. Shaw, editors, *The Biopsychology of Development*, pages 67 – 128. Academic press, 1971.
- [200] J. Gratch, J. Rickel, E. André, J. Cassell, E. Petajan, and N. Badler. Creating interactive virtual humans: Some assembly required. Technical report, DTIC Document, 2002.
- [201] L. Gray, L. Watt, and E. M. Blass. Skin-to-skin contact is analgesic in healthy newborns. *Pediatrics*, 105(1):e14, 2000.
- [202] K. M. Grewen, B. J. Anderson, S. S. Girdler, and K. C. Light. Warm partner contact is related to lower cardiovascular reactivity. *Behavioral Medicine*, 29(3):123–130, 2003.
- [203] M. Grunwald and M. John. German pioneers of research into human haptic perception. In M. Grunwald, editor, *Human haptic perception: basics and applications*, chapter 1, pages 3 – 13. Birkhäuser, 2008.
- [204] N. Guéguen. Touch, Awareness, of Touch, and Compliance with a Request. *Perceptual and Motor Skills*, 95:355–360, 2002.
- [205] N. Guéguen, F. Afifi, S. Brault, V. Charles-Sire, P.-M. Leforestier, A. Morzedec, and E. Piron. Failure of Tactile Contact to Increase Request Compliance: The Case of Blood Donation Behavior. *Journal of Articles in Support of the Null Hypothesis*, 8(1):1–8, 2011.
- [206] N. Guéguen and J. Fischer-lokou. Tactile contact and spontaneous help: An evaluation in a natural setting. *The Journal of Social Psychology*, 143(6):785–787, 2003.
- [207] N. Guéguen and C. Jacob. The effect of touch on tipping: an evaluation in a french bar. *International Journal of Hospitality Management*, 24(2):295 – 299, 2005.
- [208] N. Guéguen, C. Jacob, and G. Boulbry. The effect of touch on compliance with a restaurant’s employee suggestion. *International Journal of Hospitality Management*, 26(4):1019 – 1023, 2007.

- [209] N. Guéguen, S. Meineri, and V. Charles-Sire. Improving medication adherence by using practitioner nonverbal techniques: a field experiment on the effect of touch. *Journal of Behavioral Medicine*, 33(6):466–473, 2010.
- [210] L. K. Guerrero and P. A. Andersen. The waxing and waning of relational intimacy: Touch as a function of relational stage, gender and touch avoidance. *Journal of Social and Personal Relationships*, 8(2):147–165, 1991.
- [211] L. K. Guerrero and P. A. Andersen. Patterns of matching and initiation: Touch behavior and touch avoidance across romantic relationship stages. *Journal of Nonverbal Behavior*, 18(2):137–153, 1994.
- [212] S. Guest, J. Dessirier, A. Mehrabyan, F. McGlone, G. Essick, G. Gescheider, A. Fontana, R. Xiong, R. Ackerley, and K. Blot. The development and validation of sensory and emotional scales of touch perception. *Attention, Perception, & Psychophysics*, 73(2):531–550, 2011.
- [213] A. Gullledge, M. Hill, Z. Lister, and C. Sallion. Non-erotic physical affection: It's good for you. In L. L'Abate, editor, *Low-Cost Approaches to Promote Physical and Mental Health*, pages 371–384. Springer New York, 2007.
- [214] A. K. Gullledge, M. H. Gullledge, and R. F. Stahmann. Romantic physical affection types and relationship satisfaction. *The American Journal of Family Therapy*, 31(4):233–242, 2003.
- [215] G. Guthart and J. K. Salisbury Jr. The Intuitive™ Telesurgery System: Overview and Application. In *Proceedings of Robotics and Automation 2000*, pages 618–621, 2000.
- [216] J. Guthman. Fast food/organic food: Reflexive tastes and the making of yuppie chow. *Social & Cultural Geography*, 4(1):45–58, 2003.
- [217] A. Haans, R. de Bruijn, and W. IJsselsteijn. A Virtual Midas Touch? Touch, Compliance, and Confederate Bias in Mediated Communication. *Journal of Nonverbal Behavior*, 38(3):301–311, 2014.
- [218] A. Haans, C. de Nood, and W. A. IJsselsteijn. Investigating response similarities between real and mediated social touch: a first test. In *Proceedings of CHI '07*, pages 2405–2410. ACM, 2007.
- [219] A. Haans and W. IJsselsteijn. Mediated social touch: a review of current research and future directions. *Virtual Reality*, 9(2-3):149–159, 2006.
- [220] A. Haans and W. IJsselsteijn. Combining mediated social touch with vision: From self-attribution to telepresence? In A. Nijholt, D. E.O., and P. Lemmens, editors, *Proceedings of Special Symposium at EuroHaptics 2010: Haptic and Audio-Visual Stimuli: Enhancing Experiences and Interaction.*, pages 35–46. 2010.

- [221] A. Haans and W. A. IJsselsteijn. I'm always touched by your presence, dear": Combining mediated social touch with morphologically correct visual feedback. In *Proceedings of Presence 2009*, pages 1–6, 2009.
- [222] A. Haans and W. A. IJsselsteijn. The Virtual Midas Touch: Helping Behavior After a Mediated Social Touch. *IEEE Transactions on Haptics*, 2(3):136–140, 2009.
- [223] Y. Haile-Selassie. Late miocene hominids from the middle awash, ethiopia. *Nature*, 412:178–181, 2001.
- [224] Z. Halata and K. I. Baumann. Anatomy of receptors. In M. Grunwald, editor, *Human haptic perception: basics and applications*, pages 85–92. Birkhäuser, 2008.
- [225] K. Hale and K. Stanney. Deriving haptic design guidelines from human physiological, psychophysical, and neurological foundations. *Computer Graphics and Applications, IEEE*, 24(2):33–39, 2004.
- [226] J. A. Hall. Touch, status, and gender at professional meetings. *Journal of Nonverbal Behavior*, 20(1):23–44, 1996.
- [227] H. F. Harlow. The nature of love. *The American Psychologist*, 13(12):673 – 685, 1958.
- [228] C. Harms and F. Biocca. Internal consistency and reliability of the networked minds measure of social presence. In M. Alcaniz and B. Rey, editors, *Proceedings of the 7th Annual International Workshop on Presence*, 2004.
- [229] P. Hart. Using imitation with congenitally deafblind adults: Establishing meaningful communication partnerships. *Infant and Child Development*, 15(3):263–274, 2006.
- [230] A. Hart-Davis. *History: From the Dawn of Civilization to the Present Day*. Penguin, 2007.
- [231] H. Hashimoto and S. Manoratkul. Tele-handshake through the internet. In *International Workshop on Robot and Human Communication*, pages 90–95, Nov 1996.
- [232] L. C. Hawkey and J. T. Cacioppo. Loneliness matters: a theoretical and empirical review of consequences and mechanisms. *Annals of Behavioral Medicine*, 40(2):218–227, 2010.
- [233] V. Hayward. A brief taxonomy of tactile illusions and demonstrations that can be done in a hardware store. *Brain Research Bulletin*, 75:742–752, 2008.
- [234] V. Hayward, O. Astley, M. Cruz-Hernandez, D. Grant, and G. Robles-De-La-Torre. Haptic interfaces and devices. *Sensor Review*, 24(1):16–29, 2004.
- [235] V. Hayward and K. MacLean. Do it yourself haptics: part I. *Robotics Automation Magazine, IEEE*, 14(4):88–104, Dec 2007.

- [236] M. A. Heller and D. S. Myers. Active and passive tactual recognition of form. *The Journal of General Psychology*, 108:225–229, 1983.
- [237] N. M. Henley. The politics of touch. In P. Brown, editor, *Radical Psychology*, pages 420 – 433. Colophon Books, 1973.
- [238] L. Henningh. Functions and Limitations of Alaskan Eskimo Wife Trading. *Arctic*, 23(1):24–34, 1970.
- [239] M. Henricson, A. Ersson, S. Määttä, K. Segesten, and A.-L. Berglund. The outcome of tactile touch on stress parameters in intensive care: A randomized controlled trial. *Complementary Therapies in Clinical Practice*, 14(4):244 – 254, 2008.
- [240] P. G. Hepper. Haptic perception in the human fetus. In M. Grunwald, editor, *Human haptic perception: basics and applications*, chapter 11, pages 149–154. Birkhäuser, 2008.
- [241] M. Hertenstein. Touch: Its Communicative Functions in Infancy. *Human Development*, 45(2):70–94, 2002.
- [242] M. Hertenstein and D. Keltner. Gender and the communication of emotion via touch. *Sex Roles*, 64(1-2):70–80, 2011.
- [243] M. J. Hertenstein and J. J. Campos. Emotion regulation via maternal touch. *Infancy*, 2(4):549–566, 2001.
- [244] M. J. Hertenstein, R. Holmes, M. McCullough, and D. Keltner. The communication of emotion via touch. *Emotion*, 9(4):566–573, 2009.
- [245] M. J. Hertenstein, D. Keltner, B. App, B. a. Bulleit, and A. R. Jaskolka. Touch communicates distinct emotions. *Emotion*, 6(3):528–33, 2006.
- [246] M. J. Hertenstein, J. M. Verkamp, A. M. Kerestes, and R. M. Holmes. The communicative functions of touch in humans, nonhuman primates, and rats: A review and synthesis of the empirical research. *Genetic, Social, and General Psychology Monographs*, 132(1):5–94, 2006.
- [247] R. Heslin, T. Nguyen, and M. Nguyen. Meaning of touch: The case of touch from a stranger or same sex person. *Journal of Nonverbal Behavior*, 7(3):147–157, 1983.
- [248] J. Hewitt and D. Feltham. Differential reaction to touch by men and women. *Perceptual and Motor Skills*, 55(3f):1291–1294, 1982.
- [249] C. Hieida, K. Abe, M. Attamimi, T. Shimotomai, T. Nagai, and T. Omori. Physical embodied communication between robots and children: An approach for relationship building by holding hands. In *Proceedings of Intelligent Robots and Systems 2014*, pages 3291–3298, Sept 2014.

- [250] E. Hoggan, C. Stewart, L. Haverinen, G. Jacucci, and V. Lantz. Pressages: augmenting phone calls with non-verbal messages. In *Proceedings of UIST'12*, pages 555–562. ACM, 2012.
- [251] J. Hornik. Tactile stimulation and consumer response. *Journal of Consumer Research*, 19(3):pp. 449–458, 1992.
- [252] J. A. Horton, P. R. Clance, C. Sterk-Elifson, and J. Emshoff. Touch in psychotherapy: A survey of patients' experiences. *Psychotherapy: Theory, Research, Practice*, 32(3):443–457, 1995.
- [253] S. Hsiao and J. Yau. Neural basis of haptic perception. In M. Grunwald, editor, *Human haptic perception: basics and applications*, pages 103 – 112. Birkhäuser, 2008.
- [254] E. Hsu. Figurately speaking of 'danger of death' in Chinese pulse diagnostics. In R. Jütte, M. Eklöf, and M. Nelson, editors, *Historical aspects of unconventional medicine. Approaches, concepts, case studies*, pages 193–210. EAHHM-Publications, 2001.
- [255] D. Hughes, N. Farrow, H. Profita, and N. Correll. Detecting and identifying tactile gestures using deep autoencoders, geometric moments and gesture level features. In *Proceedings of ICMI 2015*, pages 415–422, 2015.
- [256] W. S. Hulin. An experimental study of apparent tactual movement. *Journal of Experimental Psychology*, 10(4):293 – 320, 1927.
- [257] W. A. IJsselsteijn, Y. A. De Kort, and A. Haans. Is this my hand I see before me? The rubber hand illusion in reality, virtual reality, and mixed reality. *Presence*, 15(4):455–464, 2006.
- [258] W. A. IJsselsteijn, H. de Ridder, J. Freeman, and S. E. Avons. Presence: concept, determinants, and measurement. In *Proceedings of SPIE*, volume 3959, pages 520–529, 2000.
- [259] T. R. Insel. Toward a neurobiology of attachment. *Review of General Psychology*, 4(2):176 – 185, 2000.
- [260] S. Ishiyama and M. Brecht. Neural correlates of ticklishness in the rat somatosensory cortex. *Science*, 354(6313):757–760, 2016.
- [261] A. Israr and I. Poupyrev. Control space of apparent haptic motion. In *Proceedings of WHC'11*, pages 457 –462. IEEE, 2011.
- [262] A. Israr and I. Poupyrev. Tactile brush: drawing on skin with a tactile grid display. In *Proceedings of CHI '11*, pages 2019–2028. ACM, 2011.
- [263] H. Iwata. History of haptic interface. In M. Grunwald, editor, *Human haptic perception: basics and applications*, chapter 29, pages 355–361. Birkhäuser, 2008.

- [264] A. D. Jean and D. M. Stack. Functions of maternal touch and infants' affect during face-to-face interactions: New directions for the still-face. *Infant Behavior and Development*, 32(1):123–128, 2009.
- [265] L. M. Johaneck, R. A. Meyer, T. Hartke, J. G. Hobelmann, D. N. Maine, R. H. LaMotte, and M. Ringkamp. Psychophysical and physiological evidence for parallel afferent pathways mediating the sensation of itch. *The Journal of Neuroscience*, 27(28):7490–7497, 2007.
- [266] R. Johansson and Å. Vallbo. Tactile sensibility in the human hand: relative and absolute densities of four types of mechanoreceptive units in glabrous skin. *The Journal of Physiology*, 286(1):283–300, 1979.
- [267] R. S. Johansson, M. Trulsson, K. A. Olsson, and K. G. Westberg. Mechanoreceptor activity from the human face and oral mucosa. *Experimental Brain Research*, 72:204–208, 1988.
- [268] K. Johnson, T. Yoshioka, and F. Vega-Bermudez. Tactile Functions of Mechanoreceptive Afferents Innervating the Hand. *Journal of Clinical Neurophysiology*, 17(6):539–558, 2000.
- [269] K. O. Johnson. The roles and functions of cutaneous mechanoreceptors. *Current Opinion in Neurobiology*, 11(4):455–461, 2001.
- [270] L. A. Jones, B. Lockyer, and E. Piatetski. Tactile display and vibrotactile recognition on the torso. *Advanced Robotics*, 20(12):1359–1374, 2006.
- [271] L. A. Jones and N. B. Sarter. Tactile displays: Guidance for their design and application. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 50(1):90–111, 2008.
- [272] S. E. Jones and A. E. Yarbrough. A naturalistic study of the meanings of touch. *Communication Monographs*, 52(1):19–56, 1985.
- [273] S. M. Jourard. An exploratory study of body-accessibility. *British Journal of Social and Clinical Psychology*, 5:211–231, 1966.
- [274] S. M. Jourard and J. E. Rubin. Self-disclosure and touching: A study of two modes of interpersonal encounter and their inter-relation. *Journal of Humanistic Psychology*, 8(1):39–48, 1968.
- [275] V. Jousmäki and R. Hari. Parchment-skin illusion: sound-biased touch. *Current Biology*, 8(6):R190–R191, 1998.
- [276] M. Jung, R. Boensma, G. Huisman, and E. Van Dijk. Touched by the storyteller: the influence of remote touch in the context of storytelling. In *Proceedings of ACII'13*, pages 792–797. ACM, 2013.

- [277] M. M. Jung, X. L. Cang, M. Poel, and K. E. MacLean. Touch challenge '15: Recognizing social touch gestures. In *Proceedings of ICMI 2015*, pages 387–390, 2015.
- [278] M. M. Jung, M. Poel, R. Poppe, and D. K. J. Heylen. Automatic recognition of touch gestures in the corpus of social touch. *Journal on Multimodal User Interfaces*, pages 1–16, 2016.
- [279] M. M. Jung, R. Poppe, M. Poel, and D. K. Heylen. Touching the void – introducing cost: Corpus of social touch. In *Proceedings of the 16th International Conference on Multimodal Interaction*, ICMI '14, pages 120–127, New York, NY, USA, 2014. ACM.
- [280] R. Jütte. Haptic perception: an historical approach. In M. Grunwald, editor, *Human haptic perception: basics and applications*, chapter 1, pages 3 – 13. Birkhäuser, 2008.
- [281] N. Kakuda. Conduction velocity of low-threshold mechanoreceptive afferent fibers in the glabrous and hairy skin of human hands measured with microneurography and spike-triggered averaging. *Neuroscience Research*, 15(3):179–188, 1992.
- [282] E. R. Kandel, J. H. Schwartz, T. M. Jessell, S. A. Siegelbaum, and A. Hudspeth. *Principles of Neural Science*. McGraw-Hill Medical, 2013.
- [283] C.-G. Kang, B.-J. Lee, I.-X. Son, and H.-Y. Kim. Design of a percussive massage robot tapping human backs. In *IEEE International Conference on Robot and Human Interactive Communication*, pages 962–997. IEEE, 2007.
- [284] J. Kappelman, R. A. Ketcham, S. Pearce, L. Todd, W. Akins, M. W. Colbert, M. Fesha, J. A. Maisano, and A. Witzel. Perimortem fractures in Lucy suggest mortality from fall out of tall tree. *Nature*, Published online 29 August 2016 2016.
- [285] J. Kenseth. Bernini's Borghese Sculptures: Another View. *The Art Bulletin*, 63(2):191–210, 1981.
- [286] C. Keysers, B. Wicker, V. Gazzola, J.-L. Anton, L. Fogassi, and V. Gallese. A Touching Sight: SII/PV Activation during the Observation and Experience of Touch. *Neuron*, 42(2):335 – 346, 2004.
- [287] C. D. Kidd and C. Breazeal. Effect of a robot on user perceptions. In *Proceedings of Intelligent Robots and Systems*, pages 3559–3564, 2004.
- [288] S. Kiesler, J. Siegel, and T. W. McGuire. Social psychological aspects of computer-mediated communication. *American Psychologist*, 39(10):1123–1134, 1984.
- [289] D. A. Kim, E. J. Benjamin, J. H. Fowler, and N. A. Christakis. Social connectedness is associated with fibrinogen level in a human social network. *Proceedings of the Royal Society B*, 283(1837):1–7, 2016.

- [290] J. H. Kirman. Tactile apparent movement: The effects of interstimulus onset interval and stimulus duration. *Attention, Perception, & Psychophysics*, 15:1–6, 1974.
- [291] J. H. Kirman. Tactile apparent movement: The effects of number of stimulators. *Journal of Experimental Psychology*, 103(6):1175–1180, 1974.
- [292] C. L. Kleinke. Compliance to requests made by gazing and touching experimenters in field settings. *Journal of Experimental Social Psychology*, 13(3):218 – 223, 1977.
- [293] E. Knoop and J. Rossiter. The tickler: A compliant wearable tactile display for stroking and tickling. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '15, pages 1133–1138, New York, NY, USA, 2015. ACM.
- [294] M. Konnikova. The power of touch, March 2015.
- [295] A. Kotranza and B. Lok. Virtual human + tangible interface = mixed reality human an initial exploration with a virtual breast exam patient. In *Virtual Reality Conference, 2008. VR '08. IEEE*, pages 99–106, March 2008.
- [296] A. Kotranza, B. Lok, A. Deladisma, C. Pugh, and D. Lind. Mixed reality humans: Evaluating behavior, usability, and acceptability. *Transactions on Visualization and Computer Graphics*, 15(3):369–382, May 2009.
- [297] A. Kotranza, B. Lok, C. Pugh, and D. Lind. Virtual humans that touch back: Enhancing nonverbal communication with virtual humans through bidirectional touch. In *Virtual Reality Conference, 2009.*, pages 175–178, March 2009.
- [298] M. W. Kraus, C. Huang, and D. Keltner. Tactile Communication, Cooperation, and Performance: An Ethological Study of the NBA. *Emotion*, 10(5):745–749, 2010.
- [299] S. D. Kreibig. Autonomic nervous system activity in emotion: A review. *Biological Psychology*, 84(3):394–421, 2010.
- [300] I. U. Kress, L. Minati, S. Ferraro, and H. D. Critchley. Direct skin-to-skin vs. indirect touch modulates neural responses to stroking vs. tapping. *Neuroreport*, 22(13):646 – 651, 2011.
- [301] T. Kumazawa and E. Perl. Primate cutaneous sensory units with unmyelinated (C) afferent fibers. *Journal of Neurophysiology*, 40(6):1325–1338, 1977.
- [302] J. S. Kutner, M. C. Smith, L. Corbin, L. Hemphill, K. Benton, B. K. Mellis, B. Beaty, S. Felton, T. E. Yamashita, L. L. Bryant, and D. L. Fairclough. Massage therapy versus simple touch to improve pain and mood in patients with advanced cancer: a randomized trial. *Annals of Internal Medicine*, 149(6):369–379, 2008.
- [303] K. Kuwamura, K. Sakai, T. Minato, S. Nishio, and H. Ishiguro. Hugvie: A medium that fosters love. In *RO-MAN, 2013 IEEE*, pages 70–75, Aug 2013.

- [304] D. Lakens. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, 4(863), 2013.
- [305] N. Langford, R. Hall, and R. Monty. Cutaneous perception of a track produced by a moving point across the skin. *Journal of Experimental Psychology*, 97(1):59–63, 1973.
- [306] S. J. Lederman and L. A. Jones. Tactile and haptic illusions. *IEEE Transactions on Haptics*, 4(4):273–294, 2011.
- [307] S. J. Lederman and R. L. Klatzky. Haptic perception: A tutorial. *Attention, Perception, & Psychophysics*, 71(7):1439–1459, 2009.
- [308] K. M. Lee, Y. Jung, J. Kim, and S. R. Kim. Are physically embodied social agents better than disembodied social agents?: The effects of physical embodiment, tactile interaction, and people’s loneliness in human–robot interaction. *International Journal of Human-Computer Studies*, 64(10):962 – 973, 2006.
- [309] B. Lenggenhager, T. Tadi, T. Metzinger, and O. Blanke. Video ergo sum: Manipulating bodily self-consciousness. *Science*, 317(5841):1096–1099, 2007.
- [310] K. N. Levy, K. B. Meehan, C. M. Temes, and F. E. Yeomans. Attachment theory and research: Implications for psychodynamic psychotherapy. In R. A. Levy, J. S. Ablon, and H. Kächele, editors, *Psychodynamic Psychotherapy Research: Evidence-Based Practice 401 and Practice-Based Evidence*, chapter 24, pages 401–416. Humana Press, 2012.
- [311] R. J. Lewis and L. Finkel. Nonverbal correlates of confederates’ touch: Confounds in touch research. *Journal of Social Behavior & Personality*, 12(3):821 – 830, 1997.
- [312] N. Liberati. Teledildonics and new ways of “being in touch”: A phenomenological analysis of the use of haptic devices for intimate relations. *Science and Engineering Ethics*, pages 1–18, 2016.
- [313] K. C. Light, K. M. Grewen, and J. A. Amico. More frequent partner hugs and higher oxytocin levels are linked to lower blood pressure and heart rate in premenopausal women. *Biological Psychology*, 69(1):5 – 21, 2005.
- [314] D. J. Linden. *Touch: The Science of Hand, Heart, and Mind*. Viking, 2015.
- [315] L. Lindgren, S. Rundgren, O. Winsö, S. Lehtipalo, U. Wiklund, M. Karlsson, H. Stenlund, C. Jacobsson, and C. Brulin. Physiological responses to touch massage in healthy volunteers. *Autonomic Neuroscience: Basic and Clinical*, 158(105–110), 2010.
- [316] C. J. Litt. Children’s attachment to transitional objects: A study of two pediatric populations. *American Journal of Orthopsychiatry*, 51(1):131–139, 1981.

- [317] Q. Liu, S. Vrontou, F. L. Rice, M. J. Zylka, X. Dong, and D. J. Anderson. Molecular genetic visualization of a rare subset of unmyelinated sensory neurons that may detect gentle touch. *Nature Neuroscience*, 10(8):946–948, 2007.
- [318] D. M. Lloyd. Spatial limits on referred touch to an alien limb may resect boundaries of visuo-tactile peripersonal space surrounding the hand. *Brain and Cognition*, 64(1):104–109, 2007.
- [319] M. Loiperdinger. Lumière’s arrival of the train: Cinema’s founding myth. *The Moving Image*, 4(1):89–118, 2004.
- [320] L. S. Löken, M. Evert, and J. Wessberg. Pleasantness of touch in human glabrous and hairy skin: Order effects on affective ratings. *Brain Research*, 1417:9–15, 2012.
- [321] L. S. Löken, J. Wessberg, I. Morrison, F. McGlone, and H. Olausson. Coding of pleasant touch by unmyelinated afferents in humans. *Nature Neuroscience*, 12(5):547–548, 2009.
- [322] T. Lomas. Towards a positive cross-cultural lexicography: Enriching our emotional landscape through 216 ‘untranslatable’ words pertaining to well-being. *The Journal of Positive Psychology*, pages 1–13, 2016.
- [323] M. Lombard and T. Ditton. At the heart of it all: The concept of presence. *Journal of Computer-Mediated Communication*, 3(2), 1997.
- [324] M. Lombard and M. T. Jones. Presence and sexuality. In *Proceedings of 7th international workshop on presence*, pages 28–35, 2004.
- [325] J. M. Loomis. Distal attribution and presence. *Presence: Teleoperators and Virtual Environments*, 1(1):113–119, 1992.
- [326] J. M. Loomis and S. J. Lederman. Tactual perception. In K. Boff, L. Kaufman, and J. Thomas, editors, *Handbook of perception and human performance: vol 2, cognitive processes and performances*, pages Chapter 31 1–41. Wiley, NY, 1986.
- [327] P. Lopes and P. Baudisch. Muscle-propelled force feedback: bringing force feedback to mobile devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 2577–2580. ACM, 2013.
- [328] E. Lumpkin and M. Caterina. Mechanisms of sensory transduction in the skin. *Nature*, 445:858–865, 2007.
- [329] E. A. Lumpkin, K. L. Marshall, and A. M. Nelson. The cell biology of touch. *Journal of Cell Biology*, 191(2):237–248, 2010.
- [330] B. Lunceford. telepresence and the ethics of digital cheating. *Explorations in Media Ecology*, 12(1-2):7–26, 2013.

- [331] A. Macfarlane. Olfaction in the development of social preferences in the human neonate. In R. Porter and M. O'Connor, editors, *Parent-Infant Interaction*, volume 33, chapter 7, pages 103–119. Elsevier, 1975.
- [332] K. MacLean. The impact of institutionalization on child development. *Development and Psychopathology*, 15:853–884, 2003.
- [333] M. Main, N. Kaplan, and J. Cassidy. Security in infancy, childhood, and adulthood: A move to the level of representation. *Monographs of the Society for Research in Child Development*, 50(1/2):pp. 66–104, 1985.
- [334] B. Major and R. Heslin. Perceptions of cross-sex and same-sex nonreciprocal touch: It is better to give than to receive. *Journal of Nonverbal Behavior*, 6(3):148–162, 1982.
- [335] A. Maravita and A. Iriki. Tools for the body (schema). *TRENDS in Cognitive Sciences*, 8(2):79–86, 2004.
- [336] J. Marescaux, J. Leroy, M. Gagner, F. Rubino, D. Mutter, M. Vix, S. E. Butner, and M. K. Smith. Transatlantic robot-assisted telesurgery. *Nature*, 413:379–380, 2001.
- [337] S. Mark. *Pedagogisch contact; verbondenheid door aanraking*. Centrum voor pedagogisch contact, 2015.
- [338] H. Markram. The human brain project. *Scientific American*, 306(6):50–55, 2012.
- [339] H. R. Markus and S. Kitayama. Culture and the self: Implications for cognition, emotion, and motivation. *Psychological Review*, 98(2):224–253, 1991.
- [340] L. Marshall. *The !Kung of Nyae Nyae*. Harvard University Press, 1976.
- [341] L. Martin. “Eskimo Words for Snow”: A Case Study in the Genesis and Decay of an Anthropological Example. *American Anthropologist*, 88(2):418–423, 1986.
- [342] A. Maselli and M. Slater. The building blocks of the full body ownership illusion. *Frontiers in Human Neuroscience*, 7(83), 2013.
- [343] D. S. Massey. A brief history of human society: The origin and role of emotion in social life. *American Sociology Review*, 67(1-29), 2001.
- [344] T. Massie and J. Salisbury. The phantom haptic interface: a device for probing virtual objects. In *Proceedings of the ASME winter annual meeting, symposium on haptic interfaces for virtual environment and teleoperator systems*, 1994.
- [345] S. L. Master, N. I. Eisenberger, S. E. Taylor, B. D. Naliboff, D. Shirinyan, and M. D. Lieberman. A picture’s worth: Partner photographs reduce experimentally induced pain. *Psychological Science*, 20(11):1316–1318, 2009.

- [346] C. Matuszek, B. Mayton, R. Aimi, M. P. Deisenroth, L. Bo, R. Chu, M. Kung, L. LeGrand, J. R. Smith, and D. Fox. Gambit: An autonomous chess-playing robotic system. In *Proceedings the 2011 IEEE International Conference on Robotics and Automation (ICRA)*, pages 4291–4297. IEEE, 2011.
- [347] N. Mavridis. A review of verbal and non-verbal human–robot interactive communication. *Robotics and Autonomous Systems*, 63:22–35, 2015.
- [348] A. Mayer and J. Rosenblatt. Ontogeny of maternal behavior in the laboratory rat: early origins in 18- to 27-day-old young. *Developmental Psychology*, 12(5):407–424, 1979.
- [349] C. McCabe, E. T. Rolls, A. Bilderbeck, and F. McGlone. Cognitive influences on the affective representation of touch and the sight of touch in the human brain. *Social Cognitive and Affective Neuroscience*, 3(2):97–108, 2008.
- [350] R. McCance and M. Otley. Course of the blood urea in newborn rats, pigs and kittens. *The Journal of Physiology*, 113(1):18–22, 1951.
- [351] R. R. McCrae, P. T. Costa, Jr, and T. A. Martin. The neo–pi–3: A more readable revised neo personality inventory. *Journal of Personality Assessment*, 84(3):261–270, 2005.
- [352] E. McDaniel and P. Andersen. International patterns of interpersonal tactile communication: A field study. *Journal of Nonverbal Behavior*, 22(1):59–75, 1998.
- [353] F. McGlone, H. Olausson, J. A. Boyle, M. Jones-Gotman, C. Dancer, S. Guest, and G. Essick. Touching and feeling: differences in pleasant touch processing between glabrous and hairy skin in humans. *European Journal of Neuroscience*, 35(11):1782–1788, 2012.
- [354] F. McGlone and D. Reilly. The cutaneous sensory system. *Neuroscience and Biobehavioral Reviews*, 34:148 – 159, 2010.
- [355] F. McGlone, A. B. Vallbo, H. Olausson, L. Loken, and J. Wessberg. Discriminative touch and emotional touch. *Canadian Journal of Experimental Psychology*, 61(3):173–183, 2007.
- [356] F. McGlone, J. Wessberg, and H. Olausson. Discriminative and affective touch: Sensing and feeling. *Neuron*, 82(4):737 – 755, 2014.
- [357] M. Mikulincer. Attachment, caregiving, and sex within romantic relationships. In M. Mikulincer and G. Goodman, editors, *Dynamics of romantic love: Attachment, caregiving, and sex*, chapter 2, pages 23–42. The Guildford Press, 2006.
- [358] P. Milgram, S. Zhai, D. Drascic, and J. Grodski. Applications of augmented reality for human-robot communication. In *Proceedings of Intelligent Robots and Systems’ 93*, volume 3, pages 1467–1472, 1993.

- [359] M. J. Millan. The induction of pain: An integrative review. *Progress in Neurobiology*, 57:1–164, 1999.
- [360] M. Miller, A. Denes, B. Diaz, and R. Buck. Attachment style predicts jealous reactions to viewing touch between a romantic partner and close friend: Implications for internet social communication. *Journal of Nonverbal Behavior*, pages 1–26, 2014.
- [361] P. M. Miller, M. L. Commons, and T. G. Gutheil. Clinicians’ perceptions of boundaries in brazil and the united states. *Journal of the American Academy of Psychiatric and the Law*, 34(1):33 – 42, 2006.
- [362] T. Minato, Y. Yoshikawa, T. Noda, S. Ikemoto, H. Ishiguro, and M. Asada. Cb2: A child robot with biomimetic body for cognitive developmental robotics. In *Proceedings of Humanoid Robots 2007*, pages 557–562, Nov 2007.
- [363] A. Montagu. *Touching: The human significance of the skin*. Columbia University Press, 1971.
- [364] V. B. Morhenn, J. W. Park, E. Piper, and P. J. Zak. Monetary sacrifice among strangers is mediated by endogenous oxytocin release after physical contact. *Evolution and Human Behavior*, 29(6):375 – 383, 2008.
- [365] I. Morrison, M. Björnsdotter, and H. Olausson. Vicarious responses to social touch in posterior insular cortex are tuned to pleasant caressing speeds. *The Journal of Neuroscience*, 31(26):9554–9562, 2011.
- [366] I. Morrison, L. Löken, and H. Olausson. The skin as a social organ. *Experimental Brain Research*, 204:305–314, 2010.
- [367] I. Morrison, L. S. Löken, J. Minde, J. Wessberg, I. Perini, I. Nennesmo, and H. Olausson. Reduced C-afferent fibre density affects perceived pleasantness and empathy for touch. *Brain*, 134(4):1116–1126, 2011.
- [368] G. L. Moseley, A. Gallace, and C. Spence. Bodily illusions in health and disease: Physiological and clinical perspectives and the concept of a cortical ‘body matrix’. *Neuroscience and Biobehavioral Reviews*, 36:34 – 46, 2012.
- [369] F. F. Mueller, F. Vetere, M. R. Gibbs, J. Kjeldskov, S. Pedell, and S. Howard. Hug over a distance. In *Proceedings of CHI ’05*, pages 1673–1676. ACM, 2005.
- [370] Y. Naitoh and R. Eckert. Ionic mechanisms controlling behavioral responses of paramecium to mechanical stimulation. *Science*, 164(3882):963 – 965, 1969.
- [371] K. Nakagawa, M. Shiomi, K. Shinozawa, R. Matsumura, H. Ishiguro, and N. Hagita. Effect of robot’s active touch on people’s motivation. In *Proceedings of the 6th international conference on Human-robot interaction, HRI ’11*, pages 465–472, New York, NY, USA, 2011. ACM.

- [372] H. Nakanishi, K. Tanaka, and Y. Wada. Remote handshaking: Touch enhances video-mediated social telepresence. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '14, pages 2143–2152, New York, NY, USA, 2014. ACM.
- [373] J. C. Nannberg and C. H. Hansen. Post-compliance touch: An incentive for task performance. *The Journal of Social Psychology*, 134(3):301–307, 1994.
- [374] C. A. Nelson. A neurobiological perspective on early human deprivation. *Child Development Perspectives*, 1(1):13–18, 2007.
- [375] H. Nelson and G. Geher. Mutual grooming in human dyadic relationships: An ethological perspective. *Current Psychology*, 26(2):121–140, 2007.
- [376] T. Nelson. *Computer Lib/Dream Machine*. 1974.
- [377] M. Neu, M. L. Laudenslager, and J. Robinson. Coregulation in salivary cortisol during maternal holding of premature infants. *Biological research for nursing*, 10(3):226–240, 2008.
- [378] R. Newport and H. R. Gilpin. Multisensory disintegration and the disappearing hand trick. *Current Biology*, 21(19):R804–R805, 2011.
- [379] R. Newport, R. Pearce, and C. Preston. Fake hands in action: embodiment and control of supernumerary limbs. *Experimental Brain Research*, 204(3):385–395, 2010.
- [380] T. Nguyen, R. Heslin, and M. L. Nguyen. The meanings of touch: Sex differences. *Journal of Communication*, 25(3):92–103, 1975.
- [381] J. Nie, M. Park, A. Marin, and S. Sundar. Can you hold my hand? physical warmth in human-robot interaction. In *Proceedings of Human-Robot Interaction (HRI) 2012*, pages 201–202, March 2012.
- [382] M. Nordin. Low-threshold mechanoreceptive and nociceptive units with unmyelinated (c) fibres in the human supraorbital nerve. *The Journal of Physiology*, 426:229–240, 1990.
- [383] I. Oakley, Y. Kim, J. Lee, and J. Ryu. Determining the Feasibility of Forearm Mounted Vibrotactile Displays. In *Proceedings of HAPTICS'06*, pages 27 – 34. IEEE, 2006.
- [384] A. Ogura and K. Takahashi. Artificial deciliation causes loss of calcium-dependent responses in paramecium. *Nature*, 264:170–172, 1976.
- [385] H. Olausson, Y. Lamarre, H. Backlund, C. Morin, B. Wallin, G. Starck, S. Ekholm, I. Strigo, K. Worsley, A. Vallbo, and M. Bushnell. Unmyelinated tactile afferents signal touch and project to insular cortex. *Nature Neuroscience*, 5(9):900–904, 2002.

- [386] H. Olausson, J. Wessberg, I. Morrison, F. McGlone, and Å. Vallbo. The neurophysiology of unmyelinated tactile afferents. *Neuroscience and Biobehavioral Reviews*, 34(2):185–191, 2010.
- [387] L. L. Orefice, A. L. Zimmerman, A. M. Chirila, S. J. Sleboda, J. P. Head, and D. D. Ginty. Peripheral mechanosensory neuron dysfunction underlies tactile and behavioral deficits in mouse models of asds. *Cell*, 166(2):299–313, 2016.
- [388] M. Ortiz-Catalan, N. Sander, M. Kristoffersen, B. Håkansson, and R. Brånemark. Treatment of Phantom Limb Pain (PLP) Based on Augmented Reality and Gaming Controlled by Myoelectric Pattern Recognition: A Case Study of a Chronic PLP Patient. *Frontiers in Neuroscience*, 8(24), 2014.
- [389] A. Ozolins and C. Sandberg. Development of a multifactor scale measuring the psychological dimensions of touch avoidance. *International Journal of Psychology: A Biopsychosocial Approach*, 3:33–56, 2009.
- [390] J. Palmer. Smoking, caning, and delinquency in a secondary modern school. *British Journal of Preventive & Social Medicine*, 19(1):18–23, 1965.
- [391] J. Pankseppa and J. Burgdorf. “Laughing” rats and the evolutionary antecedents of human joy? *Physiology & Behavior*, 79(3):533–547, 2003.
- [392] Y.-W. Park, S.-H. Bae, and T.-J. Nam. How do couples use cheektouch over phone calls? In *Proceedings of CHI’12*, pages 763–766. ACM, 2012.
- [393] Y.-W. Park and T.-J. Nam. POKE: a new way of sharing emotional touches during phone conversations. In *CHI ’13 Extended Abstracts on Human Factors in Computing Systems*, CHI EA ’13, pages 2859–2860. ACM, 2013.
- [394] R. H. Passman. Attachments to inanimate objects: Are children who have security blankets insecure? *Journal of Consulting and Clinical Psychology*, 55(6):825–830, 1987.
- [395] M. L. Patterson, J. L. Powell, and M. G. Lenihan. Touch, compliance, and interpersonal affect. *Journal of Nonverbal Behavior*, 10(1):41–50, 1986.
- [396] S. Paulsell and M. Goldman. The effect of touching different body areas on prosocial behavior. *The Journal of Social Psychology*, 122(2):269–273, 1984.
- [397] R. Paus and G. Cotsarelis. The biology of hair follicles. *New England Journal of Medicine*, 341(7):491–497, 1999.
- [398] M. Peláez-Nogueras, T. Field, J. L. Gewirtz, M. Cigales, A. Gonzalez, A. Sanchez, and S. C. Richardson. The effects of systematic stroking versus tickling and poking on infant behavior. *Journal of Applied Developmental Psychology*, 18(2):169 – 178, 1997.

- [399] M. Peláez-Nogueras, T. M. Field, Z. Hossain, and J. Pickens. Depressed mothers' touching increases infants' positive affect and attention in still-face interactions. *Child Development*, 67(4):1780–1792, 1996.
- [400] M. Peláez-Nogueras, J. L. Gewirtz, T. Field, M. Cigales, J. Malphurs, S. Clasky, and A. Sanchez. Infants' preference for touch stimulation in face-to-face interactions. *Journal of Applied Developmental Psychology*, 17(2):199 – 213, 1996.
- [401] J. W. Pennebaker, B. Rimé, and V. E. Blankenship. Stereotypes of Emotional Expressiveness of Northerners and Southerners: A Cross-Cultural Test of Montequieu's Hypotheses. *Journal of Personality and Social Psychology*, 70(2):372 – 380, 1996.
- [402] I. Perini and H. Olausson. Seeking pleasant touch: neural correlates of behavioral preferences for skin stroking. *Frontiers in behavioral neuroscience*, 9, 2015.
- [403] L. Perlovsky. Language and emotions: Emotional Sapir-Whorf hypothesis. *Neural Networks*, 22(5):518–526, 2009.
- [404] C. Perry. Turn up the volume my foot's asleep. *Rolling Stone*, September 26 1974.
- [405] E. Piatetski and L. Jones. Vibrotactile pattern recognition on the arm and torso. In *Proceedings of World Haptics Symposium '05*, pages 90 – 95. IEEE, 2005.
- [406] R. W. Poppe. Vision-based human motion analysis: An overview. *Computer Vision and Image Understanding*, 108(1-2):4–18, 2007.
- [407] S. W. Porges. Cardiac vagal tone: A physiological index of stress. *Neuroscience and Biobehavioral Reviews*, 19(2):225–233, 1995.
- [408] I. Poupyrev, N.-W. Gong, S. Fukuhara, M. E. Karagozler, C. Schwesig, and K. E. Robinson. Project Jacquard: Interactive Digital Textiles at Scale. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, pages 4216–4227. ACM, 2016.
- [409] I. Poupyrev, S. Maruyama, and J. Rekimoto. Ambient touch: Designing tactile interfaces for handheld devices. In *Proceedings of the 15th annual ACM symposium on User interface software and technology*, pages 51–60. ACM, 2002.
- [410] G. A. Pradana, A. D. Cheok, M. Inami, J. Tewell, and Y. Choi. Emotional priming of mobile text messages with ring-shaped wearable device using color lighting and tactile expressions. In *Proceedings of the 5th Augmented Human International Conference*, AH '14, pages 14:1–14:8, New York, NY, USA, 2014. ACM.
- [411] G. K. Pullum. The great Eskimo vocabulary hoax. *Natural Language & Linguistic Theory*, 7(2):275–281, 1989.
- [412] F. W. Putnam. Ten-year research update review: Child sexual abuse. *Journal of the American Academy of Child & Adolescent Psychiatry*, 42(3):269–278, 2003.

- [413] J. Rantala, R. Raisamo, J. Lylykangas, T. Ahmaniemi, J. Raisamo, J. Rantala, K. Makela, K. Salminen, and V. Surakka. The role of gesture types and spatial feedback in haptic communication. *Haptics, IEEE Transactions on*, 4(4):295–306, July 2011.
- [414] J. Rantala, K. Salminen, R. Raisamo, and V. Surakka. Touch gestures in communicating emotional intention via vibrotactile stimulation. *International Journal of Human-Computer Studies*, 71(6):679 – 690, 2013.
- [415] C. M. Reed, W. M. Rabinowitz, N. I. Durlach, L. D. Braidia, S. Conway-Fithian, and M. C. Schultz. Research on the tadoma method of speech communication. *The Journal of the Acoustical Society of America*, 77(1):247–257, 1985.
- [416] B. Reeves and C. Nass. *The Media Equation: How People Treat Computers, Television and New Media Like Real People and Places*. CSLI Publications, 2002.
- [417] J. Rekimoto. Smartskin: An infrastructure for freehand manipulation on interactive surfaces. In *Proceedings of CHI '02*, pages 113–120. ACM, 2002.
- [418] M. S. Remland, T. S. Jones, and H. Brinkman. Proxemic and Haptic Behavior in Three European Countries. *Journal of Nonverbal Behavior*, 15(4):215 – 232, 1991.
- [419] P. Renaud, S. Chartier, J.-L. Rouleau, J. Proulx, M. Goyette, D. Trottier, P. Fedoroff, J.-P. Bradford, B. Dassylva, and S. Bouchard. Using immersive virtual reality and ecological psychology to probe into child molesters’ phenomenology. *Journal of Sexual Aggression*, 19(1):102–120, 2013.
- [420] H. Richter, B. Blaha, A. Wiethoff, D. Baur, and A. Butz. Tactile feedback without a big fuss: simple actuators for high-resolution phantom sensations. In *Proceedings of UbiComp’11*, pages 85–88. ACM, 2011.
- [421] T. Risse-Kappen. Ideas do not float freely: transnational coalitions, domestic structures, and the end of the cold war. *International Organization*, 48(2):185–214, 1994.
- [422] B. Robins, F. Amirabdollahian, and K. Dautenhahn. Investigating child-robot tactile interactions: A taxonomical classification of tactile behaviour of children with autism towards a humanoid robot. In *Proceedings of Advances in Computer-Human Interactions 2013*, pages 89–94, 2013.
- [423] B. Robins, F. Amirabdollahian, Z. Ji, and K. Dautenhahn. Tactile interaction with a humanoid robot for children with autism: A case study analysis involving user requirements and results of an initial implementation. In *Proceedings of RO-MAN 2010*, pages 704–711, Sept 2010.
- [424] B. Robins, K. Dautenhahn, and P. Dickerson. Embodiment and cognitive learning – can a humanoid robot help children with autism to learn about tactile social behaviour? In S. Ge, O. Khatib, J.-J. Cabibihan, R. Simmons, and M.-A. Williams,

- editors, *Social Robotics*, volume 7621 of *Lecture Notes in Computer Science*, pages 66–75. Springer Berlin Heidelberg, 2012.
- [425] J. Rönnberg and E. Borg. A review and evaluation of research on the deaf-blind from perceptual, communicative, social and rehabilitative perspectives. *Scandinavian Audiology*, 30(2):67–77, 2001.
 - [426] S. A. Rose. The sense of touch. *Touch: The Foundation of Experience*. International Universities Press, Madison, WI, pages 299–324, 1990.
 - [427] L. L. Roth and J. S. Rosenblatt. Changes in self-licking during pregnancy in the rat. *Journal of Comparative and Physiological Psychology*, 63(3):397–400, 1967.
 - [428] M. B. Rothberg, A. Arora, J. Hermann, R. Kleppel, P. St Marie, and P. Visintainer. Phantom vibration syndrome among medical staff: a cross sectional survey. *BMJ*, 341:c6914, 2010.
 - [429] F. Röthling, R. Haschke, J. J. Steil, and H. Ritter. Platform Portable Anthropomorphic Grasping with the Bielefeld 20-DOF Shadow and 9-DOF TUM Hand. In *Proceedings of the International Conference on Intelligent Robots and Systems*, pages 2951–2956. IEEE, 2007.
 - [430] A. Rovers and H. Essen. Guidelines for haptic interpersonal communication applications: an exploration of foot interaction styles. *Virtual Reality*, 9(2-3):177–191, 2006.
 - [431] A. Rovers and H. van Essen. HIM: A Framework for Haptic Instant Messaging. In *CHI '04 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '04, pages 1313–1316, New York, NY, USA, 2004. ACM.
 - [432] A. F. Rovers and H. A. van Essen. FootIO: Design and Evaluation of a Device to Enable Foot Interaction over a Computer Network. In *Proceedings of World Haptics 2005*, pages 521–522, Washington, DC, USA, 2005. IEEE Computer Society.
 - [433] B. Russell. *ABC of Relativity*. Routledge, 1997 (Original work published in 1925).
 - [434] J. A. Russell, J. A. Bachorowski, and J.-M. Fernandez-Dols. Facial and vocal expressions of emotion. *Annual Review of Psychology*, 54(1):329, 2003.
 - [435] A. Rutkin. Anything you can do... *New Scientist*, 229(3065):20–21, 2016.
 - [436] E. Saadatian, H. Samani, R. Parsani, A. V. Pandey, J. Li, L. Tejada, A. D. Cheok, and R. Nakatsu. Mediating intimacy in long-distance relationships using kiss messaging. *International Journal of Human-Computer Studies*, 72(10–11):736 – 746, 2014.
 - [437] J. Saldien, K. Goris, S. Yilmazyildiz, W. Verhelst, and D. Lefeber. On the Design of the Huggable Robot Probo. *Journal of Physical Agents*, 2(2):3–11, 2008.

- [438] E.-L. Sallnäs. Haptic feedback increases perceived social presence. In A. M. Kappers, J. B. Erp, W. M. Bergmann Tiest, and F. C. Helm, editors, *Haptics: Generating and Perceiving Tangible Sensations*, Lecture Notes in Computer Science, pages 178–185. Springer Berlin Heidelberg, 2010.
- [439] E.-L. Sallnäs, K. Rassmus-Gröhn, and C. Sjöström. Supporting presence in collaborative environments by haptic force feedback. *Transactions on Computer-Human Interaction*, 7(4):461–476, Dec. 2000.
- [440] K. Salminen, V. Surakka, J. Raisamo, J. Lylykangas, J. Pystynen, R. Raisamo, K. Mäkelä, and T. Ahmaniemi. Emotional responses to thermal stimuli. In *Proceedings of the 13th international conference on multimodal interfaces*, ICMI '11, pages 193–196, New York, NY, USA, 2011. ACM.
- [441] K. Salminen, V. Surakka, J. Raisamo, J. Lylykangas, R. Raisamo, K. Mäkelä, and T. Ahmaniemi. Cold or Hot? How Thermal Stimuli Are Related to Human Emotional System? In I. Oakley and S. Brewster, editors, *Haptic and Audio Interaction Design*, volume 7989 of *Lecture Notes in Computer Science*, pages 20–29. Springer Berlin Heidelberg, 2013.
- [442] C. Salmon. The pop culture of sex: An evolutionary window on the worlds of pornography and romance. *Review of General Psychology*, 16(2):152–160, 2012.
- [443] H. A. Samani, R. Parsani, L. T. Rodriguez, E. Saadatian, K. H. Dissanayake, and A. D. Cheok. Kissenger: design of a kiss transmission device. In *Proceedings of DIS '12*, pages 48–57. ACM, 2012.
- [444] C. R. Sanders. Actions speak louder than words: Close relationships between humans and nonhuman animals. *Symbolic Interaction*, 26(3):405–426, 2003.
- [445] M. Sato, I. Poupyrev, and C. Harrison. Touché: Enhancing touch interaction on humans, screens, liquids, and everyday objects. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '12, pages 483–492, New York, NY, USA, 2012. ACM.
- [446] B. Scassellati, H. Admoni, and M. Mataric. Robots for use in autism research. *Annual Review of Biomedical Engineering*, 14(1):275–294, 2012.
- [447] B. Schiermer. Late-modern hipsters: New tendencies in popular culture. *Acta Sociologica*, 57(2):167–181, 2014.
- [448] A. Schirmer, K. S. Teh, S. Wang, R. Vijayakumar, A. Ching, D. Nithianantham, N. Escoffier, and A. D. Cheok. Squeeze me, but don't tease me: Human and mechanical touch enhance visual attention and emotion discrimination. *Social Neuroscience*, 6(3):219–230, 2011.
- [449] M. Schmelz, R. Schmidt, A. Bickel, H. O. Handwerker, and H. E. Torebjörk. Specific C-Receptors for Itch in Human Skin. *The Journal of Neuroscience*, 17(20):8003–8008, 1997.

- [450] J. P. Schneider. A qualitative study of cybersex participants: Gender differences, recovery issues, and implications for therapists. *Sexual Addiction & Compulsivity*, 7(4):249–278, 2000.
- [451] J. Seebode, R. Schleicher, I. Wechsung, and S. Möller. Investigating the affective impression of tactile feedback on mobile devices. In *Proceedings of the 27th International BCS Human Computer Interaction Conference*, 2014.
- [452] H. Seifi and K. MacLean. A first look at individuals’ affective ratings of vibrations. In *World Haptics Conference (WHC), 2013*, pages 605–610, 2013.
- [453] S. T. Selden. Tickle. *Journal of the American Academy of Dermatology*, 50:93–97, 2004.
- [454] A. Shah, S. Teuscher, E. McClain, and J. Abbott. How to Build an Inexpensive 5-DOF Haptic Device Using Two Novint Falcons. In A. Kappers, J. Erp, W. Bergmann Tiest, and F. Helm, editors, *Haptics: Generating and Perceiving Tangible Sensations*, volume 6191 of *Lecture Notes in Computer Science*, pages 136–143. Springer Berlin Heidelberg, 2010.
- [455] C. E. Sherrick. Bilateral apparent haptic movement. *Perception & Psychophysics*, 4(3):159–160, 1968.
- [456] C. E. Sherrick and R. Rogers. Apparent haptic movement. *Perception & Psychophysics*, 1(3):175–180, 1966.
- [457] M. Shiomi, K. Nakagawa, K. Shinozawa, R. Matsumura, H. Ishiguro, and N. Hagita. Does a robot’s touch encourage human effort? *International Journal of Social Robotics*, pages 1–11, 2016.
- [458] J. Sigafoos, R. Didden, R. Schlosser, V. A. Green, M. F. O’Reilly, and G. E. Lancioni. A review of intervention studies on teaching AAC to individuals who are deaf and blind. *Journal of Developmental and Physical Disabilities*, 20(1):71–99, 2008.
- [459] D. Silvera-Tawil, D. Rye, and M. Velonaki. Interpretation of Social Touch on an Artificial Arm Covered with an EIT-based Sensitive Skin. *International Journal of Social Robotics*, pages 1–17, 2014.
- [460] L. A. Sisson, V. B. V. Hasselt, and M. Hersen. Psychological approaches with deaf-blind persons: Strategies and issues in research and treatment. *Clinical Psychology Review*, 7(3):303–328, 1987.
- [461] D. E. Smith, F. N. Willis, and J. A. Gier. Success and interpersonal touch in a competitive setting. *Journal of Nonverbal Behavior*, 5(1):26 – 34, 1980.
- [462] J. Smith and K. MacLean. Communicating emotion through a haptic link: Design space and methodology. *International Journal of Human-Computer Studies*, 65(4):376–387, 2007.

- [463] R. Sodhi, M. Glisson, and I. Poupyrev. Aired: tactile gaming experiences in free air. In *ACM SIGGRAPH 2013 Emerging Technologies*, SIGGRAPH '13, pages 2:1–2:1, New York, NY, USA, 2013. ACM.
- [464] C. Soligo. Anatomy of the Hand and Arm in *Daubentonia madagascariensis*: A Functional and Phylogenetic Outlook. *Folia Primatologica*, 76(5):262–300, 2005.
- [465] J. Song, J. H. Lim, S. Kwon, I. Rhiu, B. Jin, S. Bahn, and M. H. Yun. Generating a research keyword structure on human haptic interaction using a social network analysis tool. In *Industrial Engineering and Engineering Management (IEEM), 2013 IEEE International Conference on*, pages 797–801, Dec 2013.
- [466] T. Sonneborn. Methods of Paramecium research. In D. Prescott, editor, *Methods in Cell Biology*, chapter 12, pages 241–339. Elsevier, 1970.
- [467] M. Spape and N. Ravaja. Social psychology of the digital age: The interpersonal neuroscience of mediated communication. In G. Meiselwitz, editor, *Social Computing and Social Media*, volume 8531 of *Lecture Notes in Computer Science*, pages 494–505. Springer International Publishing, 2014.
- [468] M. M. Spapé, E. E. Hoggan, G. Jacucci, and N. Ravaja. The meaning of the virtual Midas touch: An ERP study in economic decision making. *Psychophysiology*, pages n/a–n/a, 2014.
- [469] L. A. Sroufe and E. Waters. Attachment as an organizational construct. *Child Development*, 48(4):1184–1199, 1977.
- [470] L. Stafford. *Maintaining long-distance and cross-residential relationships*. Routledge, 2004.
- [471] A. Stanley and K. Kuchenbecker. Design of body-grounded tactile actuators for playback of human physical contact. In *Proceedings of WHC'11*, pages 563–568. IEEE, 2011.
- [472] J. C. Stevens and K. K. Choo. Spatial acuity of the body surface over the life span. *Somatosensory and Motor Research*, 13(2):153–166, 1996.
- [473] J. C. Stevens and J. E. Hooper. How skin and object temperature influence touch sensation. *Perception & Psychophysics*, 32(3):282–285, 1982.
- [474] R. Stone. Haptic feedback: a brief history from telepresence to virtual reality. In S. Brewster and R. Murray-Smith, editors, *Haptic Human-Computer Interaction*, volume 2058 of *Lecture Notes in Computer Science*, pages 1–16. Springer Berlin/Heidelberg, 2001.
- [475] G. Stratton. *Theophrastus and the Greek physiological psychology before Aristotle*. Bonset, 1964.

- [476] S. Ströfer, E. G. Ufkes, M. Bruijnes, E. Giebels, and M. L. Noordzij. Interviewing suspects with avatars: Avatars are more effective when perceived as human. *Frontiers in Psychology*, 2016.
- [477] R. Strong and W. Gaver. Feather, scent, and shaker: Supporting simple intimacy. In *Proceedings of CSCW'96*, CSCW'96, 1996.
- [478] K. Suhonen, K. Väänänen-Vainio-Mattila, and K. Mäkelä. User experiences and expectations of vibrotactile, thermal and squeeze feedback in interpersonal communication. In *Proceedings of the 26th Annual BCS Interaction Specialist Group Conference on People and Computers*, BCS-HCI '12, pages 205–214, Swinton, UK, UK, 2012. British Computer Society.
- [479] J. P. Sullins. Robots, love, and sex: The ethics of building a love machine. *IEEE transactions on affective computing*, 3(4):398–409, 2012.
- [480] R. M. Sullivan, S. Taborsky-Barba, R. Mendoza, A. Itano, M. Leon, C. W. Cotman, T. F. Payne, and I. Lott. Olfactory classical conditioning in neonates. *Pediatrics*, 87(4):511–518, 1991.
- [481] H. Sumioka, A. Nakae, R. Kanai, and H. Ishiguro. Huggable communication medium decreases cortisol levels. *Scientific reports*, 3, 2013.
- [482] S. Suomi. The role of touch in rhesus monkey development. In C. Brown, editor, *The many facets of touch*, pages 41 – 50. Johnson & Johnson Baby Products Company, 1984.
- [483] J. T. Suvilehto, E. Glerean, R. I. M. Dunbar, R. Hari, and L. Nummenmaa. Topography of social touching depends on emotional bonds between humans. *Proceedings of the National Academy of Sciences*, 112(45):13811–13816, 2015.
- [484] K. Suzuki and H. Jansson. An analysis of driver's steering behaviour during auditory or haptic warnings for the designing of lane departure warning system. *JSAE review*, 24(1):65–70, 2003.
- [485] V.-C. Ta, W. Johal, M. Portaz, E. Castelli, and D. Vaufreydz. The Grenoble System for the Social Touch Challenge at ICMI 2015. In *Proceedings of ICMI 2015*, pages 391–398, 2015.
- [486] L. Takayama and J. Go. Mixing metaphors in mobile remote presence. In *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work*, pages 495–504. ACM, 2012.
- [487] M. Takeuchi, H. Miyaoka, A. Tomoda, M. Suzuki, Q. Liu, and T. Kitamura. The effect of interpersonal touch during childhood on adult attachment and depression: A neglected area of family and developmental psychology? *Journal of Child and Family Studies*, 19(1):109–117, 2010.

- [488] H. Z. Tan and A. Pentland. Tactual displays for wearable computing. *Personal Technologies*, 1(4):225–230, 1997.
- [489] J. Teh, Z. Tsai, J. Koh, and A. Cheok. Mobile implementation and user evaluation of the huggy pajama system. In *Haptics Symposium (HAPTICS), 2012 IEEE*, pages 471–478, March 2012.
- [490] M. Ter Maat, K. P. Truong, and D. K. J. Heylen. How turn-taking strategies influence users’ impressions of an agent. In *Proceedings of the International Conference on Intelligent Virtual Agents*, pages 441–453. Springer Berlin/Heidelberg, 2010.
- [491] S. Thayer. History and strategies of research on social touch. *Journal of Nonverbal Behavior*, 10(1):12–28, 1986.
- [492] L. Tremblay, M. Roy-Vaillancourt, B. Chebbi, S. Bouchard, M. Daoust, J. Dénomée, and M. Thorpe. Body image and anti-fat attitudes: An experimental study using a haptic virtual reality environment to replicate human touch. *Cyberpsychology, Behavior, and Social Networking*, 2016.
- [493] C. Triscoli, H. Olausson, U. Sailer, H. Ignell, and I. Croy. CT-optimized skin stroking delivered by hand or robot is comparable. *Frontiers in behavioral neuroscience*, 7, 2013.
- [494] M. Tsakiris and P. Haggard. The rubber hand illusion revisited: Visuotactile integration and self-attribution. *Journal of Experimental Psychology: Human Perception and Performance*, 31(1):80 – 91, 2005.
- [495] M. Tsamlal, N. Ouarti, and M. Ammi. Non-intrusive haptic interfaces: State-of-the art survey. In I. Oakley and S. Brewster, editors, *Haptic and Audio Interaction Design*, volume 7989 of *Lecture Notes in Computer Science*, pages 1–9. Springer Berlin Heidelberg, 2013.
- [496] M. Y. Tsamlal, N. Ouarti, J.-C. Martin, and M. Ammi. EmotionAir: Perception of Emotions from Air Jet Based Tactile Stimulation. In *Proceedings of ACII 2013*, pages 215–220. IEEE, 2013.
- [497] D. Tsetserukou. Haptihug: A novel haptic display for communication of hug over a distance. In A. Kappers, J. van Erp, W. Bergmann Tiest, and F. van der Helm, editors, *Haptics: Generating and Perceiving Tangible Sensations*, volume 6191 of *Lecture Notes in Computer Science*, pages 340–347. Springer Berlin Heidelberg, 2010.
- [498] D. Tsetserukou, A. Neviarouskaya, H. Prendinger, N. Kawakami, and S. Tachi. Affective haptics in emotional communication. In *Proceedings of Affective Computing and Intelligent Interaction 2009*, pages 1–6, 2009.
- [499] O. H. Turnbull, V. E. Lovett, J. Chaldecott, and M. D. Lucas. Reports of intimate touch: Erogenous zones and somatosensory cortical organization. *Cortex*, 53(146–154), 2014.

- [500] A. Underdown, J. Barlow, V. Chung, and S. Stewart-Brown. Massage intervention for promoting mental and physical health in infants aged under six months (review). *Cochrane Database of Systematic Reviews*, 18:CD005038, 2006.
- [501] K. Uvnäs-Moberg. Physiological and endocrine effects of social contact. *Annals of the New York Academy of Sciences*, 807(1):146–163, 1997.
- [502] K. Uvnäs-Moberg, I. Arn, and D. Magnusson. The psychobiology of emotion: the role of the oxytocinergic system. *International Journal of Behavioral Medicine*, 12(2):59–65, 2005.
- [503] A. Vallbo, H. Olausson, J. Wessberg, and U. Norrsell. A system of unmyelinated afferents for innocuous mechanoreception in the human skin. *Brain Research*, 628(1–2):301 – 304, 1993.
- [504] Å. B. Vallbo, H. Olausson, and J. Wessberg. Unmyelinated afferents constitute a second system coding tactile stimuli of the human hairy skin. *Journal of Neurophysiology*, 81(6):2753–2763, 1999.
- [505] G. J. P. van Breukelen and K. R. A. van Dijk. Use of covariates in randomized controlled trials. *Journal of the International Neuropsychological Society*, 13(5):903–904, 2007.
- [506] J. B. F. Van Erp. Guidelines for the use of vibro-tactile displays in human computer interaction. In *Proceedings of eurohaptics*, volume 2002, pages 18–22, 2002.
- [507] J. B. F. Van Erp. Presenting directions with a vibrotactile torso display. *Ergonomics*, 48(3):302–313, 2005.
- [508] J. B. F. Van Erp and A. Toet. How to touch humans: Guidelines for social agents and robots that can touch. In *Proceedings of Affective Computing and Intelligent Interaction 2013*, pages 780–785, Sept 2013.
- [509] J. B. F. Van Erp and A. Toet. Social touch in human–computer interaction. *Frontiers in Digital Humanities*, 2:2, 2015.
- [510] J. B. F. Van Erp, H. A. H. C. Van Veen, C. Jansen, and T. Dobbins. Waypoint navigation with a vibrotactile waist belt. *ACM Transactions on Applied Perception (TAP)*, 2(2):106–117, 2005.
- [511] H. E. van Stralen, M. J. van Zandvoort, S. S. Hoppenbrouwers, L. M. Vissers, L. J. Kappelle, and H. C. Dijkerman. Affective touch modulates the rubber hand illusion. *Cognition*, 131(1):147 – 158, 2014.
- [512] H. van Welbergen, R. Yaghoubzadeh, and S. Kopp. AsapRealizer 2.0: The Next Steps in Fluent Behavior Realization for ECAs. In *Proceedings of the International Conference on Intelligent Virtual Agents*, volume 8637 of *LNCS*, pages 449–462. Springer, 2014.

- [513] A. Verendeev, C. Thomas, S. C. McFarlin, W. D. Hopkins, K. A. Phillips, and C. C. Sherwood. Comparative analysis of Meissner's corpuscles in the fingertips of primates. *Journal of Anatomy*, 227(1):72–80, 2015.
- [514] R. Verrillo. Temporal summation in vibrotactile sensitivity. *The Journal of the Acoustical Society of America*, 37(5):843–846, 1965.
- [515] I. M. Vogels, A. M. Kappers, and J. J. Koenderink. Haptic aftereffect of curved surfaces. *Perception*, 25(1):109–119, 1996.
- [516] G. von Békésy. Neural Funneling along the Skin and between the Inner and Outer Hair Cells of the Cochlea. *The Journal of the Acoustical Society of America*, 31(9):1236–1249, 1959.
- [517] E. von Holst. Relations between the central nervous system and the peripheral organs. *British Journal of Animal Behavior*, 2:89–94, 1954.
- [518] A. C. Voos, K. A. Pelphrey, and M. D. Kaiser. Autistic traits are associated with diminished neural response to affective touch. *Social Cognitive and Affective Neuroscience*, 8(4):378–386, 2013.
- [519] K. Wada, T. Shibata, T. Saito, and K. Tanie. Effects of robot-assisted activity for elderly people and nurses at a day service center. *Proceedings of the IEEE*, 92(11):1780–1788, Nov 2004.
- [520] R. Walker and C. Bartneck. The pleasure of receiving a head massage from a robot. In *Proceedings of IEEE International Symposium on Robot and Human Interactive Communication*, pages 807–813. IEEE, 2013.
- [521] F. Walsh. Human-Animal Bonds I: The Relational Significance of Companion Animals. *Family Process*, 48(4):462–480, 2009.
- [522] H. Walum, I. D. Waldman, and L. J. Young. Statistical and methodological considerations for the interpretation of intranasal oxytocin studies. *Biological Psychiatry*, 79(3):251–257, 2016.
- [523] R. Wang, F. Quek, D. Tatar, K. S. Teh, and A. Cheok. Keep in touch: channel, expectation and experience. In *Proceedings of CHI '12*, pages 139–148. ACM, 2012.
- [524] O. Weininger. Mortality of albino rats under stress as a function of early handling. *Canadian Journal of Psychology*, 7(3):111–114, 1953.
- [525] P. Weisberg and J. E. Russell. Proximity and interactional behavior of young children to their "security" blankets. *Child Development*, 42(5):1575–1579, 1971.
- [526] L. Weiskrantz, J. Elliott, and C. Darlington. Preliminary observations on tickling oneself. *Nature*, 230:598–599, 1971.

- [527] S. J. Weiss, P. Wilson, M. J. Hertenstein, and R. Campos. The tactile context of a mother's caregiving: implications for attachment of low birth weight infants. *Infant Behavior and Development*, 23(1):91 – 111, 2000.
- [528] S. J. Weiss, P. Wilson, and D. Morrison. Maternal tactile stimulation and the neurodevelopment of low birth weight infants. *Infancy*, 5(1):85–107, 2004.
- [529] S. J. Whitcher and J. D. Fisher. Multidimensional reaction to therapeutic touch in a hospital setting. *Journal of Personality and Social Psychology*, 37(1):87 – 96, 1979.
- [530] N. White and D. Back. Telephonic arm wrestling. *Shown at the Strategic Arts Initiative Symposium, Salerno, Italy*, 1986.
- [531] A. Wierzbicka. Talking about emotions: Semantics, culture, and cognition. *Cognition and Emotion*, 6(3/4):285–319, 1992.
- [532] F. H. Wilhelm, A. S. Kochar, W. T. Roth, and J. J. Gross. Social anxiety and response to touch: incongruence between self-evaluative and physiological reactions. *Biological Psychology*, 58(3):181–202, 2001.
- [533] C. J. A. M. Willemse. A warm touch of affect? In *Proceedings of Affective Computing and Intelligent Interaction 2015*, pages 766–771, Sept 2015.
- [534] F. N. Willis and V. A. Rawdon. Gender and national differences in attitudes toward same-gender touch. *Perceptual and Motor Skills*, 78(3):1027–1034, 1994.
- [535] F. N. Willis and C. M. Rinck. A personal log method for investigating interpersonal touch. *The Journal of Psychology: Interdisciplinary and Applied*, 113(1):119–122, 1983.
- [536] J. Willis, Frank N. and H. K. Hamm. The use of interpersonal touch in securing compliance. *Journal of Nonverbal Behavior*, 5(1):49–55, 1980.
- [537] B. G. Willison and R. L. Masson. The role of touch in therapy: An adjunct to communication. *Journal of Counseling & Development*, 64(8):497–500, 1986.
- [538] R. Winkelmann. The erogenous zones: Their nerve supply and significance. In *Proceedings of the staff meeting of the mayo clinic*, volume 34, pages 39–47, 1959.
- [539] D. Winnicott. Transitional objects and transitional phenomena. *The International Journal of Psycho-Analysis*, 34(2):89, 1953.
- [540] P. B. Xi Laura Cang, A. Strang, J. Allen, K. MacLean, and H. Y. S. Liu. Different strokes and different folks: Economical dynamic surface sensing and affect-related touch recognition. In *Proceedings of ICMI 2015*, pages 147–154. ACM, 2015.
- [541] I. Yeoman and M. Mars. Robots, men and sex tourism. *Futures*, 44(4):365–371, 2012.

- [542] S. Yohanan and K. E. MacLean. A tool to study affective touch: Goals & design of the haptic creature. In *CHI'09 Extended Abstracts on Human Factors in Computing Systems*, pages 4153–4158. ACM, 2009.
- [543] S. Yohanan and K. E. MacLean. The role of affective touch in human-robot interaction: Human intent and expectations in touching the haptic creature. *International Journal of Social Robotics*, 4(2):163–180, 2012.
- [544] T. Yoshikai, M. Hayashi, Y. Ishizaka, T. Sagisaka, and M. Inaba. Behavior integration for whole-body close interactions by a humanoid with soft sensor flesh. In *Humanoid Robots, 2007 7th IEEE-RAS International Conference on*, pages 109–114, Nov 2007.
- [545] K. S. Young, A. Cooper, E. Griffiths-Shelley, J. O'Mara, and J. Buchanan. Cybersex and infidelity online: Implications for evaluation and treatment. *Sexual Addiction & Compulsivity*, 7(10):59–74, 2000.
- [546] M. Zimmer. “But the data is already public”: on the ethics of research in Facebook. *Ethics and Information Technology*, 12(4):313–325, 2010.
- [547] Y. Zotterman. Touch, pain and tickling: an electro-physical investigation on cutaneous sensory nerves. *The Journal of Physiology*, 95(1):1–28, 1939.
- [548] M. Zyda. From visual simulation to virtual reality to games. *Computer*, 38(9):25–32, 2005.

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