Development of Interactive Hand Rehabilitation Tools Based on Activities of Daily Living

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ABSTRACT

Hand rehabilitation aims to improve patients' hand and arm skills, improve adherence to training and increase their participation in activities of daily living (ADLs). A novel way of achieving this is to employ ADL-based interactive rehabilitation tools and show patients how their improved skills can be transferable to daily tasks. Hence, in this paper, we report the results of a set of studies carried out with six healthy individuals and two physiotherapists to discover the potential of integrating ADLs into interactive hand rehabilitation tools. Consequently, we designed two interactive drinking-based concepts and tested those with three stroke patients. We found that ADL-based training couples particularly well with functional training. Still, selecting appropriate functional exercises that match the ADL is an essential task to transfer training outcomes to a functional setting. Based on our findings, this paper highlights that ADL-based interactive hand rehabilitation training must minimally deviate from the original ADLs.

CCS CONCEPTS

• **Human-centered computing → Interface design prototyping**; **Empirical studies in interaction design**; **User centered design**.

KEYWORDS

Hand rehabilitation, stroke, ADL-based training, interactive tools, tangible interaction

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1 INTRODUCTION

Hand rehabilitation aims to assist patients in recovering motor functions of the impaired hand, among others after a life-affecting health condition like stroke [15]. Rehabilitation starts at the hospital and aims to increase people's independence and participation in daily life [12]. Independently executing daily activities is key to recovery and improves patients' quality of life [10]. Therefore, there are several attempts to move hand rehabilitation from hospitals and rehabilitation-clinics to daily-life settings, to increase access to rehabilitation and reduce the workload of rehabilitation specialists [24, 39]. At home rehabilitation aims to keep patients active, even after the rehabilitation phase, to maintain their (improved) hand function. However, people's willingness and motivation drop over time, resulting in a decrease in adherence to rehabilitation exercises [22]. An essential cause of this drop is that the patients are required to allocate time and space to do the exercises without a therapist [3, 9].

One way to overturn this drop is to incorporate training exercises into activities of daily living (ADLs) to eliminate the required willingness, motivation, and effort to start and maintain training [37, 38]. Integrating training exercises into the use of daily objects like smartphone accessories [19], and kitchen utensils [34] turns out to be a promising direction. Such an approach enables everyday objects to train certain grips and grasps and create routine-integrated training opportunities. Interactive technology can leverage this opportunity, as it facilitates monitoring patients' performance, providing feedback, and making repetitive exercises more engaging without a therapist[6, 9]. However, integrating ADLs into rehabilitation exercises is not a straightforward task. It requires a thorough analysis of the ADL-rehabilitation exercise couplings and careful monitoring of the training outcomes. Despite the potential, there is not yet a structured and systematic analysis for incorporating ADLs into interactive hand rehabilitation exercises.

This paper investigates how ADLs can be systematically incorporated into interactive hand rehabilitation exercises to address the challenges mentioned above. We aim to address the question, "how can hand training exercises be incorporated into ADL-based interactive tools?" To address this question, we followed a set of steps to (1) determine training exercises for hand rehabilitation, (2) select ADLs that connect exercises to objects of daily living, (3) prototype interactive hand rehabilitation tools, and (4) test the tools with stroke patients. Our work was inspired by two previous studies that propose using daily objects for the hand rehabilitation of stroke patients [19, 34]. Hence, this paper follows up on prior work and focuses on stroke patients.

2 COUPLING TRAINING EXERCISES WITH ADLS

This section will explain our approach to couple ADLs with hand rehabilitation exercises. To achieve this, we first looked into different ADLs, their context, and the hand skills that need to be trained.

2.1 Determining Training Exercises for Hand Rehabilitation

We reviewed several resources (i.e., guidelines by a national rehabilitation centre, online health resources and training guides by rehabilitation developers to determine rehabilitation exercises important for hand motor function recovery. We identified four exercise categories based on the targeted functional skills: strength training, dexterity training, range of motion (ROM) training, and coordination training. Strength training targets overcoming muscle weakness in the hand, reducing grip strength and affecting arm functions[21, 32]. Dexterity training targets reducing the loss of fine motor skills [11, 21], which causes deterioration in control of hand and finger movements due to decreased ability to activate individual finger muscles [32]. ROM training focuses on regaining the ability to move [1, 25, 26] by increasing the range of motion of joints. Finally, coordination training targets improving motor coordination and control of the upper limb [5, 20]. Reduced coordination can lead to involuntary, slower, and less smooth movements [5]. All training types improve the independent movement of fingers by extending them and forming different finger postures, resulting in an increased ability to reach, grasp, and hold objects [32].

2.2 Selection of ADL

Previous work [35] identified 10 ADLs that stroke patients want to carry out independently. These include eating with a knife and fork, doing keyboard work, grooming and drinking by moving a cup to their mouth (see [35] for the complete list). Inspired by this work, we defined four additional criteria to help us select the ADL to be incorporated with interactive hand rehabilitation tools. Accordingly, the activity should (1) be performed for a sufficiently long duration or with a sufficiently high frequency each day (e.g. three times a day for 10-20 minutes [28]); (2) be performed regardless of the gender and the age of the patient for inclusiveness [33]; (3) be associated with specific objects (such as kitchen utensils [34]), and (4) not be associated with a high cognitive workload [35].

Analysing the 10 ADLs [35] in the light of the above criteria, we identified the two most promising activities for our study: eating with a knife and fork and drinking by moving a cup to mouth. Both activities are gender-neutral and are performed independent of age. Moreover, both belong to the ADL category of feeding/drinking, which has the most prolonged duration of hand use per day [35]. Drinking is generally executed for frequent short periods, while eating is performed for less frequent but longer periods. However, eating with a knife and fork presents challenges that may hinder its translation into training. It is a difficult activity involving coping strategies and careful and deliberate thought [23]. Hence the addition of training exercises may complicate eating even further. Moreover, eating is generally a social activity, and it can distract the patient from training. If the focus of the patient is purely on training, then the training can hinder the patient's participation in the social setting. Finally, patients can experience negative feelings such as feeling unable to perform eating activities or be dependent on the help of others [8].

Compared to eating, drinking requires less attention, and training can be the main focus of the patient. However, drinking also has its challenges. For instance, patients move their arms less smoothly than healthy people, who might take more time than it is for healthy people [25]. They can also have difficulties extending their arm to reach a cup [1, 25, 26]. An important advantage of drinking is its flexible nature of it. It requires less time and can be location-independent. Drinking occurs during or between meals, co-occurs with different activities, and can be both an individual and a social activity [7, 29]. We believe this co-occurrence can facilitate the integration of interactive training into ADLs. Therefore, we have decided to combine hand rehabilitation exercises with drinking activity.

2.3 Contextual Analysis of Drinking Activity

Looking into the most common difficulties that stroke patients experience difficulties with drinking, Holt and Holt [14] found that those are (1) grasping a cup, which is often caused by reduced dexterity, (2) lifting a cup by reduced strength, and (3) bringing a cup to the mouth, by a decreased range of motion and coordination. In order to better understand how a training exercise can be integrated with the ADL of drinking from a cup, we performed a contextual analysis of drinking. We asked questions about the location of the drinking activity, co-occurring activities and the social setting, to gain insight in the social and contextual factors present [7]. We additionally asked questions about the type of cups or glasses that were used and the grasps that these objects facilitate, to better understand the objects and hand movements involved. Therefore, we carried out a one-day study to better understand the context of older adults' drinking activities. We received ethical approval from our research institute before carrying out this study.

2.3.1 Participants. As the goal is to understand drinking activities and the contexts better, the participation of stroke patients was not necessarily required. Still, we aimed to recruit participants from a similar age group of stroke rehabilitation studies. In the end, we recruited six healthy participants through convenience sampling (2 male, 4 female), aged between 66 to 75 (M = 69.6). All participants were right-handed.

2.3.2 Data Collection. We conducted a survey study and asked participants to track and report their drinking activities for one day (24 hours). We were primarily interested in the participants' context

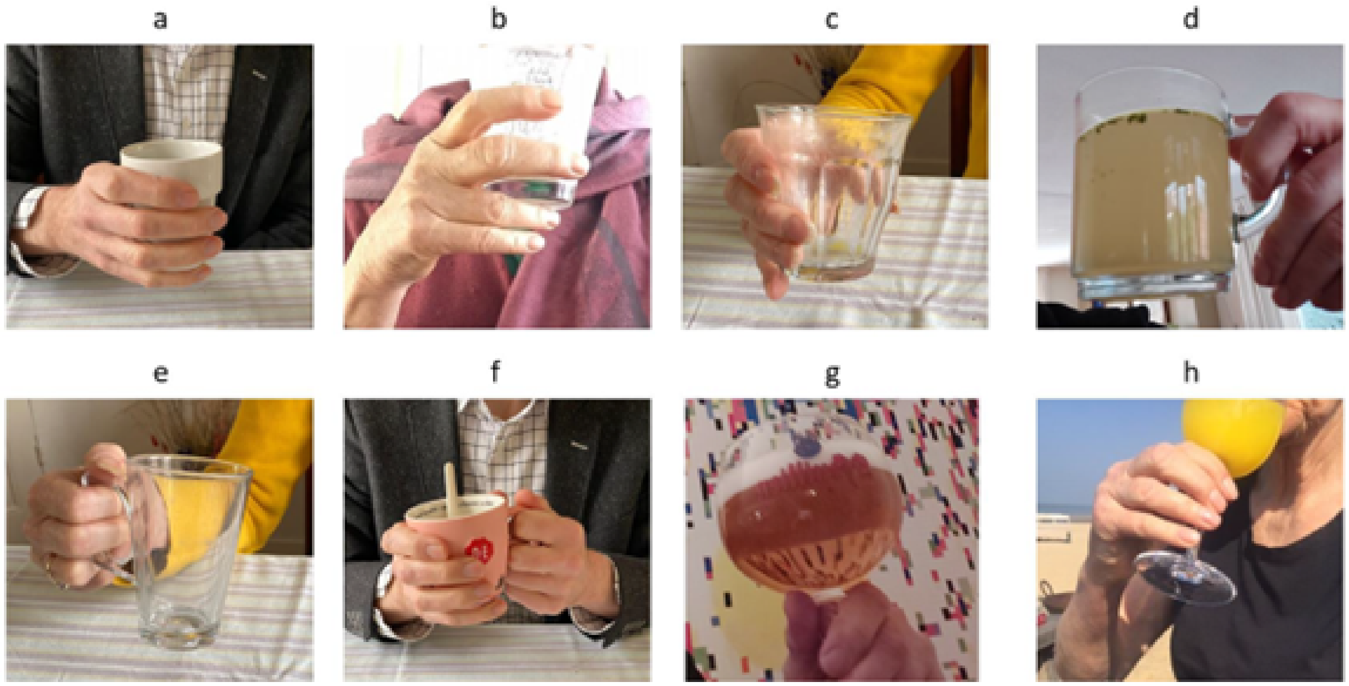

Figure 1: Overview of identified grasps

of drinking activities. Therefore we asked participants to record the drinks they consumed, the amount of liquid they finished, and the cups they used. We asked participants to take pictures of their hand and finger positions while holding the cup during the drinking activity.

2.3.3 Results. We received 61 drinking activities carried out in 24 hours, meaning, on average, a participant drinks something ten times a day. We found that coffee, tea and water are the most consumed drinks. Participants consumed a drink at different times, mostly in between meals. Fifty-eight activities were reported to be carried out at home and 37 in a living room. Participants reported spending an average of 18 minutes on a drink, while the time varied widely within and between participants. Some drinks were consumed fast (e.g. 1 to 5 minutes), others over a period of 30 to 45 minutes. Most drinks contained 150-200 ml liquid.

Drinking activities were often routines or habits. Four participants indicated that all drinking activities recurred daily. The two other participants indicated that some occurred daily and others sometimes or rarely, such as drinking at a restaurant. In total, 43 drinking activities were done alone and 18 in a social setting. Half of the participants reported that they only used their dominant hand for drinking. The other half used their dominant hand for the majority of drinking activities, but in a few cases, they used their non-dominant hand (5), both hands (7), or they switched between hands (3).

The grasp used to hold a cup was largely dependent on the shape of the cup. Of particular relevance was whether the cup had a base shape or contained a handle or stem. We identified eight different grasps (see Figure 1). We found that participants either wrapped their hands around the cup with a cylinder grasp (Figure 1.a) or held their hands partly around and partly below the cup. The latter came in two versions. In one, the thumb, index finger, and middle finger held the glass with a cylinder grasp, while the ring finger and little finger supported the bottom (Figure 1.b). In the second version, only the little finger kept the bottom (Figure 1.c). If the cup had a handle, it could be used to hold the cup. The way in which it was grasped and the number of fingers involved depended on the shape and size. If the handle was small, only the index finger was put into the handle (Figure 1.d), while bigger handles allowed more fingers to grasp the handle (Figure 1.e). In both cases, the thumb pressed onto the top of the handle, holding the cup with a lateral pinch grasp. When both hands were used to hold the glass, one held the handle while the other was wrapped around the cup with a cylinder grasp (Figure 1.f). Finally, stemmed wine and beer glasses were held by their stem, either with a cylinder grasp (with the thumb slightly adducted) (Figure 1.g) or with a prismatic 4-finger grasp (Figure 1.h).

2.3.4 Implications for Design. Our findings have implications for the development of drinking-based hand training tools. On average, 10 drinking activities occur per day, and around 18 minutes are spent per drinking activity. These numbers indicate that there are sufficient drinking-related training opportunities throughout the day. In line with previous findings [7], we found that most drinking activities occur at home, occur alone, reoccur frequently, and are accompanied by other activities. People mostly use their dominant hand to drink, making it challenging to ensure the use of the non-dominant hand if that is the affected side.

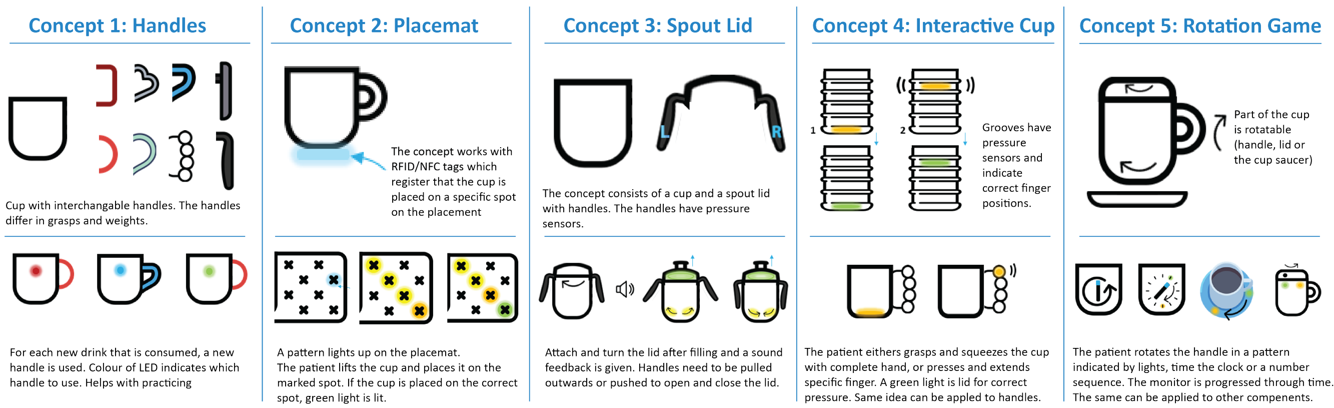

Figure 2: Five interactive concept directions.

Additionally, we found that people perform other activities while drinking and have their primary focus directed at the coinciding activity. Training will thus be added to a complex context in which multiple activities might compete for the patient's attention, and it may be that drinking will be a secondary activity. Not surprisingly, people consume different drinks throughout the day with different cups. Hence, the training should be adaptable to these changes and allow patients to use their own cups. The training cups should be appropriate for different types of beverages, or multiple training cups should be used for different drinks.

In light of these findings, we defined two criteria for developing ADL-based interactive hand rehabilitation tools: the tool's (1) suitability to ADL-based training, that the training object should fit the ADL in terms of training duration, type of activity, and type of object that is used; and (2) capabilities to train hand skills, that the training tool should target one or more of the identified hand skills (see section 2.2), facilitate different skill levels and be adaptable as the patient's skills improve.

3 ADL-BASED INTERACTIVE HAND REHABILITATION TOOLS

To explore the possibilities of integrating the drinking activity into interactive hand rehabilitation tools, we first brainstormed about ways to integrate hand training exercises with a cup, and how to integrate the key elements of a cup (such as base, handle, saucer, lid, and stem) in these. We came up with 38 ideas for ADL-based interactive hand rehabilitation tools. By using the two criteria we stated in 2.3.4, we narrowed the number of ideas to five concept directions. These were (1) handles, (2) placemat, (3) spout lid, (4) interactive cup and (5) rotation game. The concepts were selected from the set of ideas by combining separate ideas, such as combining similar exercises that can be applied to different elements of the cup or combining different exercises into one training concept.

We discussed these concepts with one rehabilitation physiatrists and one rehabilitation physical therapist by use of a semi-structured interview. We found that both experts saw potential in different concepts, while each favoured a different concept that focused on a different way on integrating training exercises with ADLs. For example, one expert explained that some concepts involve a specific cup, while others may allow patients to practice with their own cups. The Handles, Spout Lid, and Rotation Game involve a specifically fabricated cup, while the Placemat and Interactive Cup may allow using personal mugs by attaching a sleeve or sensor. Expert 2 recommended the latter. Interestingly, both clinicians suggested a combination of the Spout Lid and Interactive Cup. When providing feedback on the Spout Lid, they suggested an idea similar to the Interactive Cup. They suggested making the Spout Lid a unimanual activity. It should focus on exerting pressure on or squeezing of the cup with the impaired hand, which could then potentially open the lid. Clinician 2 also recommended making the exercise less complex by simply using sensors to measure the pressure and a green LED to indicate that sufficient force is used.

We think that the evaluation of both concepts could provide valuable insights for future work. Therefore we decided to develop both of them. In the following lines, we explain these two concepts: (1) PlayCemat and (2) Squeeze and Release. The idea in both concepts is that the physiotherapist introduces the training and the prototypes to the patients so that the patient can perform the training independently at home.

3.1 Concept 1: PlayCemat

PlayCemat is a concept where the training object is composed of a smart box and a cup sleeve. The box is a custom-built, laser-cut, thin wooden box. It contains 11 microbits that are programmable, integrated sensors with buttons, and a direct LED display. One microbit with buttons is for the start/stop function, and another one is for adjusting the training settings (Figure 3-a). The remaining nine detect whether the cup is placed in one of the circles by using the built-in magnetic field sensor and show feedback on the small LED display. The microbits communicate wirelessly via Bluetooth, while only the 'start/stop' microbit is linked to a laptop running a Python program that shows feedback to the user when they complete the training. Circle outlines signal where to place the cup, and cut-outs show the LED display and buttons. The top is covered with plexiglass making it easy to clean and reducing damage by spilling. The leather cup sleeve contains a magnet which allows the

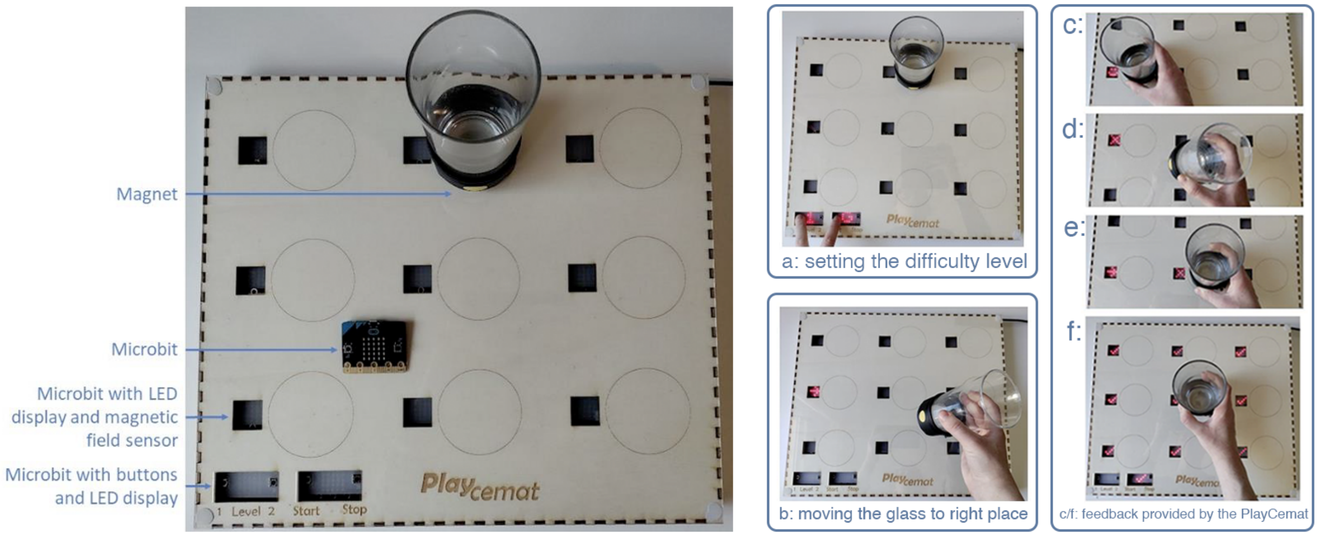

Figure 3: Conceptual design and interaction with PlayCemat.

placemat to register if and where the cup was placed. The Velcro strip allows the sleeve to be wrapped around cups in size and form.

The PlayCemat has nine pre-set locations that can hold a drinking cup and that the user can interact with. The first time the user takes a sip of their drink, the placemat displays an arrow at a random location on the box, indicating where the user should place their cup (Figure 3-b). Afterwards, a new circle is pointed out after random pauses of 3-7 seconds. With that, the user is stimulated to pick up and put down their cup multiple times during a training session (facilitating strength and dexterity training) at various distances from their body (facilitating ROM training). By performing the total reach movement to different targets, there is also a coordination training. If the cup is placed correctly and on time, a smiley appears (Figure 3-c). The cup can then be lifted or left standing on the spot. A cross appears on the screen if the user runs out of time (Figure 3-d). If the cup is placed on an 'incorrect' circle, a cross appears on the screen (Figure 3-e), and the original place remains lit. The training is completed when a number of correct placements are made, after which all LED displays show a checkmark (Figure 3-f).

3.2 Concept 2: Squeeze and Release

Squeeze and Release consists of a laser-cut box with a processing unit and a sleeve that can be attached to a cup (see Figure 4). The box contains an Arduino Uno and breadboard and is connected to a laptop. It has an on/off toggle switch and a turning knob to set the required squeeze strength (i.e., difficulty level). The sleeve is made of leather to ensure grip and comfort and reduce heat transmission. It contains two pressure sensors and a LED strip, which are connected to the Arduino with a wire. The resistors function as sensors that detect the amount of force the user applies to the cup. The cup used for this training should have a cylindrical shape to enforce a cylinder grasp, which is the most used grasp during an ADL. For such a grasp, the thumb provides the largest portion of grasp force, followed by the middle finger [16]. The sensors are therefore facing each other to measure the force exerted by the thumb on the one side and by the index, middle, and ring fingers on the other side. The LED strip is attached to the bottom of the sleeve and lights up to signal the user to perform the exercise and give feedback on the correctness of the exercise. During the training, the system visually indicates to the user to squeeze (i.e., flexing the fingers) or release (i.e., extending the fingers) the cup and how much force (i.e., strength training) they should apply. Any cylindrical cup can be used for this interaction as the sleeve facilitates adjustability to different. The difficulty level needs to be set before the first use (Figure 4-a). When the user switches on the device, the LED strip shows white light (Figure 4-b) and the exercises are randomly picked by the system. A yellow light indicates that the user has to squeeze (Figure 4-c), and a blue light indicates the user has to extend their hand (Figure 4-d). When the exercise is performed correctly for 5 seconds, the LEDs blink green (Figure 4-e). If the exercise is not completed correctly, it ends after 10 seconds. In between exercises, there is a short pause, and a new exercise is randomly picked after the break. The off button turns off the device, and before turning it off, the LED strip shines red light (Figure 4-f). The training is completed when a number of correct exercises are done, after which the LED strip lights up green. The device gives an overview of the performance results after the training on the laptop.

4 EVALUATION OF THE CONCEPTS

4.1 Participants

Three stroke survivors evaluated the prototypes (see Table 1 for participant profiles). Two participants were recruited via the Roessingh Centre for Rehabilitation, and the third was recruited directly via one of the authors. All had experienced or were still experiencing hand and arm impairments due to stroke, and differed in

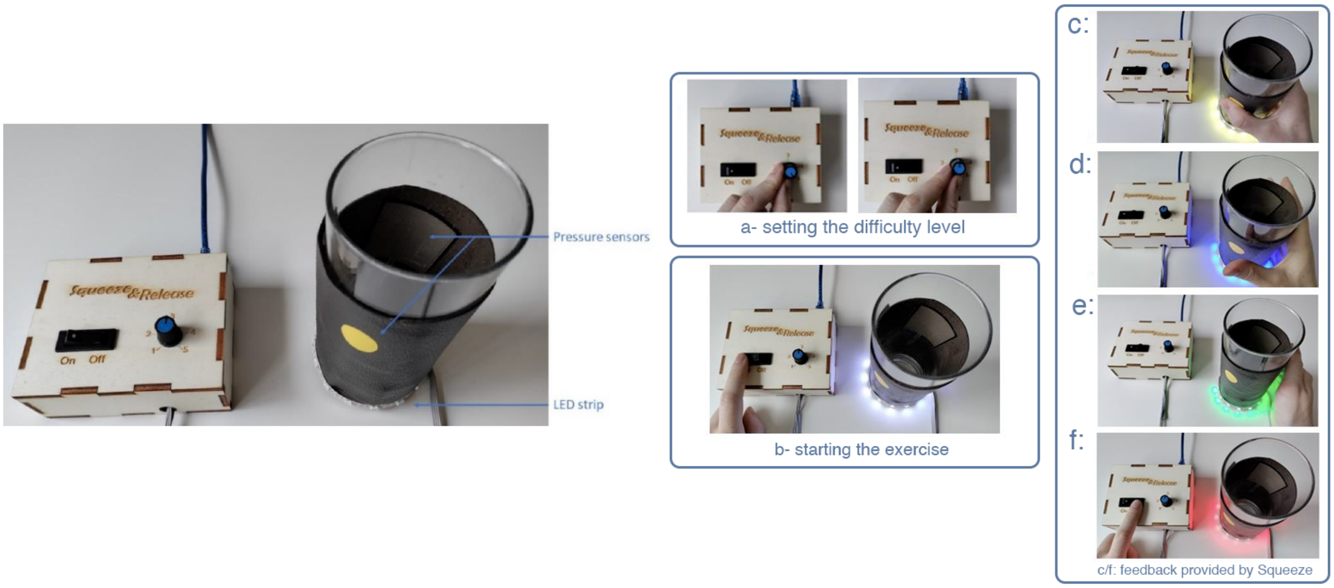

Figure 4: Conceptual design and interaction with Squeeze and Release.

various respects (see Table 1). None of them suffered severe motor or cognitive impairments at the time of the evaluation.

4.2 Procedure

We carried out interviews by following user evaluation guidelines [4]. Our procedure was evaluated and approved by the Ethics Committee of the University of Twente. We performed the interviews individually with each stroke patient. Two were conducted at the house of the participant and one at the University. Each interview took about one hour. The sessions started with informing the participants about the nature of the session. We asked them to read and sign the consent form and encouraged them to ask questions if they had any. Following, we asked questions about their experience with stroke and rehabilitation. Afterwards, we presented the prototypes and asked them to perform the exercises. This was followed by questions on their thoughts on the prototypes. Finally, we asked them their ideas about ADL-based and drinking-based training. All sessions were audio recorded, and participants were given a voucher as compensation.

4.3 Results

We transcribed voice recordings and carefully looked into the benefits and challenges the participants indicated about the prototypes. Where necessary, we related the participants' comments to the feedback we received from the two rehabilitation experts. All participants indicated that both prototypes were easy to set up. They appreciated that both tools provided clear feedback and that the difficulty level of the exercises was adjustable. In the following sections, we reflect on the insights we gained from the participants about the (1) suitability of the interactive tools to match the ADL of drinking and (2) perceived capabilities of the tools to train hand skills.

4.3.1 Suitability of the Interactive Tools to match the ADL of drinking. All participants noted the benefits of ADL-based rehabilitation training. Two participants mentioned that many ADLs, and drinking, in particular, are part of our daily lives. This makes it likely that interactive tools for ADL-based training become a reminder for training and, therefore, that the training becomes part of the daily routine. According to P1, this reminding function can be particularly beneficial for patients with cognitive impairments. The participants differed in how they would integrate the training into drinking activities. P1 preferred to do it before drinking, so "drinking forms a reward for completing the exercises". P2 recommended using an empty cup before drinking, especially in earlier rehabilitation stages. When progress is made, a filled glass could be used, and sips could be taken as a reward. According to P3, the training should take place while drinking, replicating the real drinking setting. All participants stressed that both prototypes could be used safely with a filled cup. P2 had a preference for using personal cups, arguing that as training takes place at home, it should facilitate using personal cups. This allows practising with varying weights and shapes and, in turn, different grasps and movements. Participants thought that drinking-based training should be directed at improving functions related to drinking. They stated that while the PlayCemat achieves this, the Squeeze and Release does not do so, as they would normally not "squeeze a cup when drinking". One participant in particular mentioned: "I normally would not think of extending my fingers in the context of drinking, rotating my wrist would make more sense". One participant commented that PlayCemat might deviate the drinking activity from his normal routine. All participants suggested coupling the drinking-related exercises in the prototypes better to the activity of drinking from a cup, such as rotating or filling the cup. Both prototypes were connected to a computer, and the PlayCemat was a wooden box rather than a

Table 1: Participants of User Evaluation

Participant	Gender	Age	Time since stroke	Dominant hand (R/L)	Affected hand (R/L)	Reported Drinking Ability
P1	Male	50	1.5 years	R	L	No difficulties can drink normally with the impaired hand
P2	Male	64	8 months	R	L	Difficulties with strength, coordination and sensation
P3	Male	64	8 years	R	R	Does not involve the impaired hand in drinking

flat placemat. Because of these limitations, we observed that the tangible components of the prototypes might have had an effect on how the participants perceived the interactive tools we presented as a proof-of-concept. For example, although all participants indicated that the training could be performed safely with liquid in the cup, two participants thought people might not want to squeeze the cup hard because they did not want to break the cup or spill the liquid.

4.3.2 Perceived capability of the Interactive Tools for Hand Skill Training. All participants preferred the PlayCemat over Squeeze and Release when it came to skill training. Two participants questioned the added value of Squeeze and Release for training skills. Although they acknowledged the importance of training strength, squeezing and extension, they found performing this with a cup counterintuitive. Their main concern was that Squeeze and Release lacked functional exercises related to drinking. They suggested that, aside from squeezing and releasing, the cup should provide exercises that are more closely related to drinking. These can include grasping a cup, lifting it, rotating it, and emptying it. Two participants indicated that they would perform the training with Squeeze and Release if recommended, while the third would only do so if functional exercises were added. This participant specifically mentioned that "training the strength with which I squeeze seems more of interest to my therapist than to me." In comparison, all participants stated that PlayCemat provided more useful training, as it targets important skills such as hand-arm and hand-eye coordination, as well as cognitive skills. The smoothness of arm movements can be measured and trained by adding an accelerometer to the cup used and providing feedback on the arm movement performance. Both prototypes enabled adjusting the difficulty level of one parameter (time or strength) to the patient's abilities using a button or knob. Still, the exercise of the Squeeze and Release was deemed too simple in its current form. The participants suggested adding more difficulty settings to be able to personalize the training level. Both prototypes provided direct visual feedback indicating correct or incorrect performance, while P2 mentioned that some patients might exert uncontrolled pressure to Squeeze and Release. In case of squeezing too hard, it could light up red to make them aware of the situation and stimulate them to relax their hand. Feedback on the overall performance (i.e., the number of correct and incorrect exercises) was provided at the end of the training session but was not tracked across sessions. It did not show progression over time. All participants emphasized the importance of direct and progress feedback. One patient, in particular, mentioned that "the feedback provided by the PlayCemat could be clearer." Two participants mentioned that the feedback presented by the Squeeze and Release prototype should include the amount of force and not only correct performance. Two participants wanted the feedback to be available to the physiotherapist so they get better insights in which muscle groups should receive more attention.

5 EVALUATION OF OUR APPROACH

5.1 Benefits and challenges of ADL-based Training

Clinicians have indicated that ADLs at home provide functional and meaningful training opportunities that can be performed throughout the day [37]. The participants in our evaluation study argued that most ADLs are routine-based, making it likely that the training becomes part of their daily routine. This is supported by previous work [17, 27] which reported that it is easier for patients to perform and continue with training when it is integrated into daily routines that are performed in short periods throughout the day. Participants recognized that ADL-based training couples particularly well to functional training. Selecting appropriate functional exercises that match the ADL is an essential task for the patients to be able to transfer training outcomes to a functional setting. In our evaluation study, participants considered ADL-based training exercises more effective when the content of the exercise was directly linked to a skill required for the performance of that ADL. For example, participants preferred the exercises of the PlayCemat over the Squeeze and Release concept, as the activity of putting down the glass at different locations of the PlayCemat resembles the activity of drinking from a cup more than squeezing it. In that respect, our findings support the previous work [2, 17]. The functional training concept resembles task-oriented training, a common training principle focused on repetitive training of functional tasks or subtasks [13, 18, 36]. This has been shown to have a positive effect on hand and arm function in stroke patients [36]. Participants found it important that the training objects were easy to use and safe to train with, which is in line with the usability, safety and robustness guidelines of Prange et al. [31] and Pickrell [30]. All participants appreciated the ease of use of the prototypes and the ability to use the prototypes in a self-administered manner. However, two participants had safety concerns regarding the prototypes. They feared spilling the liquid when performing the PlayCemat exercise, and breaking the glass in the Squeeze and Release exercise. Here, the skills that the training exercises require might not match the difficulty level of the exercises (e.g., controlling the skills of the hand when putting the cup on PlayCemat). Besides, the type of interaction with the object does not fit the natural interaction one would have with the object (e.g. squeezing the cup). These safety concerns should be further elaborated.

5.2 Seamlessness of Training

At the start of our study, we envisioned an approach in which training provides an intuitive interaction, fits with the context, and blends in with the ADL [34]. This approach is in line with previous works by Lemke et al. [19] and Stefess et al. [34]. In both works, authors focused on redesigning an everyday object so that its use triggers a certain grip. In our work, we focused on the integration of an exercise into an ADL. In that respect, even though the intuitiveness of the tools was our priority, we did not explicitly look into the seamlessness of training. We observed several conflicts between our results and the results of Stefess et al. [34] about the seamlessness of training. The authors state that direct feedback about the progress of the patients is a necessity for effective rehabilitation. In our study, we also provided feedback to the participants in the form of smileys (in PlayCemat) and colours in Squeeze and Release). We found that patients perceived the feedback elements positively, and they referred to those as "gamification" elements. However, as soon as the participants perceived the tools as part of a "game", the concepts lost their intention to be integrated into daily lives. We think that adding direct feedback that is perceived as a gamification element can make the tools deviate from the seamlessness vision of previous work. In that respect, we believe that the patients should not necessarily be aware of the coupling between ADLs and the training. Therefore, future research should take into account that seamless training must only minimally deviate from the regular ADL itself and look into how feedback can be implicitly conveyed to the patient without distracting them from the performance of ADL.

5.3 Limitations

The user evaluation consisted of an interview and test session. This meant that the participants tested the prototypes but did not use them in their daily life for training purposes. So they had to reflect on the usefulness of the concepts and their potential in integrating them with their daily life routines rather than experiencing this first hand. Looking back at the setup of the testing, we see that the participants thought that they were still testing the prototypes rather than using them for training purposes. This might have overshadowed the real benefit of implementing training exercises into the ADL. For example, during testing, participants focused on the gamification elements of the concept, even though they were very simplistic and minimal. In a real-life setting, their focus might have shifted to other elements of the concepts, as they might have a conversation in a social setting or perform a double-task while they perform the activity of drinking. Future research should take this into consideration. Testing should be done in a longitudinal study, and the prototypes should be tested without the involvement of a researcher and with more patients.

6 CONCLUSIONS

Through the design of two interactive ADL-based training objects for drinking, the PlayCemat and Squeeze and Release, we investigated the possibilities of translating daily activities into rehabilitation activities to improve hand and arm functions. While current practices focus on exercises that indirectly target ADLs, our study illustrates that ADLs themselves offer functional and meaningful training opportunities. By showing the potential of interactive ADL-based interventions, our work contributed to addressing the gap in the literature and current rehabilitation practices. In this paper, we have not addressed whether ADL-based training tools would actually improve the skills of the patients. In that regard, our results should be considered carefully. Still, future studies can take our approach into account when developing ADL-based interactive hand rehabilitation tools. They should closely match the training movements with the natural movements involved in the execution of the ADL and critically look into safety aspects of the training object in relation to the skill level of the user. Furthermore, they should take up the challenge of implicitly conveying feedback to the user without distracting from performing the ADL.

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