Gr!pp: Integrating Activities of Daily Living into Hand Rehabilitation

A task-specific post-stroke hand rehabilitation tool for home use

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ABSTRACT

Impaired hand function impacts many stroke patients' daily lives, leading to a lack of independence and difficulty in performing activities of daily living (ADL). There are various assistive devices and interactive exercise monitoring systems that aim to help stroke patients perform unsupervised at-home hand rehabilitation exercises. However, for these efforts to work, the patients are required to self-supervise their rehabilitation process at home and allocate time in their daily schedule, which often is challenging. In this paper, we propose an alternative method. We hypothesize and test the idea of seamlessly integrating hand rehabilitation exercises with the products used for cooking. To this aim, we followed a research through design approach, developed Gr!pp and tested it with two stroke patients. Our results show that Gr!pp can facilitate intuitive use by its form. We also found other application areas of Gr!pp (e.g., eating) and improvement points (e.g., gamification) to promote motivation. We conclude our paper with further implications and our contribution to the tangible interaction design field.

CCS CONCEPTS

• **User centred design**; • **Interactive Systems and Tools**; • **Empirical studies in interaction design**;

KEYWORDS

Hand, at-home rehabilitation, stroke, activities of daily living, tangible interaction

ACM Reference Format:

Floor Stefess, Kostas Nizamis, Juliet Haarman, and Armağan Karahanoğlu. 2022. *Gr!pp:* Integrating Activities of Daily Living into Hand Rehabilitation: A task-specific post-stroke hand rehabilitation tool for home use. In *Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '22), February 13–16, 2022, Daejeon, Republic of Korea.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3490149.3505572

TEI '22, February 13–16, 2022, Daejeon, Republic of Korea

ACM ISBN 978-1-4503-9147-4/22/02.
https://doi.org/10.1145/3490149.3505572

1 INTRODUCTION

Stroke is one of the leading causes of disability worldwide [5, 35, 41]. Research shows that 80% of stroke survivors suffer from hand function loss [40]. Low hand functionality may result in social and individual burden, which prevents people from being independent in carrying out activities of daily living (ADLs) [16, 28]. Consequently, stroke survivors experience a lower quality of life due to their limited ability to participate in ADLs and social activities [4, 31]. On the other hand, several hand rehabilitation methods help these people recover their hand functions [15]. Typically, hand rehabilitation starts in rehabilitation centers, and the exercises are carried out with the surveillance of physiotherapists. When a certain level of function improvement is reached, the rehabilitation moves to the homes of the patients, where these people often face difficulties in motivating themselves to keep doing the exercises, as they need exercise-dedicated time and space [36].

Meanwhile, there are technological attempts (e.g., assistive devices [e.g.,11] and interactive exercise monitoring systems [e.g., 2]) which aim to ease the transition from rehabilitation centers to homes. So far, these attempts focus on direct translation of clinical exercises to the home setting by assisting the exercises to be executed regardless of the location of the patient [17]. All efforts require patients to be proactive and self-motivated and allocate time and space to implement the exercises into their daily lives [24, 29, 30]. Unfortunately, this requirement is hardly realistic for patients, as they either find the practices time-consuming and non-fitting their daily routines or forget to do the exercises [36]. Besides, patients lack the supervision of a clinical professional and show a lower motivation to complete rehabilitation by themselves [15]. In the end, whereas the general recommendation for carrying out these exercises is 30 min/day, patients only spend an average of 15 minutes/day on hand rehabilitation exercises at home after being discharged from the hospital [19, 20]. This disengagement often leads to patients not following the home therapy effectively, even not following the therapy at all, which results in patients' hand function deterioration [5]. This fact overshadows the effectiveness of current approaches, all of which assume and expect perfect motivation at the patient's side. As a result, many patients prefer to use their unaffected limb instead of improving the ability of the affected hand.

We believe patients should be encouraged to use their affected hands, but reduce the effort required by them (in terms of time investment, location restriction, and a high intrinsic motivation) and take advantage of the rapid expansion of smart technologies [1-3, 42]. To address these, we hypothesize that the seamless integration of hand rehabilitation exercises into the daily life of stroke survivors with the products of ADL can increase the effectiveness of hand rehabilitation training time at home and decrease hand function deterioration.

To test our hypothesis, we followed a research design approach (RtD) [44] and designed *Gr!pp*, an interactive handle that supports and the patients' use of impaired hands and intuitively forces practicing different grasps during cooking. Then, we produced *Gr!pp* prototypes and conducted a focus group session with two patients to test the concept. Our goal was to understand if and how using tangible interactive products of ADLs can facilitate and motivate at-home hand rehabilitation. In the following sections, we will explain and discuss (i) the related work that supports the feasibility of our hypothesis; (ii) the design process of *Gr!pp*; and (iii) focus group setup and results.

2 RELATED WORK

The hypothesis we posed above is based on our earlier analysis of the existing technology and (smart) objects that have been designed to facilitate at-home hand rehabilitation. Our analysis made it clear that these products can sometimes be ineffective due to the amount of time and space they require for rehabilitation at home. For example, we found that usage of smart products such as Neofect Rapeal Smart Board [25] and wearable gloves [9, 29] require the patient to allocate a significant amount of time and space for rehabilitation exercises. Others [6-8] that are more likely to require less time, can be better adapted into the daily life of patients, but they are often perceived as challenging and mundane. Additionally, we found that the abovementioned products assist the user passively (e.g., no provision of feedback and not active instructions or adaptations) and fall short in activating users' motivation, when direct feedback about the patient's progress is proved to facilitate effective rehabilitation [18].

Hand rehabilitation products such as the WIM [10] or the Neofect Rapeal Smart Pegboard [13] provide both sensory and visual feedback. This helps the user perform tasks correctly, improving their hand motor function compared to passive products. Even though the WIM and Neofect Pegboard provide effective hand rehabilitation through feedback, they still lack connection to a context. They do not train a specific functional task but assume that their exercises can be generalized. O'Dell, Lin, and Harrison [22] concluded in their research that task-specific exercises are of value to good rehabilitation, as the training fits a particular context and ensures seamless integration, consequently ensuring proper transferability of skills. A study from Donaldson et al. [5] confirms this by presenting a task-specific context.

Products that are perceived to be fun appeal and motivate further use [21]. For example, a puzzle or a board game includes a playful element in rehabilitation [5], which results in increased intrinsic motivation [21]. Another factor that influences motivation is establishing a sense of achievement, for example, through experiencing increased hand capabilities [33]. User motivation can support regular and repetitive practice, which is beneficial for good rehabilitation [39]. Users given a task-specific context during rehabilitation showed increased hand function, whereas users with a lack of context showed significantly less improvement. Therefore, in this study, we explore the applicability of our approach in a specific ADL for deploying a rehabilitation product at home.

3 DESIGN OF *GR!PP*

In this study, we followed a research through design approach (RtD) [44], which employs design as part of knowledge generation, and uses prototypes as part of understanding complex situations [37]. In our design process, we collaborated with two experts (i.e., one physiotherapist and one occupational therapist) who have at least ten years of experience in hand rehabilitation and asked about their opinion about our hypothesis. Following, we explored the types of ADL's that would be suitable for our design implementation. We decided that *cooking* could be a good candidate for combining hand rehabilitation exercises with ADLs through discussions as during cooking a variety of grasps [34] and diverse actions [43] occur multiple times. Following these agreements, the first author generated several tangible interaction concepts (e.g., electronic kitchen devices, manual kitchen utensils, and add-ons) until all the authors agreed on the final concept direction: *Gr!pp* (Figure 1.1 - 1.5), an interactive handle for hand rehabilitation.

Gr!pp aims to facilitate practicing different grasps and improving stroke patients' hand motor functions. The user attaches *Gr!pp* (Figure 1.1) on a kitchen utensil and chooses a grasp to practice (Figure 1.2). Through LED lights and by its form (Figure 1.3) *Gr!pp* forces the user to hold the handle in a particular and correct manner. We envision that *Gr!pp* comes in different sizes so that it fits different hand sizes, and the design of the handle facilitates only left- or right-handed usage, to unconsciously force the user to use their impaired hand. The pressure sensors placed inside the handle monitor hand functions and give tactile feedback to the user in case the fingers are placed incorrectly on the handle (Figure 1.4). In addition, these sensors monitor the total time of handle usage and the type of the grasps the user practices and provide a usage and hand function progress report which the user can access through a dashboard (Figure 1.5).

We also wanted to test if a gamification function could support our at-home hand rehabilitation concept. To this aim, we envisioned and designed a point collection system. The idea here is that the user collects points by repeatedly and correctly performing the grasps and unlocks recipes that facilitate practicing different hand grasps. We developed low-fi prototypes of *Gr!pp* with these specifications and evaluated our research direction with the target users (1.6-1.7).

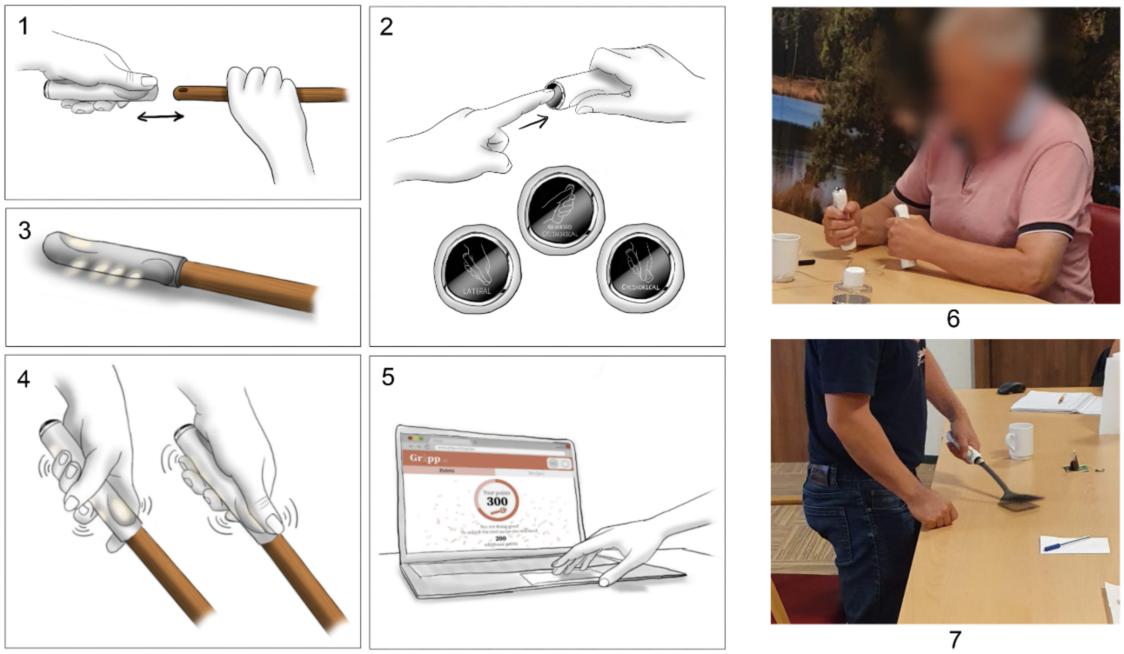

Figure 1: 1-1.7. Conceptual Design and Prototype Testing of Gr!pp

4 FOCUS GROUP

We organized a focus group session to test our hypothesis. Our goal was to explore if *Gr!pp* could and should further be implemented as an at-home hand rehabilitation practice tool. To this aim, we contacted three volunteer participants through a local rehabilitation center. Before contacting potential participants, we obtained ethical approval from our research institute (name to be provided upon acceptance). We informed the volunteers with the aims and goals of the focus group. We shared the informed consent form and asked them to tell us their decision within one week. One participant was not interested in the study for several reasons (e.g., no benefit or due to the COVID-19 pandemic). In the end, we carried out the focus group with two participants who had a mildly impaired hand because of stroke. Both participants were males over the age of 40. They both had been in the rehabilitation center for six months after they had a stroke.

The focus group took place at the local rehabilitation center (name to be provided upon acceptance). The participants were invited to the rehabilitation center, where we took additional measures for the safety of the participants. Both participants were informed that there would be another participant and the authors present in the sessions. During the focus groups, we gathered around a rectangle table where the participants were facing each other. The first author asked the questions while the other authors were present to probe the participants and note their observations. The two prototypes were placed on the table in front of the participants. At the beginning of the focus group, we asked participants to sign the consent forms and informed them that they could leave the session if they felt uncomfortable. At the beginning of the session, we made a short round of introductions and informed the participants about the session's goal. Following, we asked questions about participants' involvement in daily and social-life activities and cooking experiences. We then showed participants the concept sketches (Figures 1.1-1.5) and introduced the prototypes. Afterwards, we asked the participants of their opinion about the product concept and the prototype. We aimed to create a safe space for the participants, where they were free to use the prototypes, get a feeling of the intended product idea, and discuss the concepts freely. The sessions were held in participants' native language.

We voice-recorded the session and we also took pictures while the participants were holding the prototypes (Figures 1.6-1.7). The voice recording was first transcribed by using an online artificial intelligence software (www.sonix.ai) and was corrected by the first author where necessary. The transcript was then merged with the observations of the other researchers. Finally, we discussed the highlights of the focus groups within the researchers' team to evaluate the applicability and feasibility of the idea behind *Gr!pp*. Hence, our results consist of two sections: participant observations and participant opinions.

5 RESULTS OF FOCUS GROUP

5.1 Participant Observations

The first thing we noticed was the match between the anticipated and actual use of the *Gr!pp's* form. The prototypes were intended for either right or left-handed use, and both participants willingly and correctly held the prototypes with the intended hand (Figure 1.6-1.7). Additionally, both participants stated that *Gr!pp's* form 'nicely' supports their impaired hand use and highlighted that they would use such a multipurpose-handle more often in the future.

We observed both participants had a declined hand function in their impaired, but non-dominant, hands. We initially aimed *Gr!pp* to be used by the impaired hand of the patient, but we did not consider that the impaired hand would be the non-dominant hand. It turned out that the products of the activity (e.g., spatula) we focused on are mostly used by the dominant hand (i.e., left or right hand) of the patients. Furthermore, during the focus group, we observed that doing these activities with the non-dominant but impaired hand results in unnatural movements. Consequently, the intended use of *Gr!pp* can become less effective, as the patients tend to use the product with their dominant but not-impaired hands.

5.2 Participant Opinions

Both participants stated benefits of and improvements for the future use of *Gr!pp*. First, both participants stated that they do not necessarily need a product for cooking, but instead would use a similar product for eating. An example was cutting a piece of meat. One participant indicated that it can be challenging to cut meat, as the handle of fork can be too small to hold properly.

Second, both participants suggested that *Gr!pp* could be offered in different sizes than the presented one. For instance, a smaller one can enable patients to practice a grip when it is place on a smaller product (e.g. fork) than only on large cooking utensils (e.g. a spatula). Additionally, participants suggested *Gr!pp* to be offered in larger grip sizes, so that a patient can better practice hand stretch, which is common problem in hand rehabilitation. All these suggestions gave us the impression that the intended use of *Gr!pp* needs to shift towards facilitating various activities such as dining or handling smaller objects (e.g., a fork, knife, or pen). This way, a patient can practice lateral or cyclindirical grasps with various grip sizes.

During focus group, we also asked about potential gamification functions of *Gr!pp*. One participant told that he liked the idea of gaining points when performing a correct grasp, as this made him feel motivated. However, the other participant indicated that he only would feel motivated when the product would make a noticeable difference in the recovery of their hand and decrease the difficulty in performing tasks with this impaired hand. A suggestion to address this issue was to visualize the progression the impaired hand. It was stated that visualizations might stimulate product usage though the visual portrayal of the product's effect on hand function abilities.

Contrastingly to our idea of seamless hand rehabilitation implementation and a non-intrusive point collection system, the participants indicated that they would rather have something that actively shows their hand improvement. They liked the idea of having a product that could help them during daily activities but did not necessarily give a high value to the fact that the product was a seamless blend into their lives. They cared more about the product functioning and achieving hand function improvement.

6 DISCUSSION

We tested *Gr!pp*, a task-specific post-stroke hand rehabilitation tool for home use, and the idea of it being seamlessly implemented into ADL. We discovered several points of improvement in our prototype and methodology. The idea of using tools to support both ADL and hand rehabilitation at home was perceived as a motivating development for users. Elaborating on these points can help future research improve the development of future products for at-home hand rehabilitation that will use our proposed method.

6.1 Evaluation of *Gr!pp*

We have hypothesised that seamless integration of hand rehabilitation exercises into ADL, supported by a (smart) object, can significantly increase effective training time and ADL performance, and consequently decrease hand function deterioration at home. Throughout the development of the *Gr!pp* we have evaluated this hypothesis and came to several realizations.

First, similar products can be implemented in the daily life of users as part of ADL's (e.g. cooking). We found that, by design, the *Gr!pp* seamlessly fits within the routine cooking activities. The product stands out from other at-home hand rehabilitation products, (such as the Neofect Rapeal Smart Board [25] or smart gloves with accompanying virtual reality environments [9, 29]) as *Gr!pp* does not require large (permanent) adaptations to surroundings or additional software. Furthermore, implementing such a product for cooking creates a task-specific context and consequently facilitates seamless integration, which allows for effective hand rehabilitation. Additionally, compared to the therapy ball [7], therapy putty [8] and at home rehabilitation exercises [6], the *Gr!pp* aims to give the user a sense of achievement. We thought that this can be achieved with a point collection system that is integrated within the product. However, findings from the focus group showed that the point system might not evoke a rewarding feeling for all users, as it may lead to lower user motivation.

The focus groups showed that inclusion of direct feedback is a necessity for effective rehabilitation. The *Gr!pp* provides haptic (i.e., vibrations) and visual (i.e., LED-lights) feedback to help the users position their fingers correctly, which potentially results in improved hand motor function over time. However, this feedback principle has not been tested within the presented study. It is challenging or our study to determine whether this approach indeed leads to increased hand motor function, while there is evidence that direct feedback positively affects stroke rehabilitation [12, 26].

Another factor that should be considered is whether the implementation of *Gr!pp* increases ADL performance. We predicted that usage of the product could support patients not only in performing rehabilitation, but also performing a task correctly. Inclusion of the *Gr!pp* within an ADL (such as cooking) may increase the complexity of ADL, possibly due to the need for active implementation of the *Gr!pp* in one's habits or the constant guidance during finger placement. Therefore, the long-term usage of the *Gr!pp* needs to be examined with regards to the effect it has on the performance of ADL. If usage of such a product has the risk of impeding ADL, one should come up with solutions for hand rehabilitation at home that do not negatively influence the patient's daily life.

6.2 Limitations and Implications for Future Research

The first iteration of the *Gr!pp* was created with limited involvement of professionals and end users. We know that co-designing is beneficial for design as it provides better knowledge about users' needs, better idea generation, improved quality and speed of decisions and higher levels of acceptance [14, 32, 38]. For instance, we aimed *Gr!pp* to facilitate at-home hand rehabilitation specifically during cooking. The results of the focus group, however, highlighted that it should have assisted various activities besides cooking. Therefore, we plan to extend our design to focus on various ADL related to different grasps. To anticipate this kind of challenges earlier, we suggest follow-up studies to involve professionals and end users more intensively, and at an earlier stage of the design process.

Additionally, we had the focus group with two participants, due to the limited amount of volunteers that were willing to participate in our research due to the ongoing COVID-19 pandemic and lockdown. We acknowledge that sample size "may limit the quantity and diversity of experience that can be drawn upon" [27]. The ideal size for a focus group would be five to eight participants to ensure in-depth and more variable insights [23]. Our choice to proceed with this number of participants was also motivated by the exploratory nature of this study and our effort to cause the least possible inconvenience to people with stroke. Therefore, our conclusions must be regarded with caution. Future work will include more participants with stroke and should define whether what our participants indicate is generalizable over more people with stroke of different age, digital literacy, etc.. A more extensive protocol including multiple ADL-related tasks and bimanual activities both in clinical and home settings shall offer further insights for the long-term use of smart products for seamless hand rehabilitation. Nonetheless, the presented work here is a promising first step towards pursuing such solutions.

Finally, design for bimanual activities has not been explored in this research. Our approach focused on facilitating only impaired hand usage. This may lead to users compensating the use of the *Gr!pp* with their unimpaired hand. We think that this was an interesting finding of our study, which opens up new research direction for us to investigate the applications of Gripp that require the use of both hands. Therefore, future research should explore ADL that inherently involve usage of both hands to complete the task (e.g., opening a jar).

7 CONCLUSIONS

In this paper, we presented the *Gr!pp* concept, a novel way of integrating at-home hand rehabilitation exercises into the daily life of stroke survivors. We tested the concept in a focus group session with two stroke patients. We found that the idea behind *Gr!pp* was received positively by stroke patients, showing that at-home hand rehabilitation with smart products embedded into ADL is a promising idea. On the other hand, the findings we present in this paper offer a new direction for future smart products for at-home hand rehabilitation and offer novel insigts for the future design of the *Gr!pp* and similar tangible interactive products. The focus group results indicated that we should work on transforming the tools of ADLs into tools for hand rehabilitation, while we should delve into bimanual ADLs , to prevent patients from only using their non-impaired hands. Hence, we will keep working on this research area and implement the participant suggestions into future versions of the Gr!pp concept. implement the participant suggestions into future versions of our concept.

ACKNOWLEDGMENTS

The authors would like to thank the participants of the study and the Roessingh Research and Development for their help with the participant recruitment.

REFERENCES

[1] Bobin, M., *et al.* Smart Cup to Monitor Stroke Patients Activities During Everyday Life. IEEE International Conference on Internet of Things, IThings, and IEEE Green Computing and Communications, GreenCom, and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data, SmartData, IEEE (2018), pp. 189-195 2018.
[2] Bobin, M., *et al.* SpECTRUM: Smart ECosystem for sTRoke patient's Upper limbs Monitoring. Smart Health, 13 (2019/08/01/ 2019), 100066.
[3] Bobin, M., Anastassova, M., Boukallel, M., Bimbard, F., & Ammi, M. (2018, October). Smart Objects Ecosystem for Post-Stroke Upper Limbs' Motor Functions Monitoring: How to collect objective and quantifiable data on the upper limbs' motor functions currently assessed by visual and subjectives estimations?. In Proceedings of the 1st International Conference on Digital Tools & Uses Congress (pp. 1-4)..
[4] Chen, Q., *et al.* Health related quality of life in stroke patients and risk factors associated with patients for return to work. Medicine, 98, 16 (2019).
[5] Coleman, E. R., *et al.* Early Rehabilitation After Stroke: a Narrative Review. Current atherosclerosis reports, 19 (12 2017), 1-12.
[6] Brewer, B. 39 Restorative, Strengthening Hand Therapy Exercises to Try at Home. https://www.flintrehab.com/hand-therapy-exercises/ 2020.
[7] Maher, C. Hand therapy ball exercises to improve fine motor skills. https://www.flintrehab.com/hand-exercise-ball-stroke-patients/ 2021.
[8] Maher, C. Hand therapy putty exercises to try at home + free pdf. https://www.flintrehab.com/hand-therapy-putty-exercises/ 2020.
[9] Friedman, N., *et al.* Retraining and assessing hand movement after stroke using the MusicGlove: comparison with conventional hand therapy and isometric grip training. Journal of NeuroEngineering and Rehabilitation, 11, 1 (2014/04/30 2014), 76.
[10] Holmsten, J. and Helmer, T. Wim - Interactive stroke therapy, https://designawards.core77.com/Interaction/74152/WIM-Interactive-stroke-therapy 2018.
[11] Jung, Hee-Tae, Hwan Kim, Jugyeong Jeong, Bomin Jeon, Taekeong Ryu, and Yangsoo Kim. "Feasibility of using the RAPAEL Smart Glove in upper limb physical therapy for patients after stroke: A randomized controlled trial." In 2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 3856-3859. IEEE, 2017
[12] Khademi, Maryam, Hossein Mousavi Hondori, Alison McKenzie, Lucy Dodakian, Cristina Videira Lopes, and Steven C. Cramer. Comparing direct and indirect interaction in stroke rehabilitation. In CHI'14 Extended Abstracts on Human Factors in Computing Systems, pp. 1639-1644. 2014.
[13] Kim, M.-H., *et al.* Effects of Audiovisual Biofeedback (RAPAEL Smart Pegboard) on Cognitive Function of Stroke Patients. Therapeutic Science for Rehabilitation, 9, 3 (2020), 77-89.
[14] Kujala, S. User involvement: A review of the benefits and challenges. Behaviour & IT, 22 (01/01 2003), 1-16.
[15] Kwakkel, G., *et al.* Probability of regaining dexterity in the flaccid upper limb: impact of severity of paresis and time since onset in acute stroke. Stroke, 34, 9 (2003), 2181-2186.
[16] Langhorne, P., *et al.* Motor recovery after stroke: a systematic review. The Lancet Neurology, 8, 8 (2009/08/01/ 2009), 741-754.
[17] Levanon, Y. The advantages and disadvantages of using high technology in hand rehabilitation. Journal of Hand Therapy, 26, 2 (2013/04/01/ 2013), 179-183.
[18] Nakamura, J. and Csikszentmihalyi, M. The Concept of Flow. Springer Netherlands, Dordrecht, 2014.
[19] Nijenhuis, S. M., *et al.* Effects of training with a passive hand orthosis and games at home in chronic stroke: a pilot randomised controlled trial. Clinical rehabilitation, 31, 2 (2017), 207-216.
[20] Nijenhuis, S. M., *et al.* Feasibility study into self-administered training at home using an arm and hand device with motivational gaming environment in chronic stroke. Journal of neuroengineering and rehabilitation, 12, 1 (2015), 1-13.
[21] O'Brien, H. and Toms, E. G. What is user engagement? A conceptual framework for defining user engagement with technology Journal of the American society for Information Science and Technology, 59(6), 938-955,2008.
[22] O'Dell, M. W., *et al.* Stroke rehabilitation: strategies to enhance motor recovery, 60 (2009), 55-68.
[23] Oates, C. J. and Alevizou, P. J. Conducting Focus Groups for Business and Management Students. SAGE Publications Ltd, United Kingdom, 2018.
[24] Ommeren, A. L. v., *et al.* The Effect of Prolonged Use of a Wearable Soft-Robotic Glove Post Stroke - a Proof-of-Principle. In 2018 7th IEEE International Conference on Biomedical Robotics and Biomechatronics (Biorob) (pp. 445-449). IEEE,

2018.
[25] Park, J., *et al.* Effectiveness of the RAPAEL smart board for upper limb therapy in stroke survivors: A pilot controlled trial. In 2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) (pp. 2466-2469). IEEE, 2018.
[26] Pereira, M. F., *et al.* Application of AR and VR in hand rehabilitation: A systematic review. Journal of Biomedical Informatics, 111 (2020/11/01/ 2020), 103584.
[27] Plummer-D'Amato, P. Focus group methodology Part 1: Considerations for design. International Journal of Therapy and Rehabilitation, 15, 2 (2008/02/01 2008), 69-73.
[28] Pont, W., *et al.* Caregiver burden after stroke: changes over time? Disability and Rehabilitation, 42, 3 (2020/01/30 2020), 360-367.
[29] Prange-Lasonder Gb Fau - Radder, B., *et al.* Applying a soft-robotic glove as assistive device and training tool with games to support hand function after stroke: Preliminary results on feasibility and potential clinical impact, 1945-7901 (Electronic) (2017/07/20 2017).
[30] Radder, B. The wearable hand robot: supporting impaired hand function in activities of daily living and rehabilitation University of Twente. https://doi.org/10.3990/1.9789036546584. (2018).
[31] Ramos-Lima, M. J. M., *et al.* Quality of life after stroke: impact of clinical and sociodemographic factors. Clinics, 73 (2018).
[32] Roser, Thorsten, Alain Samson, Patrick Humphreys, and Eidi Cruz-Valdivieso. Co-creation: new pathways to value: an overview. Promise & LSE Enterprise (2009).
[33] Sabini, R. C., *et al.* Stroke survivors talk while doing: Development of a therapeutic framework for continued rehabilitation of hand function post stroke. Journal of Hand Therapy, 26, 2 (2013/04/01/ 2013), 124-131.
[34] Saudabayev, A., *et al.* Human grasping database for activities of daily living with depth, color and kinematic data streams. Scientific Data, 5, 1 (2018/05/29 2018), 180101.
[35] Sennfält, Stefan, Bo Norrving, Jesper Petersson, and Teresa Ullberg. Long-term survival and function after stroke: a longitudinal observational study from the Swedish Stroke Register. Stroke 50, no. 1, 53-61, 2019
[36] Sluijs, E. M., *et al.* Correlates of Exercise Compliance in Physical Therapy. Physical Therapy, 73, 11 (1993), 771-782.
[37] Stappers, P. J. and Giaccardi, E. Research through design. The Interaction Design Foundation, pp. 1-94, 2017.
[38] Steen, M., *et al.* Benefits of co-design in service design projects. International Journal of Design, 5, 2 (2011).
[39] Taub, E., *et al.* Technique to improve chronic motor deficit after stroke, Archives of physical medicine and rehabilitation, 74(4), 347-354, 1993
[40] Thrift, A. G., *et al.* Global stroke statistics. International Journal of Stroke, 12, 1 (2017/01/01 2016), 13-32.
[41] Virani, Salim S., Alvaro Alonso, Emelia J. Benjamin, Marcio S. Bittencourt, Clifton W. Callaway, April P. Carson, Alanna M. Chamberlain *et al.* Heart disease and stroke statistics—2020 update: a report from the American Heart Association. Circulation 141, no. 9 (2020): e139-e596.
[42] Yang, G., *et al.* An IoT-Enabled Stroke Rehabilitation System Based on Smart Wearable Armband and Machine Learning. IEEE Journal of Translational Engineering in Health and Medicine, 6 (2018), 1-10.
[43] Yordanova, K., *et al.* Analysing Cooking Behaviour in Home Settings: Towards Health Monitoring. Sensors, 19, 3 (2019).
[44] Zimmerman, John, Jodi Forlizzi, and Shelley Evenson. Research through design as a method for interaction design research in HCI. In Proceedings of the SIGCHI conference on Human factors in computing systems, pp. 493-502. 2007