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Manta and Cactaceae: Rehabilitative smartphone accessories for people with chronic mild stroke impairments

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Abstract: Stroke causes damage to the brain, often resulting in weakness or paralysis on one side of the body. Everyday objects such as smartphones can play an important role after a stroke facilitating participation in daily activities. However, commercial smartphones can be challenging to use, and people with stroke often adjust their behavior to minimize the affected arm and hand use. This study explores how an object attached to a smartphone could evoke behavior change and contribute to the initiation of use of the affected arm. As part of a design workshop, different ideas were envisioned to promote the use initiation of the affected side of the body. Two high-fidelity smartphone accessories were developed and tested with four people with chronic, mild stroke impairments based on the results. The initiation of use observed during the formative usability test seems to be evoked by the learned behavior patterns rather than the design prototypes.

Keywords: stroke; product design; rehabilitation; behavior change

1. Introduction

In 2016 stroke affected 13.7 million people worldwide with one third dying (Carroll, 2019). The risk of dying instantly from a stroke is decreasing while the prevalence (i.e., living and experiencing the effects of stroke) is increasing and as more people survive this traumatic brain injury the overall burden of stroke increases. If these observed trends continue, there will be almost 70 million stroke survivors by 2030 (Feigin et al., 2014).

This study focuses on people in the chronic stage of stroke recovery, which starts at approximately six months post-stroke. Once people reach this stage, specialized health provision is limited or missing. Furthermore, people who experience so-called mild physical impairments are most likely to return to their homes after being discharged from the hospital. They are often not referred to rehabilitation services (Rochette et al., 2007; Tellier & Rochette, 2009) despite reporting persistent stroke-related symptoms (Edwards et al., 2006; Rochette et al., 2007; Adamit et al., 2015). Their form and degree of impairment can vary, but motor impairments are a common phenomenon that often affect one side of the body. Of people with stroke, 35% report an incomplete use of fingers and hands, and 31% report issues with gripping and holding items (Australian Institute of Health and Welfare, 2013). Even when arm and hand impairments are mild, people often experience significant limitations performing daily activities such as cooking, washing, or driving a car. Due to the limited access to stroke specialists, there is a need for tailored solutions that people with stroke can access in their home environment to facilitate a self-guided rehabilitation process.

After the stroke, people tend to compensate for the lost motor abilities of the affected arm and hand by primarily using the less-affected side of the body. This behavioral compensation can contribute to neglect or so-called “learned nonuse” of the affected side (Taub et al., 1994). Studies suggest that this self-taught behavior can be overcome by restraining the less-affected arm and hand and actively encouraging the use of the affected side (Morris et al., 2006; Taub et al., 1994, 2006). One therapeutic approach that focuses on people with learned nonuse to facilitate initiation of use is “Constraint-Induced Movement Therapy” (CIMT) (Reiss et al., 2012). The patient is asked to wear a mitt on the less-affected side and perform different tasks with the affected arm and hand. The intervention also includes different behavior change techniques (e.g., behavior change contract) to contribute to sustainable behavior change (Griffith, 2016; Morris et al., 2006). Health professionals familiar with CIMT emphasize that the intervention is a behavior change intervention consisting of multiple functional elements (Lemke et al., 2019) despite the name suggesting that the constraint is a core component (Taub, 2012). The effect of the physical restraint worn during the rehabilitation session can be experienced as an extrinsic reminder rather than forcing the use of the affected arm (Lemke et al., 2019). Including core elements of CIMT into the interaction with an everyday object, to remind the user to initiate use of the affected arm and hand, could potentially facilitate CIMT in the home environment. Research exploring such applications indicates that the interaction with the object needs to resemble one that the user is familiar with to allow intuitive use and contribute to the rehabilitation process (Lemke et al., 2017a).

After a stroke, people are commonly provided with devices that help perform daily activities despite motor impairments, including work, mobility, or communication (Algurén et al., 2009; ICF Research Branch, 2013). Such objects can be classified as assistive technology (AT) (Scherer, 2002). A typical AT example used in the home environment is the spike board (Figure 1) - a chopping board with spikes that keep food items in place during the cutting motion. These boards often also contain a fixed knife that users can press down to cut food items. Such devices might be helpful in a stroke population for which recovery is unlikely and who benefit from more compensatory movement patterns. However, they reinforce non-use of the affected limb, therefore limiting its movement and delaying rehabilitation. We argue that devices used daily (e.g., coffee machines) also offer the opportunity to be designed to facilitate more movement of the affected limb and therefore self-directed rehabilitation.

We will refer to such an application as “everyday rehabilitative devices” (ERD) as they focus on rehabilitation in the home environment rather than compensating for the lost motor abilities. Such devices could contribute to securing motor capabilities gained during the first six months after the stroke and potentially increase them.

When designing ERDs for people with stroke, different user and context requirements need to be considered (de Barros et al., 2011; Magnusson et al., 2017; Willems et al., 2021) to avoid device abandonment. For example, ERDs focusing on the arm and hand need to be feasible to use for a person with stroke. Therefore, complex movement patterns need to be broken down. ERDs must be used frequently throughout the day, challenge the user, and provide feedback to encourage and remind the user to use the affected arm and hand (Lemke et al., 2017b), (Figure 2).

Figure 1. A common device provided to people with stroke is a “spike board”, which compensates for the affected arm and hand when preparing food.

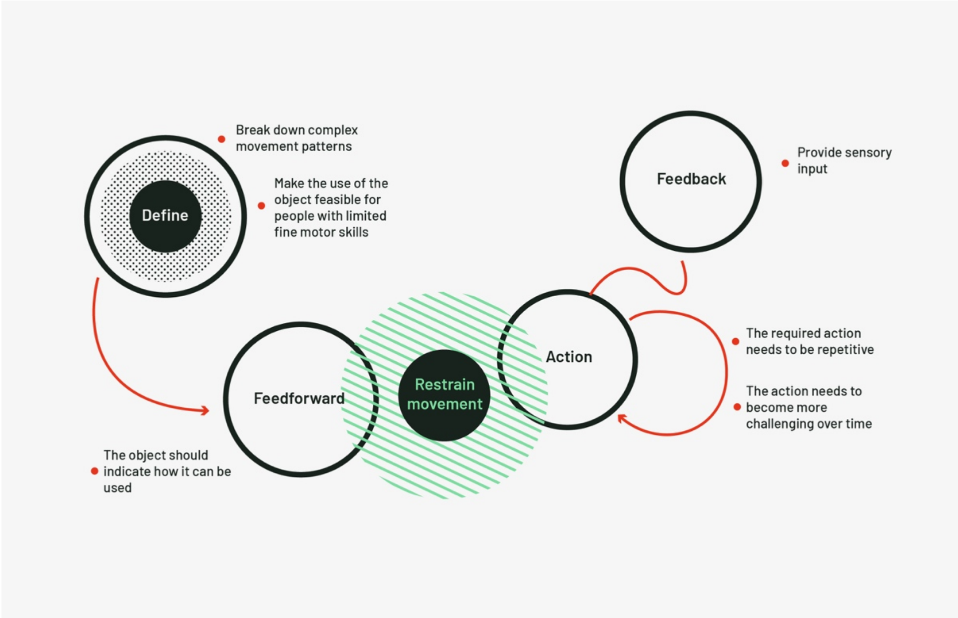

Figure 2. An ERD incorporating CIMT to evoke a behavior change in the user needs to incorporate several elements.

There are many different everyday objects that people with stroke are likely to interact with that can be used as a starting point when designing ERDs (Lemke et al., 2017c). Based on our previous findings, we focused on information and communication technology (ICT) devices (e.g., smartphones) for this study, which people with stroke are motivated to use and which can facilitate the rehabilitation process (Ferreira et al., 2014; Gustavsson et al., 2016; Zhang et al., 2015). Our previous study indicated that using commercial ICT devices can be challenging for people with stroke due to age and stroke-induced impairments (Lemke et al., 2020), (Figure 3).

This study explored how an ERD used as part of a smartphone can contribute to behavior change and evoke a use initiation of the affected arm and hand in people with mild, chronic stroke impairments. In this context, we define initiation of use as any involvement of the affected arm and hand to interact with a smartphone, such as picking it up, holding it, or tapping on the screen. Using a Research through Design (RtD) methodology (Krogh et al., 2015), we explored different design concepts to evoke a behavior change during two design phases. We conceptualized different design concepts in a design workshop in the first phase. We then clustered the anticipated behavior change influence of the different ideas based on the classification of product influence on user behavior: seductive, decisive, coercive, and persuasive effects (Tromp et al., 2011). In the second phase, we refined two concepts and tested them with participants. Our contribution to the field of behavior change includes a description of the design and evaluation process of ERD to be used by people with stroke-induced mild impairments.

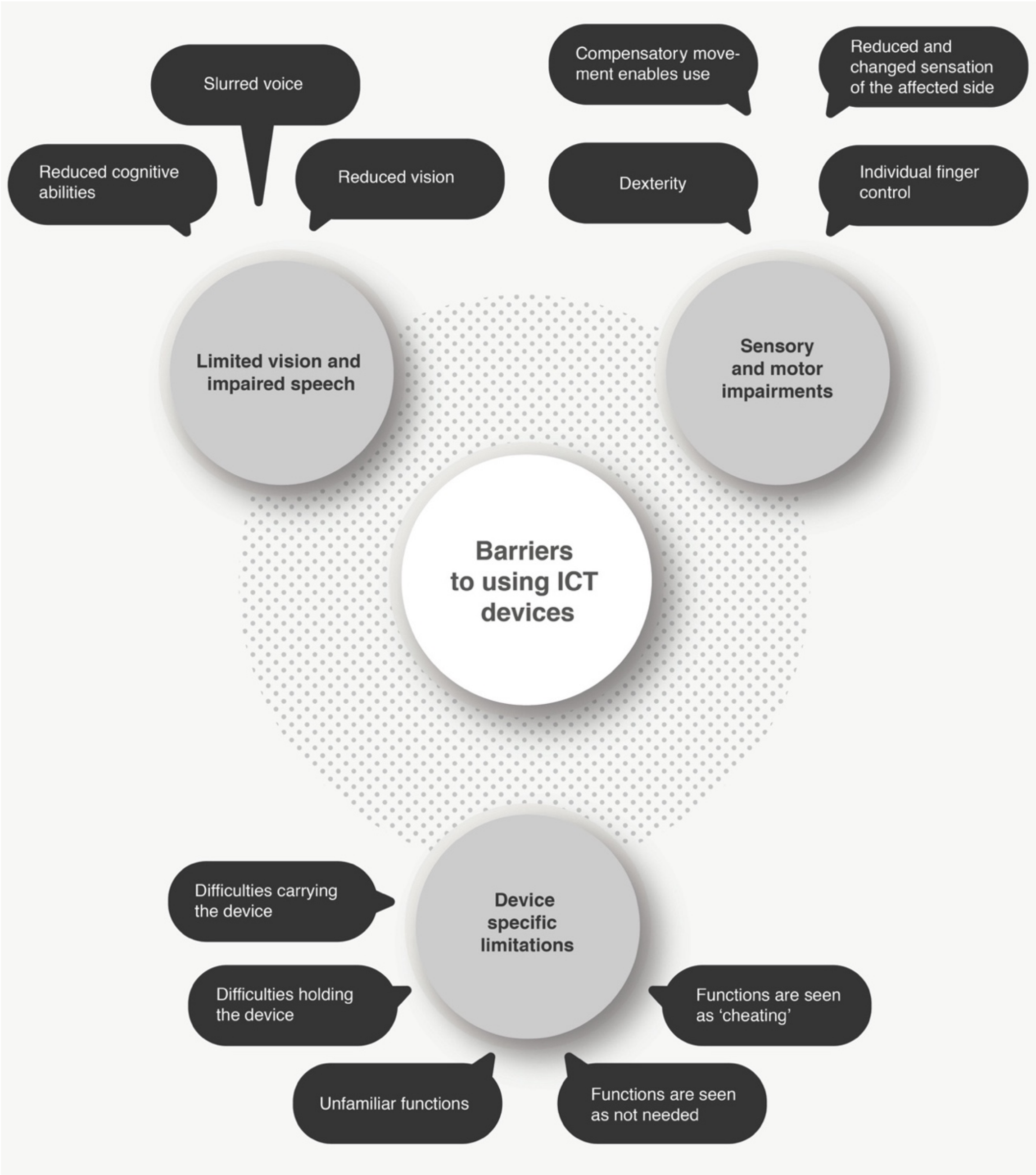

Figure 3. Barriers to using ICT devices experienced by people with stroke impairments (Lemke et al., 2020).

2. Methodology

2.1 Participants

This study was approved by the Health and Disability Ethics Committee (16/CEN/37) and the VUW Human Ethics Committee (0000022410). Participants provided informed written consent. We recruited participants through a local stroke club in Wellington (NZ) and a stroke professional in Auckland (NZ). The inclusion criteria for people with stroke included: Experience of a stroke at least six months before the study; living at home; having an active wrist and finger; the ability to walk independently; an age of 40–75 years; and good general health. The ethics approval restricted the evaluation of the prototypes to 30 minutes, and devices were not allowed to be tested unsupervised.

Five participants with a background in design took part in the first phase (design workshop). We had intended to include people with stroke impairments during this stage to increase an understanding of the user experience and context but were unsuccessful in recruiting suitable participants for this part. Four people with stroke took part in evaluating the prototypes, see Table 1.

Table 1. Phase two sample

Gender / Age / Dominant hand	**Time since stroke / Stroke impairment details**	**ICT devices used**
Male / 74 years / right-handed	2 years / Mild impairments of the upper and lower limb on the left side	Laptop, Android smartphone
Male / 70 years / right-handed	12 years / Moderate impairments of the upper and lower limb on the left side	Feature phone (First-generation mobile phone), landline
Male / 77 years / right-handed	10 years / Moderate impairments of the upper and lower limb on the right side	Laptop, feature phone
Female / 72 years / left-handed	6 months / Mild impairments of the upper and lower limb on the right side, reduced sensation on the right side	Laptop, iPad, iPhone

2.2 Phase one: Design workshop

We focused in the design workshop on developing different concepts that encourage and remind the user to use the affected arm and hand when interacting with a smartphone. We started by explaining to participants what common impairments people with stroke experience and pointed out issues when using a smartphone. We also explained different ways of restraining interaction as part of an ERD based on our previous design experiments (Lemke et al., 2017b), including:

1. Using ergonomic restrictions as part of the physical design, for example, designing the ergonomic form of a handle so it can just be used with left or right hand.
2. Focusing on bilateral tasks that require the use of both arms and hands to unlock the functionality of the object.

3. Using learned behavior patterns and ergonomic cues. For example, food-related norms include a fork being used with the left hand while a knife is used with the right hand while eating.

During the workshop, we focused on brainstorming and sketching activities. We used the creative technique the "Power of Ten" (IDEO, 2013) in the form of prompts during the brainstorming (Table 2).

Table 2. Design workshop outline

Workshop activity	**Details**
Introduction	The workshop started with an introduction to the topic and goal of the workshop. We explained common barriers to using smartphones as well as motivations. Different design strategies to restrain movement as part of the interaction were presented as a source of inspiration.
Brainstorming I	For the brainstorming activity, we used The Power of Ten in the form of different prompts, for example: How would the design work if you only had 99 cents?
Sketching I	Sketching of eight design concepts within eight minutes (one minute per sketch). A focus in the activity was on quantity rather than the quality of the ideas.
Sharing	Presentation of the eight ideas and then voting among all the presented concepts for the one with the most potential.
Sketching II	Choosing a concept and developing a refined sketch within 25 minutes followed by a presentation of the refined design concept.
Wrap up	The workshop ended with an explanation that the different concepts will be analyzed and refined in a future phase of the project.

The outcomes of the design workshop were sketches and explanations of the design concepts. The developed concepts were analyzed using thematic analysis in a deductive (top-down) form (Braun & Clarke, 2006). Deductive thematic analysis focuses on patterns within the data based on pre-determined topics of interest. We familiarized ourselves with the data and coded the concepts focusing on the anticipated behavior change influence on the user. We coded the data according to a (1) seductive; (2) persuasive; (3) coercive; and (4) decisive influence on the user based on the classification by Tromp et al. (2011). We chose this framework because our previous results indicated that users can experience an intended persuasive influence as rather forced. We also used the taxonomy of behavior change techniques by Michie et al. (2013) to label our codes and a thematic map to cluster and present the different codes.

2.3 Phase two: High-fidelity prototypes

We selected two concepts to be refined and evaluated by participants. We chose concepts for physical product design solutions and excluded game concepts and concepts involving the home environment space, for example, sensors placed on the walls. We did this to test the designs with people with stroke impairments.

We chose the two concepts based on their anticipated persuasive and coercive influence. The selection was due to our previous experimental results and the explicit behavior change influence that the devices aim to evoke, which allows the user to recognize it and reflect on its appropriateness and intensity. We also chose the two concepts because they allowed being used with a standard smartphone rather than requiring a smartphone redesign.

The first author (industrial designer) refined and produced the two prototypes in a serial design process (Krogh et al., 2015) using design criteria (Rodríguez Ramírez, 2017) developed during our initial research. We developed prototypes that could be attached to a standard smartphone for participants with an affected left or right hand. The user could hold the smartphone in a portrait orientation with the non-dominant hand holding the phone and the dominant hand to interact with the screen. This interaction style seems preferred among smartphone users (Ljubic et al., 2014). CIMT uses a behavior change contract to create a feeling of responsibility for one’s rehabilitation contributing to the long-term behavior change (Morris et al., 2006; Wolf et al., 2006). We developed two different packaging designs to include this behavior change component and reduce potential product-related stigma (de Barros et al., 2011).

The design prototypes were evaluated during a formative evaluation process using a pluralistic walkthrough with people with stroke (Wilson, 2014). We developed a smartphone replicate (Huawei model) for the testing process that was used rather than real smartphones to avoid any potential bias of being fearful of dropping a real smartphone.

The smartphone replicate had a size of 14.5 cm x 7.5 cm, a smooth surface, and a screen with some icons on the front. We provided three prototypes with the additions attached (Figure 4) to ensure that we could test all prototypes within a 30-minute time constraint.

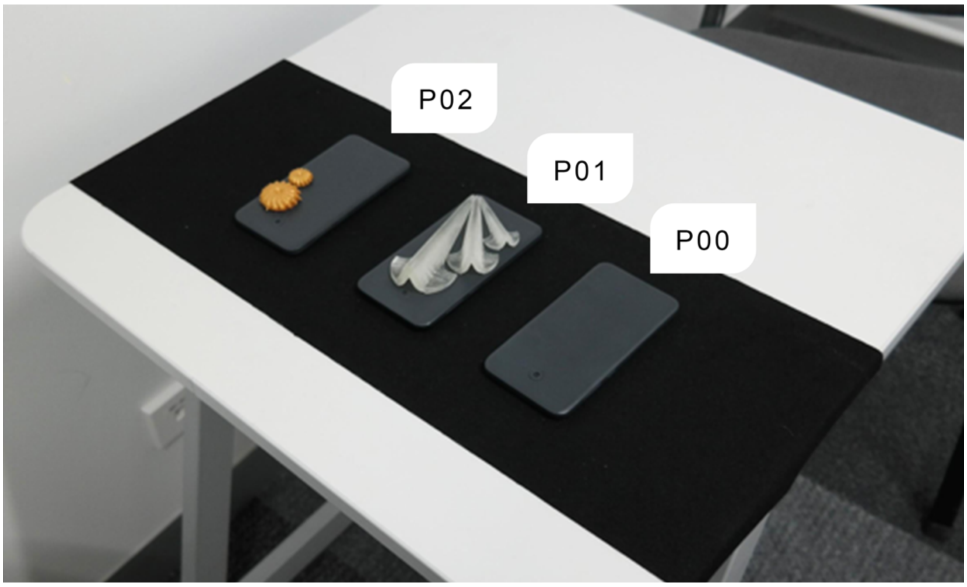

Figure 4. Setting for the formative usability evaluation process.

The task that was focused on was picking up the three different prototypes and tapping on the screen. The participants sat for the individual evaluation, and a research assistant placed the three prototypes in front of them. Each testing started with picking up the standard phone P00 used as a control device. P00 contained no accessories. Then followed P01 (persuasive influence) and P02 (coercive influence). The participants were told that they could pick up the phone in any way that felt comfortable to them. Once participants had tested all the prototypes, they were asked to try them in the left and right hand again and describe their impressions. We presented the packaging designs containing the behavior change note at the end, and participants were asked for their opinion. We used the following semi-structured questions during the evaluation:

P00, P01 & P02 are presented to the participant:

1. Could you please pick up the object?
2. Could you please describe how the use of the object makes you feel?
3. Do you find it easier to hold the object with your affected hand or with the less affected hand?
4. Would you use such an object?

The packaging and behavior contract are shown to the participant:

5. Could you please describe your thoughts regarding the packaging?
6. The packaging contains this behavior change contract that you would be asked to sign. Would you sign something like that?
7. Are there any elements that you would like to change?

The participants were then asked to rate the three different phones (P00, P01, P02) based on their preference. The use of the prototypes was video and audio recorded with the participants' consent and analyzed using thematic analysis in a deductive form (Braun & Clarke 2006), following the previously mentioned steps. We coded the data for the preconceived themes of (1) initiation of use and restraining effect; (2) usability issues; and (3) evoked behavior change.

3. Results

3.1 Phase one: Design workshop

Thirty-one ideas were developed in the form of sketches and notes and analyzed using deductive thematic analysis according to their anticipated user influence. We developed 14 different codes (Figure 5). The various codes were clustered according to their expected influence on the user. Below are the four themes of decisive, coercive, seductive, persuasive influence and corresponding codes described in detail.

Decisive design concepts focused on physical and visual prompts (No 1) that reminded the user of the desired behavior and made it the only possible behavior. For example, developing a digital phone application that requires the use of both hands. The decisive influence is likely to depend on the user's perception, e.g., the requirement to use both hands could be perceived as a coercive influence.

Coercive design concepts comprised of punishment (No 6) in the form of physical pain or alarm sounds and counter-conditioning (No 7) in the form of requiring the use of the affected arm and hand to unlock the functionality of the phone.

Seductive design concepts focused on habit formation (No 5). For example, by asking the user to text someone multiple times a day using the affected hand.

Persuasive design concepts comprised of general social support (No 8); emotional, social support (No 9); environmental restructuring (No 10); feedback on the behavior (No 11); physical and visual prompts and cues (No 12); others are monitoring with awareness (No 13); and material reward (No 14). Two games were mentioned – a balancing game using the phone as a controller and a conversation game during which the user had to reply with the affected hand.

Some of the decisive and seductive design concepts focused on enabling the use of the phone rather than restraining its use (No 2-4). The three themes focused on enabling the use of the software; enabling the use of the hardware; and reducing the likelihood of dropping the phone were therefore situated under *problem-solving.* The design components that addressed this problem solving could be experienced as decisive and seductive and were consequently grouped among the two areas.

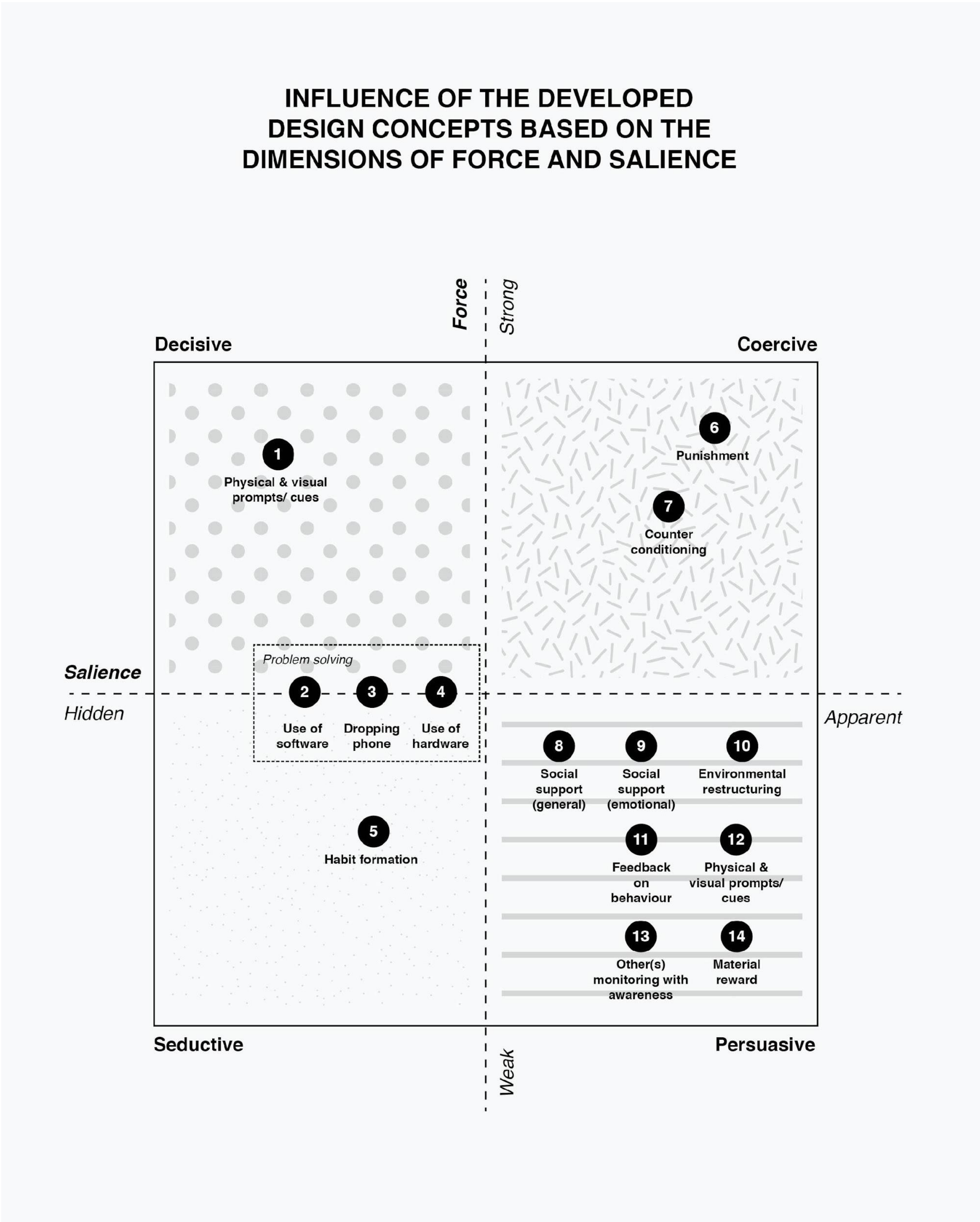

Figure 5. Thematic map of the different design concepts developed during the design. Adapted from Tromp et al. (2011).

4.2 Phase two: High fidelity prototypes

For the second phase of the study, we focused on refining two design concepts. We chose a persuasive and a coercive influence on the user due to the explicit rather than implicit influence.

For the persuasive design influence, we focused on the code of *visual and physical prompts and cues* (No 14) as this allowed testing by the participant without the need to have other people present or restructuring the environment. We combined initial design ideas of providing a kind of handle attached to a standard phone with the design strategy of ergonomic restriction to evoke an initiation of use (Lemke et al., 2017b). The final design consisted of three grip elements attached with double-sided tape to the back of the smartphone prototype (Figure 6). The design creates an uneven surface at the back, limiting its use on a flat surface to compensate for the affected arm. People with stroke tend to perform this compensatory movement pattern when using commercial phones (Lemke et al., 2020). The three different elements of Manta could be attached separately to the phone to account for differing hand sizes. Furthermore, it was possible to decrease the number of parts to increase the challenge in the interaction, which is an essential element in CIMT.

Figure 6. We named the persuasive concept Manta due to user feedback indicating that the design looked like a kind of sea creature.

The coercive design concept focused on the code of *punishment* (No 6) due to the explicit and strong influence on the user. The initial concept focused on providing electrical shocks when the wrong hand was used, and we decided to concentrate on physical discomfort as a form of punishment for *Cactaceae* to allow safe testing of the design. P02, consisted of two golden cacti with several spikes attached with double-sided tape to the back of the smartphone prototype (Figure 7). The design created an uneven surface at the back of the phone to decrease the possibility of putting the phone down and compensating for the affected arm and hand.

Figure 7 We named the coercive design Cactaceae given that we based the form on the physical shape of a cactus.

Figure 8. Packaging and behavior change notes. The note asks the user to sign it and put it up where it can be regularly seen.

CIMT uses a behavior change contract to create a feeling of responsibility for one's rehabilitation. We developed a packaging that presents the behavior change contract for the two design concepts. The packaging also aimed to reduce potential product-related stigma and lacked reference to stroke or older adults (Figure 8). Each package contained a note asking the user to sign it to increase commitment to the process. The note also stated that the user should put it up somewhere visible to work as a reminder.

4.3 Phase two: Evaluation process

The formative usability evaluation process revealed several insights, see Table 3 for an overview.

Restraining effect

Prototype P00, the standard smartphone, did not contain any design elements to restrain movement. Nonetheless, two of the participants initiated using the affected hand to hold the phone. P01 was not used in an intended way by placing the fingers between the grip elements. Participants instead used the less affected hand to pick up the prototype and transferred it to the affected side. Three of four participants initiated the use of the affected hand to hold the prototype, but no one used the affected hand to pick it up. One of the three participants used the design as a grip, and the fourth participant used only his less affected hand and put P01 on his left thigh to compensate for the uneven back of the phone. Participants furthermore seemed to prefer a firm grip from the back holding on the left and right side of the phone prototype, which caused P01 to be experienced as uncomfortable. One of the participants had issues using the device and described holding a phone as quite difficult in general because his shoulder would tense up. P02 evoked an initiation of use, in three of the four participants, to use the affected hand to hold it. No one used the affected hand to pick it up. None of the participants described touching P02 as uncomfortable or forcing any specific action.

Table 3. Formative usability evaluation results overview

Participant / Prototype	**Restraining effect**	**Initiation of use: Picks it up with the affected hand / Holds it with the affected hand**	**Preference**
P1 / P00	None	Picks it up: No Holds it: Yes	1st choice: P00 2nd choice: P02 3rd choice: P01
P1 / P01	None: Use with the less affected side is described as more comfortable	Picks it up: No Holds it: Yes	
P1 / P02	None: Texture feels comfortable	Picks it up: No Holds it: Yes	
P2 / P00	None	Picks it up: No Holds it: No	1st choice: P01 2nd choice: P02 3rd choice: P00
P2 / P01	None	Picks it up: No Holds it: Yes, but upside down. Easier to hold than P00	
P2 / P02	None: Tries to hold onto it during the testing	Picks it up: No Holds it: Yes. Holds onto the design elements	
P3 / P00	None	Picks it up: No	1st choice: P00

		Holds it: No	2nd choice: P02 3rd choice: P01
P3 / P01	None: Doesn't use the affected hand at all	Picks it up: No Holds it: No	
P3 / P02	None: Doesn't use the affected hand at all	Picks it up: No Holds it: No	
P4 / P00	None	Picks it up: No Holds it: Yes	1st choice: P01 2nd choice: P02 3rd choice: P00
P4 / P01	None: Holds onto it from the side	Picks it up: No Holds it: Yes	
P4 / P02	None: Object is described as textured rather than uncomfortable	Picks it up: No Holds it: Yes	

Usability issues

General usability issues included the semantic interpretation of the design (what it was for), the orientation of the design elements, the size of the prototypes, and smartphone-specific elements. The participants who felt comfortable with their feature phone (First-generation mobile phone) expressed no motivation to change to a smartphone. P01 and P02 were not used in the intended way, suggesting a lack of clear feedforward elements indicating how the participants should use the accessories. Observations indicate that participants preferred to grip the smartphone firmly from the sides rather than having it in the orientation that the prototypes encouraged. The opening of the fingers, accidental touching of the screen with the thumb, the wrong orientation of P01, too little support of P02, and unintentional changing the volume button due to the firm grip were mentioned as usability issues. The size of P01 was perceived as too large and limiting the possibility to carry the device in a shirt pocket.

Behavior change effect

All the participants mentioned that they would try to use the affected arm and hand as much as possible in everyday situations, even before the behavior change contract was presented. One of the participants liked the reminding function, but none of the participants indicated they would sign it.

> "I think the psychology of having someone sign it, is good. That's very good because you have the commitment there […] The mantra and the signing are very, very good. But I am not a fridge person." — Participant 01 (asked about the behavior contract, which asked the participant to put the signed note on their fridge as a reminder).

5. Discussion

This study reports on the development of two ERDs in the form of smartphone additions for people with mild chronic stroke. The ERDs aim to encourage and remind the user to use the affected arm and hand. Persuasive and coercive design concepts were developed based on a design workshop and evaluated by four participants. Our persuasive design lacked feedforward elements and was not used in the intended way. The coercive influence was not recognized as such, and it remains unclear if such an influence would be accepted. We chose a coercive design influence based on user feedback on earlier developed prototypes indicating that our designed persuasive influence was seen as rather forced and coercive. The design of *Cactaceae* evoked a feeling of physical discomfort when we tested it but was not perceived in such a way by participants and a stronger operationalization of a coercive influence could be more effective. However, while a coercive influence often seems to be accepted in a public context (Tromp et al., 2011), where it aligns with collective concerns, it is less accepted and therefore likely to be less effective in a private context where individual concerns are dominant.

The persuasive and coercive design did not effectively contribute to the use initiation of the affected arm and hand. However, using a smartphone is often a bilateral task (Ljubic et al., 2014), and three of the four participants used the affected hand to hold the device during our testing. While holding the device with the affected hand seems to be feasible, picking it up remains a challenge which might be due to the smooth surface of the device, limited range of motion, decreased ability to feel texture and muscle strength (Raghavan, 2007). It needs to be considered that the observed bilateral use to hold the phone and tap on the screen might be evoked by learned behavior patterns or the phone's screen size, requiring both hands or a flat surface to put the phone down to interact with the screen (Lemke et al., 2020). Future studies could explore which ERDs demanding both arms could contribute effectively to the rehabilitation process (e.g., cooking tools). In this context, it should be considered if the affected hand is the dominant or non-dominant hand of the user (e.g., being affected on the right hand as a right-handed person).

It needs to be emphasized that the anticipated long-term effect was not tested as part of our study. Participants rejected the current form of the behavior change contract aiming to evoke a long-term change. However, there might have been a potential recruitment bias with all the participants recruited through a private research facility, and they were quite engaged in their therapies. Furthermore, the current design and wording of the behavior change contract might simply be ineffective or regarded as patronizing rather than encouraging, although it remains an essential component of CIMT to secure compliance (Morris et al., 2006; Taub et al., 2006; Tuke, 2008). Interviews with health professionals emphasize the role of the contract in reinforcing the affected arm and hand use in daily activities (Lemke et al., 2019). Future studies are needed to investigate different forms of a behavior change contract to secure the long-term use of the affected hand among people with mild, chronic stroke, for example, by including the contract when purchasing the device.

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