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Empathic Avatars in Stroke Rehabilitation: A Co-designed mHealth Artifact for Stroke Survivors

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Abstract. Stroke is the second highest cause of death and disability worldwide. While rehabilitation programs are intended to support stroke survivors, and promote recovery after they leave the hospital, current rehabilitation programs typically provide only static written instructions and lack the ability to keep them engaged with the program. In this design science research paper, we present an mHealth artifact that builds on behavior change theory to increase stroke survivors' engagement in rehabilitation programs. We employed a co-design methodology to identify design requirements for the stroke rehabilitation mHealth artifact, addressing stroke survivors' needs and incorporating expertise of healthcare providers. Guided by these requirements, we developed design principles for the artifact pertaining to visual assets that are essential in immersing users in the design. We carried out a two-stage development process by having workshops and interviews with experts. Following this, a prototype was developed and evaluated in a series of workshops with multiple stakeholders.

Keywords: Co-design, Empathic Avatars, mHealth, Stroke Rehabilitation

1 Introduction

Stroke is the second highest cause of death and disability worldwide [1], accounting for nearly six million deaths per year and another five million left in permanent disabilities. In a broader context, stroke is part of a global increase in non-communicable diseases (NCDs), linked, among other factors, to preventable lifestyle behaviors such as smoking, nutrition, alcohol over-consumption, and physical inactivity [2]. Stroke can be a devastating event in a person's life, leading to severe loss of mobility, cognitive impairment, inability to participate in daily living activities, associated loss of independence, curtailment of social life, isolation, and depression. A critical component for the mid- and long-term effects of stroke on a person's life is *rehabilitation*. Effective rehabilitation can aid stroke survivors to reduce physical impairment, recover movement, increase participation in everyday life, and improve the overall quality of life. However, rehabilitation is *often ineffective*, as it requires a high level of physical participation and emotional engagement from the stroke survivor, both of which are challenging for stroke patients to achieve [3].

In this paper, we follow a design science approach to explore how a mobile health (mHealth) solution can support stroke survivors in effective rehabilitation. Existing approaches for stroke rehabilitation are primarily about providing stroke survivors with

information on exercise and medication regimes, usually conveyed by means of simple text documents with detailed instructions from their healthcare professional. In contrast, our study is rooted in *behavior change theory* [4, 5], and builds on the rationale that engaging stroke survivors in an empathic and meaningful way can increase compliance with exercise and medication regimes and improve overall health outcomes. In particular, we designed, implemented, and evaluated an mHealth artifact we refer to as *Regain*, which aims to support stroke survivors to stay engaged with their rehabilitation program. To ensure that our approach adequately considers the various perspectives in the complex landscape of stroke rehabilitation, we adopted a co-design approach that included workshops with multiple stakeholders such as carers, clinicians, health behavior psychologists, and actual stroke survivors.

The remainder of this paper is organized as follows. In Section 2, we identify the problem of effective stroke rehabilitation and requirements for a potential solution. In Section 3, we describe the employed co-design process and derive a set of design principles for maintaining users' motivation to use the device (e.g., animation, empathic self-avatars, familiar context). In Section 4, we outline the implementation and evaluation of the *Regain* app. In Section 5, the paper concludes with some general discussion of how *Regain* may assist stroke rehabilitation and directions for future research.

2 Problem Identification and Requirement Elicitation

Over the past decade, costs associated with NCDs have increased so rapidly that they threaten the healthcare systems of every developed nation [6]. As part of this development, there is growing pressure on healthcare professionals to discharge stroke survivors quickly from a hospital, creating a shift towards outpatient (i.e., out of hospital) rehabilitation in their home care environments. This shift, however, comes at the increased risk of non-compliance with medical advice in terms of exercise and medical regime [7], as the time and resources for clinician-patient interaction are scarce. In other words, current rehabilitation programs fail to effectively engage stroke survivors to comply with medical advice in a home care environment, leading to worse health outcomes because of non-compliance with medications and exercise programs and, ultimately, even higher costs for the healthcare system [8]. While mHealth technology offers important opportunities to increase patients' engagement in rehabilitation activities, the effectiveness of existing mHealth artifacts is low [9].

Stroke rehabilitation can only be effective if stroke survivors actively engage in targeted behaviors, and this almost always entails a change in behavior to align to the rehabilitation goals. The development of effective rehabilitation programs therefore has to take into account the psychology of behavior change. Current rehabilitation programs focus primarily on providing detailed verbal and written advice on exercise and medication regimes.¹ However, there is a large body of psychological literature show-

¹ It is important to highlight that recent research has successfully explored the application of virtual reality for stroke rehabilitation (e.g., see [53, 54]). Yet, these approaches are used to a lesser extent compared to traditional rehabilitation techniques.

ing that providing accurate information alone is necessary, but *not sufficient* for achieving sustainable behavior change. Based on a systematic review of behavior change literature, Michie et al. developed a comprehensive framework that integrates the interacting components that make up and define human behavior, namely opportunity, capability, and motivation [4]. Engaging individuals in targeted behaviors requires one to adequately address each of these components in the given context. Building on behavior change theory, we derive the following set of requirements for effective stroke rehabilitation.

The first requirement (R1) refers to the stroke survivors' *psychological capability*, that is, "the necessary knowledge and skills" (p. 4, [4]) to engage in rehabilitation activities. Due to their medical condition, which usually involves some level of cognitive impairment, stroke survivors often find it difficult to understand the verbal and written instructions provided to them, limiting their psychological capacity to engage in rehabilitation activities [10], as well as understanding their personal health benefits from following the rehabilitation plan. However, without the psychological capacity to engage in targeted behavior, it is impossible for stroke survivors to perform the activities that are necessary for effective rehabilitation. Hence, recent research suggests to focus on technological and methodological innovations to assist compliance by exploring new ways of communicating medical advice [11].

R1: *The design artifact has to communicate medical advice in a way that increases stroke survivors' psychological capability to engage in rehabilitation activities, addressing their understanding of how to perform the activities as well as the benefits of these activities in terms of health outcomes.*

The second requirement (R2) refers to the stroke survivors' *physical capability*, that is, the physical ability to perform the activities required by the rehabilitation plan. In other words, stroke survivors should only be recommended activities that they are physically able to perform. Ideally, these activities should be challenging to the patients, yet not too challenging, as this can lead to increased stress, despair, or even injury [12]. As the negative impacts of a stroke on the survivors' mobility and the improvements from rehabilitation vary strongly from person to person, the activities have to reflect individual physical capabilities of the stroke survivors.

R2: *The design artifact has to select rehabilitation activities that individual stroke survivors are physically capable to perform, ensuring that the activities are sufficiently challenging while at the same time avoiding activities that are too challenging.*

The third requirement (R3) refers to the stroke survivors' opportunity to engage in rehabilitation activities, that is, "the factors that lie outside the individual that make the behavior possible or prompt it" (p. 4, [4]), which may include restriction, environmental restructuring, and enablement. At present, limited Information Technology (IT)-mediated approaches for directly changing the home care environments of stroke survivors exist. However, there are several elements in the context of environmental restructuring that can be addressed by IT (e.g., enabling to perceive their home care environment in a different way by showing them how to engage in rehabilitation activities within that given environment).

R3: *The design artifact has to create opportunities for stroke rehabilitation by nudging stroke survivors to engage in rehabilitation activities and showing them how these activities can be performed in their home care environments.*

The fourth requirement (R4) refers to increasing stroke survivors' motivation for sustained behavior change, that is, "all those brain processes that energize and direct behavior" (p. 4, [4]). Even when individuals have the physical and psychological capacity as well as the opportunity to engage in targeted behavior, behavior change will not occur unless there is a sufficient level of motivation. Motivation can be directly driven by increased levels of capability and opportunity [4], e.g., by understanding how rehabilitation activities will lead to benefits in terms of better health outcomes. However, if the benefits have no meaning to an individual, particularly if they do not translate into achievable, short-term milestones, behavior change will not occur. Hence, addressing motivation needs to go beyond the mechanisms associated with capability and opportunity, e.g., by leveraging the potential of social cues and short-term feedback.

R4: *The design artifact has to include elements that motivate stroke survivors to engage in rehabilitation activities.*

The fifth requirement (R5) refers to providing accessibility for healthcare professionals to monitor the progress of stroke survivors, and making adjustment to the rehabilitation program based on the progress. In order to achieve this, it is necessary for a healthcare professional to select a set of adequate rehabilitation activities (R2), then measure progress against those goals. For instance, feedback from users, consisting of physiological measures such as heart rate and skin conductance, has been shown to permit the adjustment of difficulty in real-time during stroke rehabilitation in a study by Jelinek and colleagues [12]. Such measures can be used to assess the mood of the user (see p. xiv, [13] for some detailed discussion on content validity and construct validity in the context of physiological measurements), and then adjust the difficulty of a video game used in the context of stroke rehabilitation. IT systems can support R5 by providing data that can be sent back to the healthcare professional, in order to assist in assessment and to provide opportunities for intervention in the form of modification of exercise programs and other aspects of a rehabilitation program.²

R5: *The design artifact has to enable healthcare professionals to have access to the stroke survivors' data remotely and in a secure way in order to assess the progress, and make adjustment to the rehabilitation program.*

² Although the technology for such interventions exists, it seems that this opportunity has been overlooked: out of 29,000 medical apps in the US iTunes® store, 130 (16%) could be used in rehabilitation, but less than 1% specifically assist the caregiver to better face the challenges of stroke survivors [55]. Our artifact differs from these apps by building on the theory of behavior change, a co-design process with multiple stakeholders, and empirical validation using clinical trials.

3 Design

Recent reviews indicate that research into patient-centric mHealth IT systems is still at an early stage, and a wide range of existing mHealth approaches have shown to yield little or no effectiveness [9, 14]. Samhan et al. identified specific gaps in the literature, including limited knowledge of the effects of mHealth IT systems on health outcomes, and how these systems can be designed for patients with a particular disease [14]. Co-design, sometimes also referred to as participatory design, is a methodology in which multiple stakeholders contribute to ensure that the design solution aligns with users' needs and experiences [15]. Typical elements of co-design include idea generation, problem understanding, prototyping, and storytelling. Empirical evidence has shown that the best health outcomes are derived via models co-designed with users and healthcare professionals' inputs [16]. Co-design therefore goes beyond designing for a given audience but directly involves the audience in the design.

In this study, we build on the co-design methodology, using workshops involving stakeholders, to explore issues of communication, accessibility and motivation. These issues were approached through storytelling and prototyping, in order to achieve problem understanding, and to collaboratively design an artifact for stroke rehabilitation. After this, the multidisciplinary research team iteratively built interactive visual assets into compelling user interface elements, using empathic patient-centered scenarios and characters. The underlying paradigm of this approach is that the resulting solutions will be more patient-centric and will meet the needs of stroke survivors, rather than being designed by researchers and health practitioners who have not experienced this illness themselves. Fig. 1 illustrates the design process of the work described here. It commences with informal workshops held with researchers from design, health, and IT, to facilitate problem understanding through storytelling and explore the boundaries of what is possible through idea generation from the viewpoints of users and capabilities of the relevant technology. These workshops led to the production of an early prototype that enabled the research team to co-design a full prototype with the key stakeholders of stroke survivors and healthcare professionals.

Fig. 1. Illustration of the co-design process used in developing the artifact.

3.1 Empathic Self-Avatars

An important design aspect in addressing requirements R1 and R4 is to build interactive visual assets into the *Regain* app, using empathic patient-centered scenarios and characters. Instead of simply communicating *information* on healthcare advice to stroke survivors, such empathic elements can be used to convey medical advice in a way that they translate into the life of the user, increasing their psychological capacity (R1) and motivation (R4) to engage in targeted rehabilitation behaviors. Recent research has shown that the so-called *self-avatars*, i.e., avatars that “resemble users’ physical appearances” [17], can be an effective way to convey social cues and encourage targeted

behaviors. From the theoretical perspective, instigating behavior change via self-avatars can be achieved through the *Proteus Effect* [18]. This effect describes a phenomenon in which the behavior of an individual is changed by the visual characteristics of their avatar [18]. Wrzesien et al. argued that the appearance of self-avatars can influence behavior, and this change in behavior can be utilized to encourage desirable behaviors [19]. Importantly, *empathic* self-avatars may motivate users to adopt new behaviors (desirable or undesirable) associated with digital representations [20] (R4). Here, *empathy* is defined as the process of placing oneself in the place of someone else, seeing matters from the other's point of view, perceiving the other's emotion and thoughts, and conveying this awareness to that specific individual [21].³ Moreover, the expression of feeling from avatars will increase the likelihood of behavioral change in the real world [22].

The use of empathic avatars in co-design requires the artifact to incorporate scenarios based on a user's experience, in order to help make the avatar 'real' [23]. This can be achieved through systematic action research, reviews, observations, and interviews [24]. In the context of technology-enhance learning, it has been shown that empathic avatars can encourage learners to stay engaged with a learning program [25]. In addition, empathic avatars can demonstrate the usefulness of engaging in desirable behaviors (R1), e.g., showing that the movement of the avatar gets better every time the avatar finishes an exercise, to ensure that stroke survivors follow the instructions from their rehabilitation program. Taken as a whole, the more empathic an avatar is, the more likely it will influence user behavior towards targeted behaviors, and this emotional link can be strengthened by making the avatar customizable [26]. In the context of the *Regain* app, these behaviors refer to engaging in the rehabilitation program, where self-avatars are able to respond to stroke survivors and address their mood [27].

Design Principle 1 (P1): *Use empathic, customizable self-avatars to convey social cues, increase stroke survivors' psychological capabilities, and ensure that they have a compelling experience to stay engaged with the rehabilitation program.*

3.2 Animations in a Familiar Environment

The animation principle refers to illustrating the typical exercise that has to be performed by stroke survivors, enabling them to better understand the activities that they need to engage in (R1) and reshaping their perception of their home care environment to create opportunities to engage in this behavior (R3). Animation allows a more immersive illustration of exercise than textual descriptions or even line drawings, as the user can see how the avatar completes the entire exercise, in contrast to a static image.

³ It appears that the notion of empathy is of particular importance in healthcare settings, as individuals are experiencing a life-changing event with potentially devastating consequences on their everyday lives. For instance, Javor et al. found that Parkinson's disease patients exhibit significantly lower trust levels towards other humans than healthy subjects do [56]. In a follow-up study, Javor et al. showed that trust levels can be increased by using avatars [57].

Including animation with an avatar conveys more compelling and enhanced communication [28, 29], which can provide an entertaining and hence motivating experience (R4), and ensure that the user follows and stays engaged with a program. Dodds et al. found that avatar animation can be used to simulate certain behavior, and to enable users to move and perform better [30]. Therefore, animation can be useful in stroke rehabilitation as a means to increasing the psychological capability of stroke survivors, and to provide the necessary knowledge and motivation for them to stay engaged with the program (R1). Such animation shows stroke survivors how to do a certain exercise, which in turn can increase their understanding of its benefits. Avatars can provide stroke survivors an animated, personal, and engaging interaction, which in turn can influence patients' behavior [31].

Importantly, the animation should be situated in a familiar context for stroke survivors, in a way that they feel more comfortable and relaxed [32]. Previous research has shown that being in a familiar physical environment will help to motivate targeted behaviors in patients and, overall, patients prefer home care (i.e., a familiar environment) over clinical-based therapy [33]. Hence, situating the animation in a familiar environment, e.g., a home garden or a living room, would make stroke survivors feel more relaxed and comfortable while performing the rehabilitation activities [34]. In other words, illustrating the empathic self-avatar in a familiar environment for stroke survivors will provide an opportunity to reduce their feeling of anxiety, and increase their confidence because they will perform activities in their familiar context [32, 35]. In addition to the positive influence on stroke survivors' emotional states, the approach of using a familiar environment creates an opportunity for stroke survivors to engage in rehabilitation activities (R3), as it reshapes users' perceptions of their home care environment, demonstrating how this environment can be used to engage in behaviors while at the same time taking advantage of the relaxing influence of their home.

Design Principle 2 (P2). *Use animations with the empathic self-avatar in a familiar environment to convey information on how to perform the rehabilitation activities to the stroke survivors in an effective and motivating way, creating an opportunity to engage in such activities in their home care environment.*

3.3 Shape and Color Aesthetics

The shape and color principles refer to the use of shapes and colors that can positively influence stroke survivors' perceptions and behaviors. As for shape aesthetics, the artifact makes use of *gestalt* (i.e., shapes or forms) for shapes used in the self-avatar design and animation. It has been shown that a more round face-like shape appears more friendly to users [36], hence designing self-avatars with a round face-like feature would indicate friendliness of the character to stroke survivors. A study shows that round shapes with face-like features can enforce positive emotion on learners [37]. Such shapes can be used in designing the empathic self-avatar to induce positive emotion upon stroke survivors, which can keep them motivated (R4) and engaged (R4) with the rehabilitation program. Therefore, the empathic self-avatar will be designed using a round face-like characteristic to enforce friendliness in engaging animations. Gestalt should have similar characteristics to humans' features, but not too realistic to avoid

affecting stroke survivors with the *uncanny valley effect*. This uncanny valley effect describes a phenomenon that arises when designing visual artifacts that are intended to resemble human features (e.g., an avatar) in an overly realistic way, and it can cause an aversive response in humans and make them feel uncomfortable [38, 39], which in turn may disengage stroke survivors from the rehabilitation program.

Design Principle 3 (P3). *Use gestalt (round face-like shapes) with an empathic self-avatar to indicate friendliness of the self-avatar while avoiding photorealistic features.*

The visual design of the user interface does not only have to consider the shape aesthetics but also the colors used in combination with those shapes. Um et al. stated that saturated warm colors and round face-like shapes can induce positive emotion in users, and increase their learning capability [36]. Hence, warm colors and round face-like shapes can be used to induce positive emotion, and increase users' psychological capability and motivation (R1, R4). Color theory is the study of the effect colors exert on the cognitive and affective processes of individuals [40]. According to this theory, a color can be used to trigger a broad range of emotional responses, e.g., to increase attention and deliver information (R1) [41]. More importantly, colors can have beneficial but also detrimental effects on human behavior [42]. Particularly high hue colors, that is, pure colors with high levels of brightness and saturation such as red, blue, green and yellow, exhibit a strong influence on user perception, physiology and behavior (R4) [43]. For example, Greene et al. found that warm colors (e.g., yellow, red, and orange) can prevent boredom and maintain activities [44]. Such colors may motivate stroke survivors (R4) and increase their psychological capability (R1). Moreover, using the green color has the ability to reduce stress and make users more calm and relax [42]. Applying high hue colors and rounded shapes to the empathic self-avatars and background environment therefore is expected to provide a positive impression and emotional appeal that will encourage use of the artifact.

Design Principle 4 (P4). *Use high hue colors (e.g., yellow, red, blue, and green) with the empathic self-avatar and the animations in order to draw stroke survivors' attention to the empathic self-avatar and create an engaging user experience.*

4 Implementation and Evaluation

4.1 Implementation

The design artifact presented in this paper was developed in a two-stage implementation process (see Fig. 1). In a pilot study that was undertaken in late 2014, a multidisciplinary team of researchers with convergent interests, which include clinicians, health informatics specialists, programmers and designers, was assembled. The output was an early prototype that demonstrates how empathic avatars can be created for stroke rehabilitation using design of visual assets and animation. First, visual assets were created by the multidisciplinary team using a co-design process. The result of this

stage was an early prototype as shown in Fig. 2.⁴ The left part shows an example of an empathic avatar (P1) in the early prototype that was developed in order to provide animated scenes illustrating typical rehabilitation exercises. The animation allows a more immersive illustration of exercise than line drawings, as the avatar completes the entire exercise, in contrast to a static image (P2). A male version and a female version of the avatar were designed in consultation with experts in user experience design. The color scheme was designed to avoid the dreary nature of illustrations commonly used in written healthcare advice, making use of compelling gestalt features (P3) and bright colors (P4). Once the appearance was designed, pivot points were created, as indicated in the avatar on the left of Fig. 2 using circles.

Fig. 2. Left: Empathic avatars developed for animation from the *early prototype*. Right: A screenshot of the *early prototype* with the avatar animated into a sequence.

The right part of Fig. 2 shows an animation created using the designed avatars. In this case, the exercise is “lift and carry” and it encourages the stroke survivor to improve balance and manipulation skills by grasping a small object and carrying it for a few steps. The animated avatar is situated in a familiar environment (P2), i.e., a home garden scene. This illustrates the possibilities for this technology, but also the implied message, which in this case is one of escape and self-empowerment through increased mobility in recovery following these exercises. Once the preliminary design was realized, as can be seen in the left part of Fig. 2, it was shown to healthcare professionals and health behavior psychologists with an interest in stroke rehabilitation – these people are important stakeholders for embedding the future product into a rehabilitation program in practice. This early prototype was designed to explore the characteristics of an avatar in the context of a mobile app on a tablet device. After informal and formal workshops and interviews, design goals were developed to assist in the production of an improved prototype. The full prototype was developed in collaboration with professional user experience designers and software developers.

Fig. 3 shows two screenshots from the full prototype. Based on comments received from stakeholders in the co-design workshops, the amount of textual material has been reduced to the minimum required for explanation. This can be seen in the brief instructions for an individual exercise, coupled with an image representing the exercise, shown in the left part of Fig. 3, and the small amount of text used in the exercise description,

⁴ The process is summarized in a short video: <http://youtu.be/MV23MdmlfAg>

shown in the right part of Fig. 3. Furthermore, following the advice of professional designers and health behavior psychologists, the menu has been implemented using images that represent the type of exercise (left part of Fig. 3).

Fig. 3. Left: Selection of exercises in the *full prototype*. Right: Instructions provided for a typical rehabilitation exercise in the *full prototype*.

4.2 Future Development

Building on the existing prototypes, the *Regain* app will be iteratively evaluated and improved with users (stroke survivors) and carers. The future implementation will follow the process shown in Fig. 4. The first step is to have focus groups with stroke survivors and carers to introduce the full prototype of *Regain*, providing these important stakeholders a platform to share their stories and have in-depth discussions about the opportunities of mobile technology and the design of *Regain*, ensuring their current and emerging requirements are documented and addressed. Through supervised interaction with the designed visual assets based on mobile platforms, stroke survivors will be invited into the design process to work in focus groups to explore their experiences, collect feedback, and to continuously involve users in the design process. Participants will be invited to take a tablet computer home, loaded with the full prototype app, for an extended period of time. Then, data collection and analysis will take place after the full prototype of the *Regain* app has been used in clinical trials or home environments by users, to check their interactions with the app and gather their feedback. The *Regain* app will be refined based on the results from the data analysis and user feedback, and that will assist in developing the (final) commercial app.

Fig. 4. Illustration of the implementation process of the commercial app.

4.3 Evaluation

At this stage, evaluation of functionality was achieved by face to face interviews with domain experts in the fields of user interface design, clinical care, health informatics, software development, health behavior psychology, health insurance and health policy, as well as with stroke survivors. The mHealth literature supports such a sample and an interdisciplinary approach [45]. In addition, the co-design approach requires the involvement of application-oriented practitioners who work in these mHealth contexts, encompassing industry, government and technology viewpoints [46]. Existing networks within the University of Newcastle and Hunter New England Local Health District were used to identify and recruit participants, who were invited via email. Semi-structured interviews were used, of approximately one hour in duration. Questions revolved around details of the prototype design, as well as more general questions about what elements or features were considered appropriate. Interviews were transcribed and coded according to thematic recurring elements. The thematic elements identified are: (1) provide user-created and customizable empathic avatars, as these can assist user capability and motivation; (2) make avatar appearance similar enough to the user so that a connection can be made; (3) make sure the avatar is not too similar in appearance to make the user uneasy (as reflected in design principles P1–4).

These identified themes were taken into account in the iterative development of the above stated design principles and the co-design process. In relation to the design requirements, we note that requirement R1 was met by the ability of the prototype to communicate medical advice. This directly addresses the psychological capability of stroke survivors [4]. R3 was met by the technological innovation of presenting medical advice in this new format. The prototype was able to demonstrate the possibility to nudge stroke survivors to engage in rehabilitation activities and how these activities can be performed in their home care environment. R4 was met by the manner of the avatar based training, which can increase stroke survivors' motivation for sustained behavior change. On the other requirements, we note that at present the prototype does not meet R2 by allowing medical practitioners to select the exercises. However, this is a trivial addition to the *Regain* app and is planned to be included in the clinical trials. The current prototype also does not address R5, that is, to provide feedback to a medical practitioner. This is more of a challenge but is planned for the clinical trial. As for the specific design principles, feedback from the face-to-face interviews showed a high degree of convergence between the design principles and the operation of the prototype.

5 Discussion and Conclusion

5.1 Discussion of Results

Stroke has such a high prevalence in the modern society that if this phenomenon was caused by an infection, it would be regarded as a pandemic [47]. Rehabilitation programs are employed to assist stroke survivors and promote recovery after leaving the

hospital. In order to harness the whole benefits of rehabilitation programs, it is important that stroke survivors are informed not only with written texts, but also in a way that is entertaining and engaging. This is particularly challenging as the general trend of increases in NCDs will ultimately lead to a shift in responsibility from the collective to the individual, as treatment costs are rising in an unsustainable manner [6]. In addition, there is pressure on clinical personnel to discharge stroke survivors quickly from the hospital, increasing the risk of non-compliance with medical advice [7]. As a consequence, there are issues with communicating information to stroke survivors as well as issues with depression and social impairment [27]. In this paper, we used a co-design approach to pursue the development of an mHealth artifact to support stroke rehabilitation by increasing stroke survivors' psychological and physiological capability, motivation, and opportunity based on behavior change theory [4, 5]. The overall goal of this approach is that stroke survivors will receive improved communication of health advice, become engaged with the rehabilitation program, and be motivated to follow that advice leading to better health outcomes.

First, based on workshops with design, health and IT professionals, we identified five specific design requirements for a solution artifact (R1-5). The artifact has to provide and communicate the necessary skills and knowledge that will aid in increasing the psychological capabilities of stroke survivors in order to enable them to understand how rehabilitation activities should be performed and what their benefits are (R1). In addition, the artifact has to suggest rehabilitation activities that are not too challenging for stroke survivors, which in turn aids in increasing the physical capabilities of stroke survivors (R2). The artifact has to create opportunities for stroke survivors to engage in the rehabilitation activities by changing their perception of their home care environment (R3). Also, the artifact has to increase motivation (1) indirectly through increased capability and opportunity and (2) directly through compelling user interface elements (R4). Importantly, healthcare professionals should have access to the stroke survivors' data to enable progress assessment and adjustment in the rehabilitation program (R5).

Second, we developed a set of specific design principles (P1-4) for the mHealth artifact in order to meet the identified requirements related to the interaction of the stroke survivor with the user interface (R1, R3, R4). We proposed a new approach to the self-management of stroke rehabilitation, using a mobile device to assist with carrying out a rehabilitation program in a home care environment. This approach, which follows the co-design methodology, features frequent consultation with stakeholders, including stroke survivors, carers, clinicians and IT specialists, to provide an end result product that meets the needs of its intended audience. An empathic self-avatar has been identified as a concept that will assist in creating a sense of emotional connection (i.e., attachment) with stroke survivors as well as a powerful medium to enable behavior change (P1). Animations in a familiar environment are used in combination with the empathic self-avatar to increase the psychological capabilities of stroke survivors as well as provide entertaining experience in such an environment (P2). One way to make the avatar more empathic in a future extension of the artifact might be to capture the user's facial expression with a camera and change the appearance of the avatar accordingly [48]. Shape and color aesthetics are used to deliver information to stroke survivors in friendly and engaging ways, designed to reduce anxiety and increase attention to keep stroke survivors engaged with their rehabilitation program (P3, P4). This proceeds

not with static factual information, but through the medium of some moving guide to the exercise, which the user can identify with by use of an avatar.

Third, we evaluated the effectiveness of the design artifact in workshops with multiple stakeholders such as carers, clinicians, health behavior psychologists, and actual stroke survivors. To this end, a prototype has been developed based on feedback from design, health and IT professionals. Building on the early prototype and the full prototype, the future development and evaluation will include focus groups with stroke survivors and their carers, as well as clinical studies. The former will provide feedback on usability that will be used to improve the prototype to the point of a commercially ready artifact, while the latter will provide clinical evidence of the efficacy of an intervention using the employed design principles, when compared to the control group that will receive only the conventionally used written instructions and line drawings. This approach will provide a positive experience for stroke survivors that validates their importance and gives them a voice in the design of the next wave of rehabilitation assistance. In addition, this will provide knowledge to inform further research, including how avatars can help to convey various health messages, what kind of impact such technologies might have, and how the needs of stroke patients can be met.

5.2 Limitations and Future Research

Our study must be seen in view of several limitations. First, some functionality has not been implemented yet, because the design process focused primarily on the user interface for the stroke survivors rather than on data sharing, which requires consultation with additional stakeholders. This functionality relates to enabling healthcare professionals to select specific exercises and individually adjust the rehabilitation program (R2), and to assess and monitor the progress of stroke survivors (R5). However, these two functionalities are not crucial to the assessment of the empathic avatars, and are planned for inclusion in the commercial app. Second, the current design does not include serious games and gamification elements, which may offer additional advantages to address user capability, opportunity and motivation to engage in rehabilitation activities [5, 49]. Using game elements in the *Regain* app may add entertainment aspects for stroke survivors, which in turn may motivate them to follow the rehabilitation program and promote recovery. A five minute gaming experience with certain avatars is sufficient to reverse behavioral patterns [50]. One likely explanation is that immersion [51], derived from the gaming experience imbues people with agency. Third, cultural aspects have not been included in the design of the visual assets in the *Regain* app. For instance, previous research has shown that culture may affect the meaning of colors and their influence on user perception and behavior [52]. Hence, future research may explore how the color schemes in apps for stroke survivors may need to be adapted for different cultures. The advantages and disadvantages of including these elements will be explored in the focus groups with stroke survivors and their carers. Finally, the overall effectiveness of the artifact in improving the health outcomes of stroke survivors will have to be empirically established in clinical trials. Participants in the clinical trials will be invited to take a tablet computer loaded with the *Regain* app home for an extended period of time, after which the focus groups will be held to gather feedback to be used for refining the software.

5.3 Concluding Remarks

This study explored how mobile technology may support stroke survivors in their rehabilitation program, by providing an engaging experience for stroke survivors and communicating information in an entertaining way rather than just written instructions. Using a co-design methodology to include inputs from different disciplines has ensured that stroke survivors have a say on the design of the *Regain* app, and their requirements are addressed. Importantly, the use of animated empathic self-avatars in a familiar environment with warm colors and round face-like shapes will help stroke survivors to increase their psychological and physical capabilities, as defined by the model of Michie et al. [4], thereby making sustained participation more likely. In addition, the *Regain* app can help to create an opportunity to facilitate recovery in a home care environment. Using mobile technology can provide the required information for healthcare professionals about the stroke survivors and enable them to assess their progress and make adjustments. Using such design principles will ensure that stroke survivors are motivated and engaged with their rehabilitation program.

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