Audio-tactile stimuli
to improve health and well-being

A preliminary position paper

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Abstract

From literature and through common experience it is known that stimulation of the tactile (touch) sense or auditory (hearing) sense can be used to improve people's health and well-being. For example, to make people relax, feel better, sleep better or feel comforted. In this position paper we propose the concept of combined auditory-tactile stimulation and argue that it potentially has positive effects on human health and well-being through influencing a user's body and mental state. Such effects have, to date, not yet been fully explored in scientific research. The current relevant state of the art is briefly addressed and its limitations are indicated. Based on this, a vision is presented of how auditory-tactile stimulation could be used in healthcare and various other application domains. Three interesting research challenges in this field are identified: 1) identifying relevant mechanisms of human perception of combined auditory-tactile stimuli; 2) finding methods for automatic conversions between audio and tactile content; 3) using measurement and analysis of human bio-signals and behavior to adapt the stimulation in an optimal way to the user. Ideas and possible routes to address these challenges are presented.

1 Introduction

1.1 Improving health and well-being through touch and hearing

People perceive the world through their senses: sight, smell, taste, hearing and touch. The tactile (touch) sense is an important one: it is in fact the first sense to develop in the womb. Touch can give people strong emotional experiences [1] and is vital for health and well-being [1]. Tactile stimulation or *somatosensory* stimulation, applying touch to the human body, is often used as a way to make people feel better or to reduce stress. Examples range from basic touch to comfort someone, massaging techniques, whole-body vibration training and physiotherapy to alternative treatments such as acupressure, Reiki and vibro-acoustic therapy.

Besides touch, the sense of hearing is also used to make people feel better: one can listen to spoken encouragements, relaxing music, or nature sounds to sleep better. Music therapy [2,3] is an established practice and has been extensively investigated in the scientific community.

The scientific literature shows evidence that specific methods of stimulation of the auditory (hearing) or tactile senses can indeed effectively reduce stress and muscle tension, increase well-being, or promote sleep. Furthermore, there are indications [4-7] that stimulating the two senses of hearing and touch *at the same time* can have stronger effects on the human body and mind than stimulating only one of these senses at a time. Hence a promising area of scientific research is the use of a combination of sound heard and touch felt by a user at the same time to influence the user's body and mind in a positive way.

1.2 Scope

The research area discussed in this paper we refer to as *combined auditory-tactile stimulation and its effects on human health, well-being, body state and mental state*. However, little scientific work has been done so far in this field. The aim of this paper is to present our vision on this research field of auditory-tactile stimulation, and to present research challenges and opportunities that we have identified.

Although we often refer to the term *health* as a goal of the systems we investigate, we do not mean to replace established treatment methods with new ones. Instead, in healthcare contexts the goal of our approach is to augment the existing care and treatment methods where possible by stimulating well-being, relaxation or sleep.

1.3 Example applications

1.3.1 Healthcare

One particular use case is a small relaxation room in a care institute where a user can sit in a comfortable chair with their eyes closed. Light, music and sounds are played in the room, and the user feels gentle taps on the body and calming oscillations. The chair senses how the individual user reacts to these stimuli in real-time. During a session the stimuli are composed by an intelligent system in such a way that the combined effect is optimally relaxing for this user. Maybe one user prefers taps, while another prefers gentle vibrations. And each user may have a personal level of intensity and patterns that he/she likes best.

A similar use case could be envisioned for people with autism, analogous to a multisensory environment investigated earlier in the MEDIATE project [8].

1.3.2 Home

Another use case example is in the home (consumer) environment. Imagine a user at home, who wants to relax after a busy day at work. He owns a multisensory relaxation/entertainment system that consists of a blanket with integrated tactile actuators (e.g. [5,6]) and headphones. The system provides a combination of sounds, music and tactile stimulation that is designed to relax. After a session of 20 minutes, the user feels much more relaxed than before.

1.3.3 Public transport

In public transport, it is vital that train drivers are alert during their work shift. However, the working hours in this profession are often irregular, inducing the risk of decreased alertness at times when it is most needed. The largest Dutch railway company NS has already experimented [9] with special power-nap relaxation rooms, which have the multi-sensory stimulation product AlphaSphere [7] installed. The goal is to enable personnel such as train drivers to have a quick, 25-minute rest e.g. during their break, in order to increase alertness during their work.

1.4 Structure of the paper

To be able to clearly outline our vision and the research challenges ahead in Section 3, we first provide an overview in Section 2 of the current relevant state of the art and its limitations. Section 4 ends with discussion and conclusions.

2 Current state of the art

The present section does not aim to be a complete overview or review of the state of the art. Rather, we briefly sketch the research and application fields that are considered relevant, with the help of a few key references. We expect that this Special Symposium at EuroHaptics 2010, *Haptic and Audio-Visual*

Stimuli: Enhancing Experiences and Interaction, or possible follow-up events will contribute to a more complete overview and hence an improved vision for the future of auditory-tactile stimulation.

2.1 Stimulating the sense of touch

Stimulating the tactile sense can give people strong emotional experiences and is vital for health and well-being [1]. Interpersonal touch is known to be an important element of human love and social bonding. Tactile stimulation is used today in methods to reduce stress or muscle tension, train the body, or to make people feel good, feel cared for, happy, energized, sleep better or simply more relaxed [10-14]. There are studies on the subjective pleasantness of touch [14] and studies on the mental, health-related and bodily effects of low-frequency vibration [10-13,15].

These methods can involve a human performing the stimulation, a machine, or a human helped by a machine. Of course it cannot be expected that touch by a machine, in general, will have as similar effect to touch applied by a human. But on the other hand, the properties of machine-generated or machine-mediated touch are still being actively researched. A recent result [16] suggests that the effect size of machine-produced touch in a specific experimental situation could be similar to that of touch performed by a human, although more research would be needed to substantiate such hypotheses.

2.2 Touch actuators

To fully understand the opportunities in the field of auditory-tactile stimulation, it is helpful to look at tactile actuation (i.e. touch stimulation) technology. In recent years, advances in actuators and embedded computing have enabled a wide range of machine-driven methods for tactile stimulation. The strong growth of haptic (tactile feedback) technology in the mobile phone market has brought a variety of small mechanical actuators onto the market. Such actuators are used in for example jackets ([4] or Figure 1) that can stimulate different points on the upper body or a blanket [5] that can provide tactile stimuli to the whole body. Miniature actuators can be combined [17] with larger actuators, which enables interesting compositions of effects. Today, a large variety of tactile effects can be achieved relatively easily, at low cost and be suitable for daily use situations.

The types of tactile actuators that we currently consider for our purposes are:

1. Miniature ERM (Eccentric Rotating Mass) vibration motors, used in many cell phones. These do not offer precise independent control of frequency or amplitude of tactile effects. Used in [4,5].
2. Small tactile transducers, capable of playing effects with precise frequency/amplitude control. Used in some cell phones and in [17].
3. Larger tactile transducers, used in certain home cinema products and theme parks for powerful bass effects (called "rumblers" or "shakers"). Also used in [17].
4. Common bass loudspeakers, sometimes used as an alternative to option 3 above. Used in [7].
5. Actuator systems for providing mechanical displacement or pressure on the body. For example solenoids, rotary driven pistons or pneumatic/hydraulic actuators. Motion is used by [18].

See Figure 1 (left side) for an example product: the *Feel The Music Suit* created by Sense Company [sense-company.nl] with the Utrecht School of Arts [hku.nl] and TNO [tno.nl].

2.3 Stimulating the sense of hearing

Like touch, the human sense of hearing is often used in methods for health and well-being. Examples are relaxation music, nature sounds, or self-help audio guides. In the literature, the effects of music and therapeutic use of music have been well investigated (e.g. [2,3]). Various audio products exist for well-being and mental state influencing, including so-called brainwave entrainment methods such as *binaural beats* or *isochronic tones*.

Figure 1: Dutch minister of Economic Affairs wearing a Feel The Music Suit at a public event (top-left). On the bottom left, design sketches of the suit. On the right, a demonstration of the TNO tactile dance suit showing coordinated dance movements by three users.

A good example of innovative audio content with well-being application is *Meditainment* [19] (= Meditation + Entertainment), which combines relaxing music, ambient soundscapes, nature sounds, voice coaching and guided meditation and visualisation techniques. One particular use of this content which is reportedly being investigated is pain management for hospital patients. Typically, the audio content in existing products such as Meditainment is static, id est not interacting with the user nor automatically adapting to the user. One of our hypotheses is that making this content more adaptive to the user could make audio stimulation much more effective and attractive.

2.4 Combined stimulation of touch and hearing: *auditory-tactile stimulation*

An interesting concept is to combine stimulation of the sense of hearing with the sense of touch. If each one alone can have positive effects, can the combination be even more effective or more enjoyable? See Figure 2 for an impression of this stimulation approach. As an example, the Meditainment audio content presented in the previous section does not include tactile stimuli – could tactile stimuli significantly increase the effectiveness of such content? Next, we look at what the scientific literature tells us about the health and well-being effects of combined stimulation.

Some work has been done on a specific method of combined auditory-tactile stimulation called vibro-acoustics [2,4,5]. Here, a tactile (vibration) effect is directly derived from the lower frequencies of music and played by one or two tactile actuators. Experimental results suggest that this combination may work well for relaxation or sleep. An experiment [15] with playing the didgeridoo, which evokes vibrations in the upper body along with sounds, shows promise as a specific medical treatment.

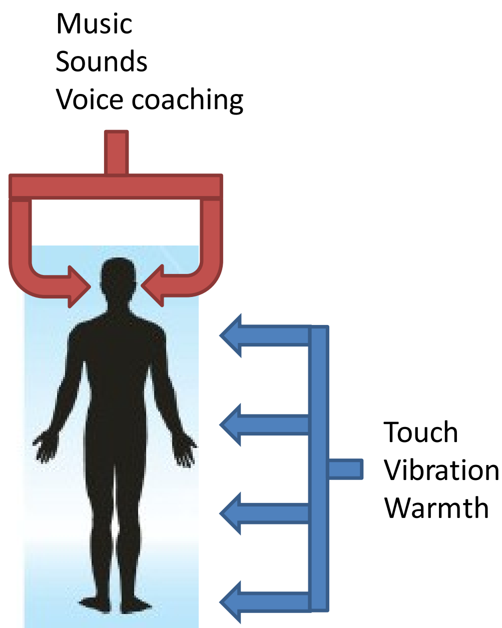

Figure 2: Impression of auditory-tactile stimulation of a user

Initial experiments at Philips Research with a combination of ambient sounds, relaxing music and patterns on a tactile blanket [6] also appear to be promising. The results suggest that the different modalities can mutually strengthen each other to provide a total experience that people really like and find relaxing.

On the other hand, a great deal of knowledge does exist in literature about the mutual interactions of the auditory, tactile and visual modalities, so-called *cross-modal effects*. This knowledge can be roughly categorized into in number of sub-areas [20,21]: perception and sensory thresholds, information processing performance, spatial attention, navigation/orienting in spaces, synaesthesia, neural plasticity, aging, perceptual illusions and sensory substitution. But the aspects of health, well-being and pleasantness are only addressed to a limited degree in this existing work.

2.5 Audio-tactile composition

A related area of research and creative work is *audio-tactile composition* [17,22,23], which refers to composing a musical piece or audible (ring) tone and at the same time composing tactile vibration effects that a user can feel. This is starting to become a commercially viable area, due to the rapid growth of haptics features in cell phones. However, in this field a number of topics have not yet been addressed in scientific work:

1. A link to human health and well-being has not been investigated;
2. Automatic audio to tactile conversion methods, suitable for driving multiple tactile actuators at the same time have not yet been investigated in a well-being context;
3. There is lack of well-founded composition tools to compose audio-tactile experiences, especially when considering applications, like ours, that are outside the limited context of mobile phone haptic ringtone composition.

3 Beyond the state of the art

3.1 Introduction

The aim of the scientific research identified in the previous section is to employ a combination of sound heard by a user and touch felt by a user at the same time, to influence the user's state of body and mind in a positive way.

We conclude from the previous section that stimulating the human senses of hearing and touch at the same time has great potential but needs further scientific study. We also found that existing approaches for auditory, tactile and auditory-tactile stimulation for health and well-being use fixed *content* that does not adapt to, nor interact with, the individual user. Content here refers to the combination of sounds and touch effects and how these are arranged in time and how touch stimulation patterns are arranged across the body. The adaptivity that a software-based solution for driving the auditory-tactile stimulation would provide, has not yet been exploited anywhere. To make our vision more concrete, we have provided example use cases in Section 1.3.

In this section, we first present in Section 3.2 three key scientific challenges/questions that have been identified. In the subsequent sections 3.3-3.5 the research topics are presented in somewhat more detail. Section 3.7 concludes by sketching a vision of the type of system that we believe is interesting for the research community to work towards, combining the results that should come out of the three research topics.

3.2 Scientific challenges

Within the wider area of auditory-tactile stimulation, we specifically want to highlight the following three scientific challenges/questions:

1. What are the mechanisms of human perception of combined auditory-tactile stimuli, and how can these mechanisms be modeled and used by a software-based system to influence the state of the human body and mind towards a desired state?
2. What are good methods for *conversion* between the audio domain and the tactile domain, in this context? *Conversion* here refers to converting content, for example music, from one domain to another, but also at a meta level to converting methods or paradigms from one domain to another. For example, how could a paradigm from music composition be converted into a paradigm for tactile composition? Tactile to music conversion is also something we consider.
3. How should measurement and interpretation of a user's biosignals and behavior during a stimulation session be done, to adapt the stimuli in an optimal way? Adaptation should help to better and faster achieve the users' well-being goals.

To start addressing these scientific challenges, we will outline a number of related potential research directions in the remaining text of Section 3.

3.3 Topic 1: Effects of multimodal stimuli on health and well-being

In the first proposed research topic, the goal is to study multi-actuator tactile stimulation of the human body and the effect of this stimulation on human health and well-being, alone and in combination (*cross-modal* effects) with the sense of hearing. Also other senses such as smell and vision may have to be taken into account here.

For a user, desired states can be (depending on the application) relaxed, peaceful, sleepy, engaged, dreamy, satisfied, active, et cetera. The mechanisms of human perception here may include auditory-tactile *sensory illusions*. Sensory illusions - perceiving things that are not really physically there - can be a very powerful way to evoke emotions.

A first step is to investigate existing literature on auditory and tactile perception and the related stimulation methods that use touch and hearing. Based on experimental tests, requirements from the application field, and findings from literature, one could apply an iterative, user-centered design and research process to come up with auditory-tactile stimuli that are likely to have a certain health or well-being related effect. These effects will then have to be investigated in user tests. Artificial Intelligence (AI) techniques such as rule-based systems, machine learning, personalization and (real-time) adaptation need to be investigated and employed to design models and systems that make it possible to link user characteristics and user experience to the properties of temporal and spatial patterns of auditory-tactile stimuli. Results of this type of research can then be applied in the work described under Topic 3 in Section 3.5.

The models just mentioned may use or incorporate existing models of human mental state, known from literature. One example is the well-known valence/arousal model proposed by Russell [24]. This model could be used to represent the known arousal-decreasing effects of certain tactile stimuli as described in [10,13].

3.4 Topic 2: Audio to tactile and tactile to audio conversion methods

The second research topic focuses on conversions between the audio domain and the tactile domain. One purpose is for example automatic conversion of existing music and non-music audio content to corresponding tactile stimuli. The audio and generated tactile stimuli can then be played simultaneously, creating a combined auditory-tactile user experience. By using the music content as the basic ingredient, a potentially large number of auditory-tactile compositions can be created from existing music.

Automatic translation methods of audio to corresponding tactile stimuli will have to take into account the (well-being) effects on the human and the methods will have to be suitable for multi-actuator tactile stimulation systems. Translation should be done in such a way that the user's health goal (e.g. muscle relaxation, sleep, energizing, etc.) and other goals (e.g. pleasantness, compositional coherence) are achieved. Conversion methods may include detecting the structural and symbolic expression of a piece of music, and using this information such that the tactile composition will reflect the same expression.

At a more general level, we also consider the possibility of conversion of methods and paradigms between the audio and tactile domains. For example, the existing knowledge on music composition and musical expression and communication of meaning could possibly be "translated" into approaches for tactile composition and tactile expression and communication of meaning. For music to tactile conversion and vice versa, a musical ontology can be used as a basis. Specifically, the system of Schillinger [25] is a candidate. Schillinger explored the mathematical foundations of music, and was particularly inspired by Fourier analysis and synthesis.

The topic of studying conversion methods that translate tactile stimuli into audio or music seems less obvious at first sight. However, we also envision useful applications here such as translating an existing tactile massage pattern that works well into matching music, in order to strengthen the psychological effect of the stimulation on the user.

3.5 Topic 3: Audio-tactile systems that adapt to the user based on sensor information

The third research topic involves so-called *closed-loop systems* or *biocybernetic loop* [26]: a sensory stimulation system, in which biosignals and behavior from a user are measured and used to adapt the stimuli that this user receives. To do the adaptation properly, relevant user influencing strategies should be used. Based on measurements on the user state, the system can then select the optimal influencing strategy.

User-adaptive methods have an added potential to be more effective, and at the same time more appealing to the user. This potential is still untapped today. Besides having the possibility of explicit multimodal interaction [27,28,29] with a user, interactive content can also be created by *implicit personalization* of auditory-tactile experiences. This is very useful in cases where the user cannot be expected to actively interact a lot with a system, foe example for elderly, people with impairments, or hospitalized people with temporary impairments. Research into multimodal (vision, hearing, touch, speech, gesture) user interfaces that optimally combine explicit and implicit interaction to provide the best level of personalization during a session could be a part of this research theme.

The biosignals that can be sensed and used for an adaptive system may include brain signals (EEG), heart signals (ECG), respiration, or skin conductivity (SCL); but also behavioral signals such as the user's movements, speech utterances or facial expressions during a session.

A particular research challenge for the use of biosignals in an automated system is that there are large inter-person variations. A system using a person's biosignals, would first have to learn about the user, id est calibrate its interpretation of signals towards the current user. This calibration challenge is also part of the research area that we propose.

3.6 Synergies in the three research topics

The above three research activities may require close cooperation mutually. Also they involve a cooperation between the field of artistic content creation on the one hand, and on the other hand scientific areas such as haptics, perception, brain and cognition. The perceptual mechanisms studied in topic #1 are on the one hand linked to lower-level brain mechanisms and to cognition, but on the other hand also to topics such as aesthetic perception. The audio-tactile conversion in topic #2 is primarily linked to composition and to the arts, but can only succeed if the physical and mental health goals are respected – topics related to multi-sensory perception, brain and cognition. Similarly for topic #3: although measurement and interpretation of user state mainly links to psychophysiology, perception, brain and cognition, it is also necessary to have influencing strategies in place that guide a user towards a desired state. These influencing methods will probably have a strong creative/artistic component in them.

3.7 Vision: Sensing + algorithms + content = optimal personalized experience

Combining the work proposed in the above three topics, we can sketch a vision to work towards. With recent advances in ICT such as low-cost embedded data processing, solid-state storage growth, ubiquitous networking, and recent progress in unobtrusive brain and biosignal sensors, a novel type of sensory stimulation system becomes feasible. This type of system will in real-time adapt a stimulation session towards an optimal, personalized experience for the current user. This personalization can be based on a generic model of a user and his/her mental state, which is continuously updated based on sensor interpretation and data mining. Here, the data is sensed (preferably in an unobtrusive way) from the user during a stimulation session.

The measured signals and their interpretation can be used to construct a software model of the current user state, which may describe current estimated levels of relaxation, sleepiness and comfort. Based on the model, influencing strategies can be chosen to help achieve the user's health and well-being goals.

Artificial Intelligence methods could be used effectively in construction of the user state model and in the optimal selection of influencing strategies. This would be a novel approach beyond the current state of art for auditory-tactile or tactile stimulation. In addition, this approach could be extended in the future to include also stimulating the visual sense (with images, video or light) or olfactory sense.

4 Discussion and next steps

4.1 General conclusions

In this position paper we have introduced auditory-tactile stimulation as a possible means to increase health and well-being, applicable in various application areas. The existing state of the art has been briefly addressed and based on our findings so far we conclude that there is clear potential for innovation in auditory-tactile stimulation approaches. Three specific areas for further research have been identified. Finally, a vision is presented of a software-based learning system that can automatically or semi-automatically adapt to the individual user based on general knowledge plus sensor information obtained from the user during a session. The system will then decide which specific auditory or tactile stimuli to render, to optimally achieve the user's goals.

4.2 Relevance of the proposed topics

If we take a broader look at society as a whole, one trend is that due to an aging population, Western economies are increasingly struggling with increasing healthcare costs and shortage of healthcare personnel. Therefore, there is a growing need for preventive healthcare. Preventive care is a useful instrument, not only to improve the quality of people's lifes, but also to partly avoid the cost of expensive regular treatments. The results of the research we propose could be applied for preventive healthcare, and can therefore have a positive impact on society.

Other potential users could be the healthcare workers themselves. Due to the ageing trend and economic constraints, their work will become ever more efficiency-oriented, time-pressured and stressful. Looking outside the domain of healthcare, other potential user groups can be identified who increasingly have to cope with highly stressful events occurring at work or who have to work under pressure. For example public transport personnel, school teachers, fire fighters or police officers. All these user groups could benefit from innovative new ways of coping with stress, or ways of inducing relaxation or sleep, quickly and on-demand. Auditory-tactile stimulation holds this promise.

One concrete example where results can be applied on the shorter term is the small enterprise Sense Company, an active supplier of sensory stimulation solutions to care organizations. Their portfolio includes tactile stimulation products. Other examples would be providing enjoyable relaxation solutions for hospital patients or medical personnel, or products that help to manage pain for chronically ill users at home.

As another example of application of results, the Utrecht School of the Arts (HKU) has already done various projects with partner organizations over the past years, aiming at people with special needs such as people who are deafblind. They investigated how these people can benefit from musical and rhythmic tactile stimulation.

4.3 Creating a research community

By organizing the Special Symposium "Haptic and Audio-Visual Stimuli: Enhancing Experiences and Interaction" as part of the EuroHaptics 2010 conference, the authors aim to start the process of gathering a research community around the topic of tactile (haptic) stimulation combined with other modalities, for applications in healthcare, well-being, entertainment and user interaction. We plan to organize a follow-up event around these topics in the future, possibly as a workshop linked to an existing conference.

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