Graduation Project

Designing Smart Daily Training Objects for Hand and Arm Rehabilitation after Stroke

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Introduction

Stroke is a prevalent medical condition in the Netherlands and worldwide and has a large social, economic, and health care burden [1, 2]. A stroke occurs when blood flow to the brain is partly blocked leading to damage of brain tissue [3]. Nearly forty thousand people experience a stroke every year in the Netherlands [2]. Most survive the initial injury but face long-term impairments [4]. In the Netherlands, it is one of the top causes of disability and impairment [2, 5]. A common and impactful one is motor impairment in hand and arm [4]. As they are vital for daily activities, this reduces participation in daily life, wellbeing, and quality of life [6, 7].

Rehabilitation aims at the recovery and improvement of skills and increasing participation in daily life [8]. An important strategy is home-based rehabilitation supported by technologies because this can increase quality and efficiency of care, provide personalised care, and is associated with positive functional outcomes and gains in quality of life [9, 10]. The use of technologies offers additional advantages such as making care more accessible and cost-effective, and increasing the number of patients per caregiver [11, 12]. Technologies can also monitor performance, offer feedback or assistance, and make repetitive exercises more engaging and challenging [13].

Despite these benefits, home rehabilitation is characterised by low adherence. Only one in three patients adhere to it [14]. This reduces the treatment efficacy [15]. An important cause is that in the absence of a therapist, the patient has to be sufficiently motivated to sit down at a specific place at home setting aside time to train and ignoring competing commitments [13, 14, 16].

A promising alternative strategy is integrating rehabilitation technologies into activities of daily living (ADLs) [17]. Rehabilitation exercises can be linked to activities or objects that are already performed or used on a daily basis, such as eating with cutlery or brushing teeth. Making use of training opportunities already present in patients' daily life bypasses the need for high intrinsic motivation and reduces the effort required for training regarding time investment and location restriction. As such, it can have a positive impact on adherence because training no longer needs to take place during a set-aside time slot or at a specific place. Although this ADL-based training strategy shows potential, as outlined in the Research Topics report [18], it is underexplored and could benefit from further investigation. Therefore, central to this Graduation Project is the following research question:

"How can we design interactive ADL-based training objects for hand and arm rehabilitation of mild stroke patients at home?"

The research question regards the design of interactive technologies integrated into daily objects to enable stroke patients to train and improve their hand and arm functions. The idea is that this can increase adherence to home rehabilitation training because it reduces training barriers. The objective is to address the gap in literature and stroke rehabilitation practices regarding interactive ADL-based training technologies.

Answering this research question and developing an interactive ADL-based training object requires a good understanding of the key facets of ADL-based training for hand and arm rehabilitation at home. Various facets have been researched and described in the Research Topics report of this project [18]. Different types of stroke-induced hand and arm impairments have been investigated and the advantages and disadvantages of home rehabilitation have been analysed. Additionally, factors mediating motivation and adherence as well as ADLs that can play a role in hand and arm rehabilitation have been identified. Lastly, the potential of interactive technologies to bridge the gap between daily activities and rehabilitation activities has been explored. The resulting Research Topics report [18] offered a theoretical framework for the design of interactive ADL-based training technologies for hand and arm rehabilitation. As such, it laid the theoretical foundations that this Graduation Project report further builds on. For more background information please refer to the Research Topics report included in Annex 1.

Before the design process can start, it is necessary to select an ADL suitable to ADL-based training and specify which hand and arm skills will be trained. So, the objectives of this Graduation Project report are to study these remaining facets of the research question and go through the design cycle to develop an ADL-based training object that can be evaluated by stroke patients. This allows determining the potential of ADL-based rehabilitation training. To achieve these objectives, a literature study and research through design method are used.

To design the training object, it is important to better understand the ADL-based training concept. This is the subject of chapter 1. Next, different ADLs are explored and evaluated to determine the most suitable ones for the training (chapter 2). Those are further analysed in chapter 3 to select the one that will be used in this project. For a better understanding of the selected ADL, drinking, its kinematics and context are studied (chapter 4). To ensure the training targets important hand and arm functions, different skills that are frequently trained in rehabilitation and corresponding exercises are investigated (chapter 5). Given these research activities, design guidelines and personas are developed (chapter 6). After these foundations are laid, the design process can start. The ideation phase studies different glass designs. Insights into these designs are combined with those on rehabilitation exercises to ideate a range of drinking-based exercises and objects (chapter 7). Five ideas are further conceptualised and evaluated by two clinicians to select those with the most potential (chapter 8). These two are developed into prototypes (chapter 9) to be tested by stroke patients in a user evaluation (chapter 10). Chapter 11 discusses the lessons learned from the user evaluation as well as the ADL-based training concept. It offers recommended design guidelines, a reflection on the used methods and limitations, and suggestions for future work. Lastly, chapter 12 presents the conclusions of this Graduation Project.

1 ADL-based training

Correctly and independently executing ADLs is key to patients' recovery and can increase their quality of life [19]. An important objective of rehabilitation is thus to improve independence in performing ADLs [20]. It is therefore surprising that interventions generally do not directly use ADLs to achieve this. While patients' performance of ADLs is used as a measure for interventions outcomes, such as the Barthel Index [21-23], ADLs are seldom used as direct training interventions. Naturally, there are some exceptions, like task-oriented training, but ADL-based training seems to be a gap in the literature and current rehabilitation strategies. Instead of using ADLs for training, the focus is currently on monitoring or assisting the performance of ADLs [24, 25]. This chapter describes the ADL-based training concept and its potential.

ADL-based training is about transforming daily activities into training activities. It makes use of training opportunities already present in people's daily activities, objects, or routines. The training is integrated into activities that would be performed or objects that would be used anyway. This allows patients to train more intuitively and seamlessly as part of their routines. This can reduce barriers associated with training. It no longer requires setting aside time or a large space, a specific location, and high intrinsic motivation. By reducing these efforts, it potentially increases perseverance and training adherence.

The integration of rehabilitation activities and technologies into daily life has been identified as promising opportunity [17]. Incorporating exercises and objects into ADLs can decrease the required willingness, motivation, and effort to start training and increase training dose [9, 10]. Similarly, Kytö, et al. [26] reported that patients prefer short exercises integrated in their routines as this reduces motivation needs and time constraints. Vourganas, et al. [10] recommended using rehabilitation technologies to support and be incorporated into ADLs and concluded this is currently a gap. They argued that this strategy can positively impact motivation, engagement, and acceptance. As such, it can have a positive impact on adherence and facilitate training perseverance [27]. The concept of translating regular activities into rehabilitation activities is also supported by stroke professionals. They indicated that this may be an effective strategy because daily home activities provide meaningful task-specific training that can be performed throughout the day [9]. These studies show the potential of ADL-based training for stroke rehabilitation at home.

ADL-based training makes use of interactive, smart technology as it can monitor performance, provide feedback, and enhance motivation [24]. It can help patients perform exercises correctly and stay motivated in the absence of a therapist who would normally ensure this [24]. Like most rehabilitation strategies, the goal of ADL-based training is to improve and maintain skills or reduce a decline therein.

For this project, the target group and context are defined and justified in the Research Topics report [18]. The target group is stroke patients who have mild hand or arm impairments, are in the subacute or chronic stroke phase, and do not have severe cognitive impairments. Home rehabilitation is the training context. Patients perform the training independently, i.e. without the presence of a therapist, at their own home and it forms a substitution of or addition to inpatient or outpatient rehabilitation in the subacute or chronic phase of stroke.

The idea is that patients have various ADL-based training objects at their disposal, each linked to a specific ADL and targeted at a different skill. For instance, there could be a toothbrush to practice finger strength, a pen to practice a certain grasp, and a hairbrush to practice wrist movements. As patients perform their regular activities during the day, they simultaneously perform the accompanying rehabilitation exercises. At the end of the day they have performed a range of exercises and completed sufficient training.

In the future, physiotherapists can have a toolkit with different ADL-based training objects. They determine which objects, and thus exercises, a patient should receive given their impairments and skills. The physiotherapist explains the training and object. The objects also come with instructions that the patient can check if needed. The therapist sets the difficulty level and receives feedback on the patient’s performance. This lets them tailor the training to the needs of the patient, for instance by changing the difficulty settings or recommending a new training object.

2 Identification of ADLs for training

As explained before, incorporating rehabilitation training into daily activities can target the low adherence characteristic of home rehabilitation. To determine which ADLs are promising for ADL-based training, different activities are identified and evaluated. The Research Topics report [18] presented common ADLs performed at home. This chapter elaborates upon these findings to determine the ADLs with most potential for training.

2.1 Identification of training ADLs

A wide range of ADLs that people perform at home can be used in rehabilitation. The Research Topics report discussed various studies [25, 28-31] on common ADLs at home and ADLs that play a role in rehabilitation. Here, one of these is considered in more depth, namely Timmermans, et al. [28]. Their work is particularly relevant as they studied which ADLs stroke patients want to train on.

2.1.1 Stroke patients' preferences for training ADLs

Timmermans, et al. [28] studied which ADLs (or skills) Dutch stroke patients with mild to moderate impairments preferred to train on for hand and arm rehabilitation in the subacute and chronic stroke phases, with the goal of implementing these into rehabilitation technologies. They identified the 12 most preferred ADLs for training by interviewing stroke patients, see Table 1 (in descending order of preference scores). No significant differences were found between subacute and chronic patients. So, Timmermans, et al. [28] argued that it is not necessary to develop different rehabilitation technologies for these two groups.

Table 1. ADLs preferred by stroke patients for rehabilitation training. Table adapted from [28].

Activities
Eating with knife/fork
Holding object while walking
Keyboard work
Taking money from purse
Open/close clothing
Grooming
Writing
Holding rake/broom/spade
Cup to mouth
Arm in sleeve/reach high/sewing
Wash and dry body
Handling telephone and steering wheel car

Timmermans, et al. [28] related these ADLs to different motor categories and found that patients preferred to train on ADLs related to fine motor skills, such as manipulation and grasp. The most preferred categories were 'manipulation in combination with positioning', 'manipulation', 'grasp in combination with positioning', and 'positioning'. They also investigated why patients wanted to train on these ADLs. Reasons include: “hope on transfer to other activities, avoid frustration, avoid embarrassment in public, independence, not to be a burden to others, pride, joy, back to work” [28].

For each patient, the Motor Activity Log score was determined for the ADLs. This score reflects the amount of use and quality of use of the impaired hand during the execution of ADLs [32, 33]. The higher this use score of an ADL, the more the impaired hand is used for that ADL. Figure 1 presents the preference and use scores of each ADL. A positive correlation between the preference and use scores has been found by Timmermans, et al. [28]. This indicates that patients prefer to train on ADLs for which they already have a certain level of ability, rather than their most impaired ones.

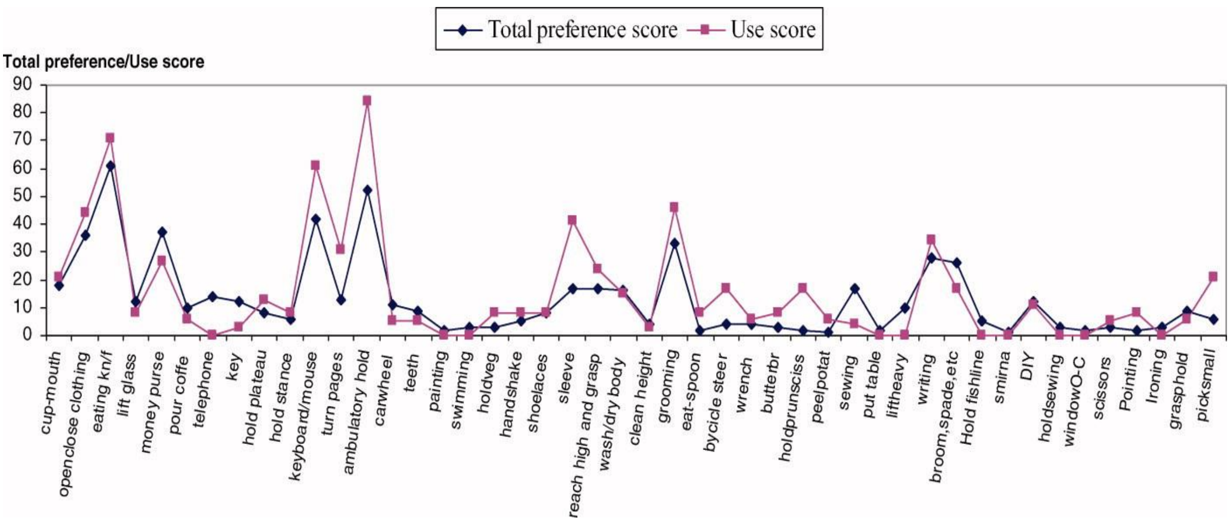


Figure 1. Association between the preference scores and use scores of each ADL. The figure is taken from [28].

2.2 Evaluation of training ADLs

To determine which ADLs are most suitable for rehabilitation, the top ten ADLs preferred to train on are used (see Table 1) [28]. To select the most promising ones, seven criteria are used, presented in Table 2.

Table 2. Criteria for selecting the most promising ADLs.

Criterion	*Explanation*
Time: sufficient duration or frequency	For training to have a beneficial effect, it should be performed for a sufficient amount of time each day (e.g. 3 times a day for 10-20 minutes [34]). So, the ADL should be performed for a sufficiently long duration or with a sufficiently high frequency each day.
Not gender or age-specific	The ADL should not be gender-specific or age-specific but be performed by a large group of mild stroke patients.
Specific objects	The ADL should be associated with specific objects, as the focus of this strategy is on integrating rehabilitation into daily-used objects. ADLs not linked to specific objects hamper the incorporation of smart technology.
Home	The ADL should be performed at home because the proposed strategy focuses on home-based rehabilitation.
Bimanual or executable by either hand	The ADL should be executable by either hand or both hands. Bimanual activities are included as these incorporate both hands, while activities that are solely performed by either the dominant or non-dominant hand are excluded. This

	ensures that the training activity can be performed by the impaired hand, regardless of it being dominant or non-dominant.
Low workload	The ADL should not be associated with a high workload demanding all attention and concentration from the patient. This could make performing a training task at the same time too difficult or hinder performing the ADL.
Integration of smart tech	The ADL should be integrable with smart interactive technology as this is one of the key components of the proposed strategy.

The top ten ADLs are evaluated against these criteria. Table 3 shows the criteria that each ADL meets. As it is not always a matter of simply meeting or not meeting a criterion, a scale is used. Here, '+' indicates the ADL generally meets the criterion, while '-' indicates the ADL generally does not. If the ADL meets the criterion to some extent or only in some cases '0' is used. For instance, 'taking money from purse' requires some attention to ensure the right amount is collected but may not require a person's complete attention.

Table 3. Evaluation of the ADLs against the criteria.

ADLs	*Time: duration*	*Time: frequency*	*Most patients*	*Specific objects*	*Home*	*Either hand/ bimanual*	*Low workload*	*Smart technology*
Eating with knife/fork	+	+	+	+	+	+	0	+
Holding object while walking	-	+	+	-	+	+	+	0
Keyboard work	0	0	-	+	0	+	-	+
Taking money from purse	-	-	+	+	-	+	0	+
Open/close clothing	-	0	+	0	+	+	+	0
Grooming	0	0	+	0	+	+	+	0
Writing	0	0	0	+	+	-	0	+
Holding rake/ broom/spade	0	-	-	+	+	+	+	+
Cup to mouth	0	+	+	+	+	+	+	+
Arm in sleeve/ reach high/sewing	-	-	0	-	+	+	+	0

Table 3 shows differences between ADLs in the number of criteria they meet. The ADLs that meet most criteria are 'eating with knife/fork' and 'cup to mouth'. Both meet nearly all criteria, only somewhat not meeting ('0') one criterion. Based on this evaluation, they are most suitable for the ADL-based training and are thus considered for the next parts of this project. Below follows an explanation on the criteria that both ADLs meet.

2.2.1 Justification of selected ADLs

The ADLs 'eating with knife/fork' and 'cup to mouth' meet almost all criteria. Both are not gender or age-specific but can be performed by anyone and are often executed at home. They are also associated with the use of specific objects, such as a fork or cup, allowing for the integration of smart technology. Additionally, they meet the criterion of being executable by either hand or being a bimanual ADL. ‘Eating with knife/fork’ is a bimanual activity, requiring both the impaired and unimpaired hand. Drinking is an activity that can be performed by the dominant and non-dominant hand. ‘Eating with knife/fork’ is associated with some effort and attention from stroke patients to ensure eating safely and properly, for instance to prevent spilling [35]. It is expected that the activity of drinking is not associated with a high workload and thus that a training task can be performed simultaneously. Lastly, ‘eating with knife/fork’ and ‘cup to mouth’ are executed on a daily basis for a considerable amount of time. Both activities belong to the ADL category of feeding, which is the category with the longest duration of hand use per day (1h 9 min) [30]. Similarly, people in the Netherlands spend about 61-70 minutes per day on eating and drinking [36]. It should be noted that drinking is generally executed for frequent short periods of time, while eating is executed for less frequent but longer periods of time.

Both ADLs are listed as recommended exercises for stroke patients to perform independently at home by the Kenniscentrum Revalidatiegeneeskunde Utrecht [34]. This shows the potential and relevance of these ADLs for rehabilitation training.

To summarise, the ADLs ‘eating with knife/fork’ and ‘cup to mouth’ show potential for ADL-based rehabilitation as they are characterised by long or frequent durations of hand and arm use, are performed at home, associated with specific objects, and preferred for training. The other eight ADLs are excluded as they meet less criteria and are deemed less viable. Appendix 1 substantiates why these are excluded based on the criteria they miss.

2.3 ADLs of eating and drinking

The study of Timmermans, et al. [28] provides additional insights into the two selected ADLs that may be relevant for the development of a rehabilitation training. ‘Eating with knife/fork’ and ‘cup to mouth’, hereafter referred to as eating and drinking respectively, are linked to the motor categories that are most preferred for training by stroke patients. The most preferred categories relate to manipulation, positioning, and grasping. Eating and drinking both consist of grasping and manipulating an object (e.g. knife or cup) and positioning it, for instance on a table.

The findings of Timmermans, et al. [28] also highlight two important differences between the ADLs. The preference and use scores for eating with knife and fork are higher than for drinking. Stroke patients thus prefer to train on the eating activity and already use their impaired hand more for this. This difference may be explained by the fact that eating is a bimanual activity. In contrast, drinking is generally a unimanual activity that can be done by either hand. It is therefore likely that stroke patients rely less on their impaired hand. The high use score for eating means it is likely that the training will be performed with the impaired hand but that the improvement in that hand for this ADL may not be large because it is already quite good. In contrast, the low use of the impaired arm in the drinking activity may mean that stroke patients are less likely to perform the training with their impaired hand but that there is a lot of room for improvement.

3 Contextual analysis of eating and drinking

It is important to consider the context as well as the situational factors of eating and drinking. This provides a better understanding of the setting in which the ADL-based training may take place. This chapter provides a broad contextual analysis of the two ADLs to determine which one shows most potential for the ADL-based training.

3.1 Eating and drinking

Eating and drinking play a significant role in the daily home life of Dutch people. In the Netherlands, almost 80% of foods and drinks are consumed at home and people drink and/or eat nine times a day on average [37]. In terms of time, people spend a sizeable portion of their day on food and drinks. In the Netherlands, men spend on average 61 minutes and women 70 minutes per day on eating and drinking [36]. A survey of the Social and Cultural Planning Office [38] found that Dutch people spent 1h 42 min per day on eating and drinking in 2011. This was also specified per age category, with people above the age of 50 spending even more time, around two hours per day [38]. As stroke prevalence increases with age [2], this group is of particular interest. Overall, both eating and drinking often occur next to other activities, such as watching TV, reading, socialising, and listening to the radio [39].

These findings indicate that eating and drinking play a key role in people's daily life and that it is important for stroke patients to be able to perform these ADLs to improve their independence and participation in daily life. Furthermore, the large amount of time people spend on eating and drinking indicates that these activities provide useful training opportunities.

3.2 Eating

3.2.1 Context

Most people in the Netherlands eat three main meals per day. Breakfast is generally eating between 6:30-9:00, lunch between 12:00-13:00, and dinner around 18:00 [37, 38]. These meals entail a variety of products, including bread, vegetables, meat, and dairy [37]. Eating in the Netherlands is a social event. Overall, nearly three quarters of the time people eat in the company of others at home, such as family or friends, and one quarter of the time alone [38]. Bisogni, et al. [39] studying eating habits of Americans also found that socialising is an important aspect of eating. Dinner activities are often social events during which people socialise or converse [39]. In contrast to dinner, breakfast and snacks are generally not associated with a social aspect but done alone [39].

3.2.2 Eating activity

Eating with knife and fork is a bimanual activity [40]. More specifically, it is an asymmetrical bimanual activity as the two hands perform different movements [41]. Furthermore, it requires sufficient dexterity to manipulate the cutlery [42].

Some studies have divided the activity of eating with knife and fork into functional components to better describe the action. Two studies [40, 43] did this in the context of hand and arm rehabilitation after stroke. Based on these studies, the components of eating with knife and fork are: reach for the utensils, grasp them, lift them, bring them to the plate, manipulate food on the plate with the utensils (e.g. cut with the knife, prick with the fork), bring food to the mouth, and lastly eat the food. In the present study, the ADL of eating with knife and fork refers to these components, an activity taking on average 11.2 seconds [44].

3.2.3 Eating difficulties due to stroke

Stroke patients experience various difficulties with eating. Interviews with stroke survivors one to two years after the stroke indicated that eating is characterised by difficulties, such as coughing, spilling, dribbling, and being unable to handle food properly on the plate or in the mouth [45]. Patients can experience negative feelings such as feeling unable to perform eating activities and feeling dependent on the help of others [45].

Medin, et al. [35] explored the eating difficulties of patients in the subacute and chronic phases of stroke. They found that common issues are swallowing, managing food on a plate (e.g. cutting up food and loading it onto cutlery), transporting food to the mouth, placing food on a plate, and thinking which food should be cut into smaller pieces. They also identified two important goals of stroke patients, namely eating safely and properly, that is eating without unwanted consequences, like choking or spitting, and eating according to social norms. To achieve this, they often use four coping strategies. Firstly, patients are careful when eating, making sure food does not get stuck in their mouth and taking small bites. Secondly, patients analyse their eating behaviour to ensure that they eat properly and safely, for instance considering how big of a bite they should take. They also mention that eating takes longer than before. Thirdly, patients sometimes avoid certain foods as well as social settings, like eating at a restaurant, party or with unfamiliar people, to prevent feelings of shame. Lastly, patients may need help from others, for instance with cutting their food or bringing it to their mouth. Overall, the process of eating can be a conscious and troublesome act as patients have to actively reflect on what to eat, how to chew, and the size of bites [35].

3.3 Drinking

3.3.1 Context

The focus of the ADL of drinking is on non-alcoholic drinking activities. In the Netherlands, adults drink about 1.9 litres per day of non-alcoholic beverages [37]. As shown in Figure 2, people consume several types of drinks with different quantities. Overall, water is the most consumed beverage [37]. Drinking occurs at various moments. Drinks are mostly consumed between meals, but also occur during meals, as shown in Figure 2 [37]. The study by Bisogni, et al. [39] on drinking and eating activities reported that most drinking episodes, in contrast to eating episodes, are not accompanied by social interactions, but done alone.

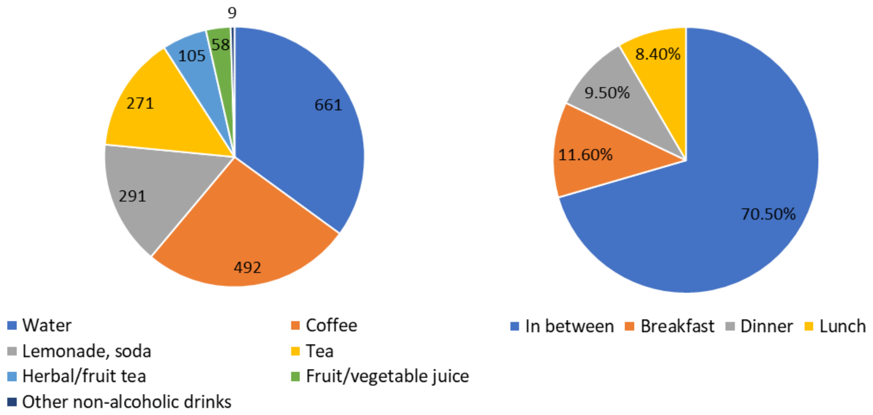


Figure 2. Left: Quantities of drinks consumed in grams per day. Right: Moment of drinking relative to the total. The data is taken from [37].

3.3.2 Drinking activity

Drinking is usually a unimanual activity which can be performed by either hand. It can also be a symmetrical bimanual activity when both hands are used [41]. The non-dominant hand then mirrors the dominant hand [41]. Drinking is a complex kinematic task as it contains various movements, such as lifting the cup with the arm and rotating the wrist to turn the glass [46]. It also involves the activation of several muscles in the shoulder, elbow, and wrist joint [47].

Some studies have decomposed the ADL of drinking into functional components describing the action in detail. Five studies [43, 46, 48-50] did this regarding upper limb impairments, for instance after stroke. These studies identify the components of drinking as: reach for the cup, grasp it, lift it, transport it to the mouth, drink from it (includes tilting the cup), transport the cup to the table or surface, and release it. In the present study, the ADL of drinking refers to these components. This activity takes on average between 6.8 and 9.7 seconds [44, 46].

3.3.3 Drinking difficulties due to stroke

Stroke patients may have difficulties with drinking [47, 48]. For instance, they take more time and move their arm less smoothly than healthy people [49]. They can also have difficulties extending their arm to reach the glass [48-50].

3.4 Selecting the training ADL

Both eating and drinking play a key role in people’s daily life and provide promising opportunities for hand and arm rehabilitation training. To determine which ADL is more suitable, the advantages and disadvantages of both are discussed based on the contextual analysis described above. This is used to select an ADL.

An important argument for linking the training to eating with knife and fork is that this is the most preferred ADL for training by stroke patients [28]. In contrast, drinking is ranked at the ninth place. Furthermore, eating is important to train because it is associated with feelings of independence [45]. Additionally, it is a bimanual activity, which may better guarantee the use of the impaired hand as both hands are required [26, 51]. However, this positive effect of a bimanual activity is countered by the fact that unimanual training has been found to provide more effective rehabilitation training and outcomes [8, 52, 53].

Eating with knife and fork is associated with some downsides that may hinder the addition of a training activity. An important disadvantage is that it is a complex activity requiring attention and a high workload. The workload is further increased as eating after stroke is associated with various difficulties that require extra attention for eating safely and properly [35]. Eating is already considered a difficult activity involving coping strategies and careful and deliberate thought [35]. The addition of a training exercise may complicate the ADL even further. Moreover, as eating is a generally a social activity [38, 39], this can distract the patient from training, making it less effective. Vice versa the training can hinder the patient's participation in the social setting and thus lead to feelings of exclusion, shame, or inconvenience.

Compared to eating, drinking requires less attention so the training can be the main focus of the patient. An important additional advantage is the flexible nature of drinking, making it less time-dependent and location-dependent. It can take place at various locations and times, occur during or in between meals, co-occur with different activities, and be an individual or social activity [37, 39, 54]. Overall, drinking is a less complex, more flexible, and less social activity than eating which may facilitate the integration of an interactive training.

Another advantage of drinking is that it can take place alone or with others while eating with knife and fork is usually a social activity. This means that while eating-based exercises have to be integrated into a social setting, drinking still allows the exploration of training in both individual and social contexts. It seems sensible to keep both options open and investigate their differences. Perhaps one context provides more opportunities for increasing effectiveness or adherence.

To conclude, while stroke patients have a higher training preference for eating with knife and fork [28], it is associated with some important limitations that can hinder the integration of a training activity. Drinking provides more opportunities because it is a more flexible activity, associated with less difficulties and a lower workload, and can take place alone or in company. So, the present project will focus on the ADL of drinking for the development of a rehabilitation training object.

4 Analysis of drinking

The activity of drinking has already been explored in section 3.3. However, a better understanding is required to comprehend the actions, motions, and context. This chapter considers the kinematics and context of drinking by studying the differences between stroke patients and healthy people and conducting a survey about drinking activities. This can provide insights into the skills that the training should target or contextual factors that could hinder or improve the training.

4.1 Kinematic analysis of drinking

Drinking consists of diverse motor actions executed by different parts of the upper limb (e.g. grasp with the hand, lift with the arm) which are also involved in other common ADLs, like eating [55, 56]. These motions require good coordination between the hand, upper limb, trunk, and head [50]. It also requires good hand-eye coordination because drinking entails an action-perception loop involving various senses, including visual, tactile, and proprioceptive feedback [56].

4.1.1 Differences between stroke patients and healthy people

Various studies have compared drinking actions of healthy people to stroke patients and found significant differences. This indicates that stroke alters the drinking kinematics. Stroke patients show less smooth and more segmented arm movements [48, 49]. They also have lower peak velocities and take a longer time to perform the different components of drinking as well as the complete movement [48, 49].

While healthy people extend their arm to reach a glass, stroke patients keep their elbow flexed and compensate for that by leaning forward with their trunk and head [48-50]. This even occurs when the glass is within arm's reach [48]. The movements of a healthy person and stroke patient are shown in representative drawings in Figure 3. Not only are there differences between healthy people and stroke patients but also between patients with mild and moderate impairment. Those with moderate impairment take more time, move less smoothly, and lean more forward with the trunk [48, 49].

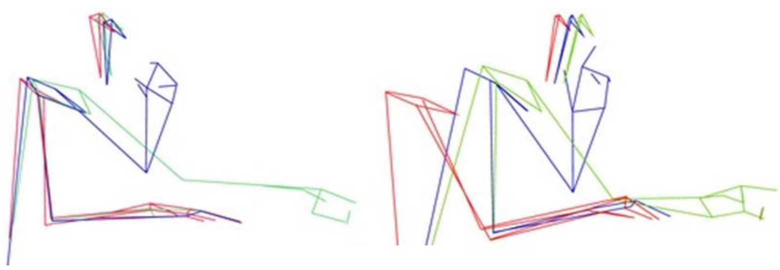


Figure 3. Arm and trunk movements for the initial position (red), reaching for the glass (green) and transporting it to the mouth (blue) for a healthy person (left) and stroke patient (right). The images are taken from [50].

4.1.2 Common drinking difficulties in elderly

Elderly people can experience difficulties with drinking as they become less abled due to a stroke or other causes. Four common issues were identified by Holt and Holt [57]. Elderly may have difficulties grasping a glass, often caused by reduced dexterity, and lifting it because of less strength [57]. It may also be more challenging to bring a glass to the mouth, often caused by a decreased range of motion, and to control the rate of flow. These difficulties can increase the risk of spilling and choking and may also extend to stroke patients [57].

4.2 Contextual analysis of drinking

A good grasp of the context of drinking is required to develop an appropriate drinking-based training object. This includes what, when, how, and why people drink. A survey is conducted to study this.

4.2.1 Survey methodology

Six participants completed a survey about their drinking activities. They were asked to track their drinking activities for one day (24 hours). For every activity, they recorded various elements, including the type of drink, amount of liquid, and cup type. These variables are largely based on the ones used by Bisogni, et al. [39]. They studied the situational nature of eating and drinking of a group Americans for a week to form a conceptual framework. In their study, participants described the nature of eating and drinking activities, including the foods and beverages consumed, time taken, location, co-occurring activities, social setting, mental processes, physical condition, and recurrence. All variables except for physical condition were adopted in the present survey. Other dimensions of particular interest to this project were added, such as cup and grasp type. A total of 17 variables were included, shown in Appendix 2.

As the goal is to get a better understanding of drinking activities and contexts, the participation of stroke patients is not necessarily required. Therefore, healthy individuals were recruited. Stroke patients are more difficult to recruit and the survey is quite elaborate. Completing it takes time and effort which may be too demanding for patients. Six participants were recruited through convenience sampling, of which two males and four females. The participants were elderly, aged 66 to 75 (M = 69.6), to more closely represent stroke patients as stroke prevalence increases with age [2, 5]. All were right-handed.

The survey was distributed online via email together with a consent form, a brochure explaining the purpose of the study, and a list of the variables with explanations and examples (see Appendix 2). The survey could be filled in digitally or be printed out and filled in by hand. It was provided in English, but participants could respond in English or Dutch. Half of them completed it online and the other half on paper. Similarly, half filled it in in English and the other half in Dutch. Survey responses were completed and retrieved between 15 March and 6 April 2022. Note that for the grasp dimension, participants were asked to provide a picture of how they held the glass. This was done because describing this may be difficult.

4.2.2 Survey results

All participants completed the survey. A total of 61 drinking activities were reported and analysed. The responses are presented in Annex 2. Here, the results are discussed per variable and relations between variables are explored. Finally, the implications of the findings for the development of a drinking-based training object are described.

Type of drink

All participants consumed different drinks in a day. Figure 4 shows an overview of the different drinks and their frequencies. In total 14 different drinks were reported, most commonly tea, (black) coffee, and water. They can be divided into five categories: hot beverages, water, juice, dairy, and alcoholic beverages. Multiple drinks were consumed only once, showing individual drink preferences. The diversity of liquids consumed in a day differed per participant, ranging from 3 to 7 distinct types of drinks. The total number of drinking activities in a day ranged from 6 to 15, with an average of 10 drinking activities per participant.

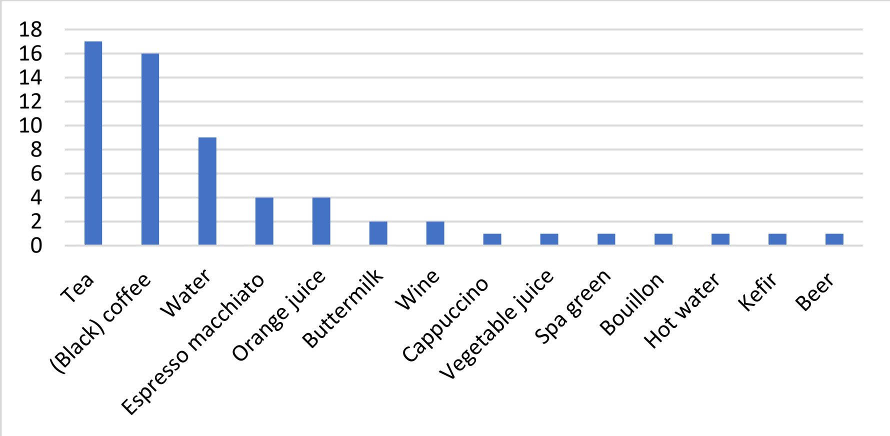


Figure 4. Overview of consumed drinks with their frequencies.

Time

Drinks were consumed at different moments in the day, mostly in between meals (48 out of 61). Four participants drank during breakfast and lunch, while only one drank during dinner. The duration of drinking activities was not reported for all activities (only for 36 out of 61). Based on these, participants spent an average of 18 minutes on a drink, but the time varied widely within and between participants. Some drinks were consumed fast, from 1 to 5 minutes, others over a period of 30 to 45 minutes. An explanation might be that functional drinks, such as those for hydration or taking pills, are consumed fast while drinks for taste are enjoyed over a longer period of time.

Amount of liquid

The amount of liquid consumed during a drinking activity differed from 50 to 330 ml, although most drinks were 150 or 200 ml. The amount often related to the type of drink or glass used. For instance, espresso is generally served in small quantities while beer comes in bottles or cans of 330 ml.

Location

Participants drank at various locations, most drinks being consumed at home (58). Figure 5 shows the locations with their frequencies. The most frequent location was by far the living room.

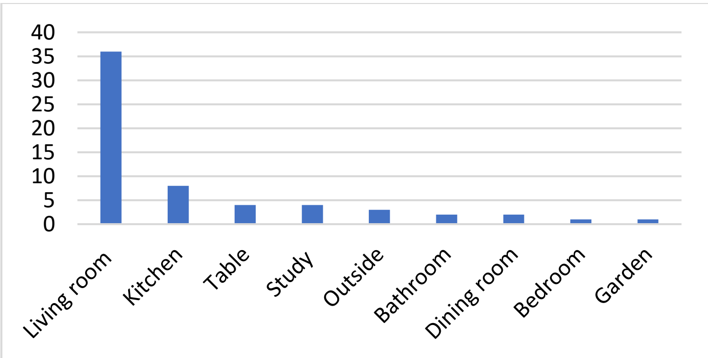


Figure 5. Locations where drinking activities take place and their frequencies.

Social setting

Drinking occurred both solitary and in company. The company was often the partner, especially when drinking at home. It could also involve a friend. For half of the participants, the majority of drinks were consumed alone. For two participants, about half of the drinks were consumed in the presence of someone else and the other half alone. For one participant, all drinking activities occurred alone. In total, 43 drinking activities were done alone, 18 in a social setting.

Activities and focus

Drinking nearly always coincided with other activities except for two instances. Figure 6 shows an overview of the variety of co-occurring activities and their frequencies. Sixteen different activities were described. The most frequent ones included watching TV/Netflix, eating, and reading. When drinking in a social setting, talking was a common activity. For some drinking activities, participants reported two co-occurring activities. The focus of the participants' attention was nearly always on the co-occurring activity. Only in six cases was the primary focus directed at drinking.

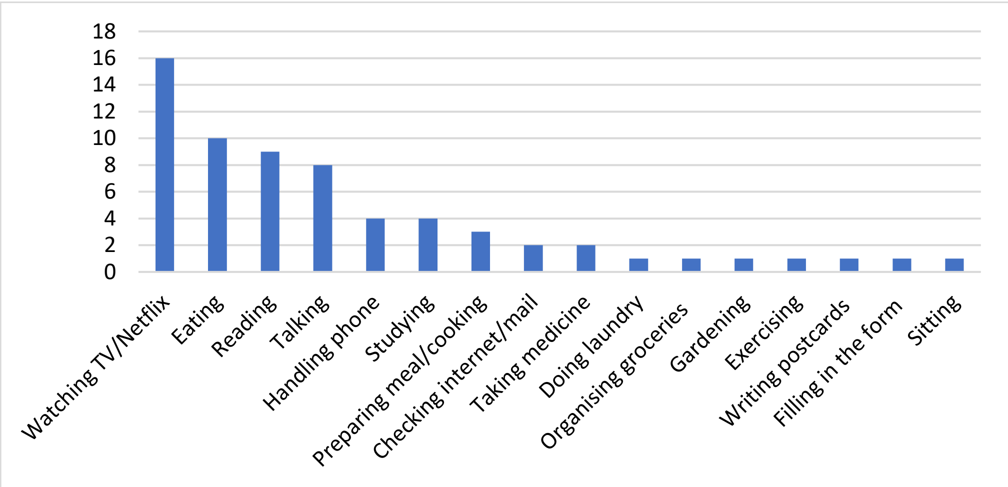


Figure 6. Activities that co-occur with drinking and their frequencies.

Goal

Participants drank to achieve different goals and one drink could serve multiple purposes. The most frequently reported goals were hydration (33), nice flavour (16), and relaxation (13). Different drinks targeted different goals. For instance, water and tea were often drunk for hydration, coffee for taste, and butter milk and orange juice for health benefits.

Cup type

In general, participants adapted their glass to the drink, using several types of glasses in one day. For instance, a teacup was used for drinking tea, an espresso cup for espresso, a regular glass for water or juice, and a wine glass for wine.

Hand

The dominant hand was used for most drinking activities (46). Half of the participants only used their dominant hand. The other half used their dominant hand for the majority of drinking activities, but in a few cases their non-dominant hand (5), both hands (7), or they switched between hands (3).

Lifting the glass

Drinks were consumed in varied ways. Some in one big gulp, lifting the glass only once, others in many small sips, lifting the glass multiple times. The number of lifts ranged from 1 to 21, with participants lifting their glass an average of 5.8 times per drinking activity. For large amounts more lifts were used than for small amounts or functional drinks (e.g. to swallow pills). Lifting also differed between participants. The one who lifted their glass the least number of times did that on average 4.0 times per drinking activity and the one who lifted it the most did that 13.0 times.

Grasps

The grasp used to hold a glass largely depended on the shape. Of particular relevance was whether the glass had a base shape or also contained a handle or stem. Eight different grasps were identified.

If the glass had a base shape, three grasps were reported. Participants either wrapped their complete hand around it with a cylinder grasp (Figure 7.a) or held their hand partly around and partly below the glass. This 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 7.b). In the second version, only the little finger supported the bottom (Figure 7.c).

If the glass had a handle, this was used to hold the glass. 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 7.d), while bigger handles allowed for more fingers to grasp the handle (Figure 7.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 glass with a cylinder grasp (Figure 7.f). Finally, stemmed wine and beer glasses were held by their stem, either with a cylinder grasp (with the thumb slightly adducted) (Figure 7.g) or with a prismatic 4-finger grasp (Figure 7.h).

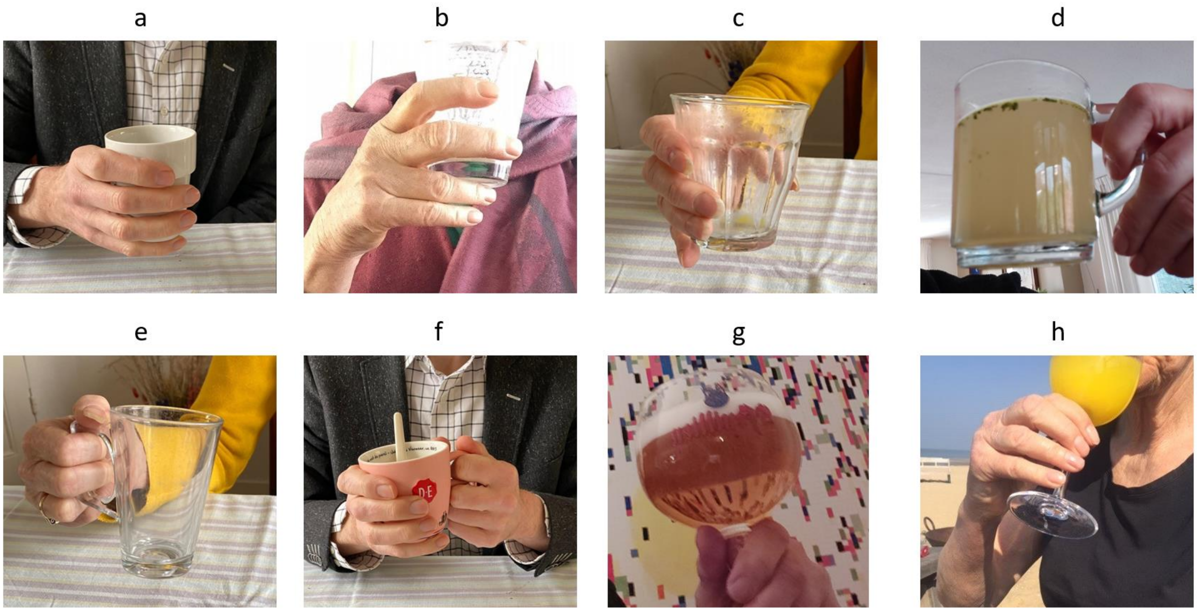


Figure 7. Overview of the identified grasps: a) cylinder grasp; b) cylinder grasp with two fingers supporting the bottom; c) cylinder grasp with one finger supporting the bottom; d) lateral pinch grasp with index finger; e) lateral pinch grasp with index and middle finger; f) bimanual grasp; g) cylinder grasp around the stem; h) prismatic 4-finger grasp.

Objects

A diverse range of objects was used during drinking. Nineteen different objects were reported. In most cases these related to the co-occurring activity, such as a newspaper, book, and cutlery. Some participants mentioned objects related to drinking, like a spoon and teabag, and objects to prepare drinks, such as a water cooker, coffee machine, and wine bottle.

Frequency

Drinking activities were often routines or habits. Four participants indicated that all drinking activities recurred on a daily basis. The two other participants indicated that some occurred daily and others occurred sometimes or rarely, like drinking at a restaurant.

Mood and experience of time

A variety of moods was reported, but one was mentioned frequently (42 out of 61 activities). This was feeling relaxed. Other moods included calm, energetic, tired, focused, and curious. Most drinks were consumed in a relaxed manner, where participants could take their time and had no rush. Only nine drinks were consumed hastily, for instance because of other activities that had to be done.

Conclusions and implications

Although drinking activities are highly individual, with differences between people in terms of what and how they drink, some patterns can be identified. In line with the findings of Bisogni, et al. [39], this survey shows that most drinking activities take place at home, occur alone, reoccur frequently, and are accompanied by other activities.

These findings have implications for the development of the drinking-oriented training object. Most drinks are consumed at home which aligns with the concept of training in the home environment. Furthermore, drinking plays a significant role in people's daily lives in terms of time and frequency. On average, 10 drinking activities occur per day and 18 minutes are spent per drinking activity. Although the number of drinks and their duration vary, these numbers indicate that there are sufficient drink-related training opportunities in day.

Most drinking activities are habits or routines. It may be easier to integrate an exercise into a consistently performed activity than one that is prone to change. Furthermore, linking training to a habit means it is likely to become a habit as well. Another advantage is that people are not in a hurry while drinking but feel relaxed and take their time. This suggests that people have time to perform an exercise even if it would prolong their drinking activity.

The findings also indicate that there are challenges to the drinking-based training concept. People mostly use their dominant hand to drink, making it a challenge to ensure the use of the non-dominant hand if that is the affected side. Additionally, people generally perform other activities while drinking and have their primary focus directed at the coinciding activity. Training is thus added to a complex context in which multiple activities take place and compete for the person's attention. Another challenge is that people consume different drinks in a day and adapt their glasses to these drinks. Ideally the training can be performed with different glasses. This can be achieved by allowing patients to use their own cups, by ensuring the training cup is appropriate for different types of beverages or by providing multiple training cups to be used for different drinks.

5 Identification of skills and exercises

To develop a suitable and effective drinking-oriented training object, not only the drinking context needs to be understood but also the skills that need to be trained. This requires an investigation of the hand and arm functions that are frequently affected by stroke and the types of exercises that can improve them.

As discussed in section 4.1 as well as the Research Topics report section 2.1 [18], stroke is associated with various kinds of hand and arm impairments, such as weakness and reduced range of motion [58, 59]. To reduce these impairments and regain lost abilities, a wide variety of skills can be trained, each with different exercises. For example, arm strength can be improved by lifting weights and range of motion by performing rotating exercises.

To get an overview of these skills and corresponding exercises, several resources that present hand and arm rehabilitation exercises have been investigated. These include a practice guide by a Dutch rehabilitation centre [34], online health resources [60, 61], and training guides by rehabilitation developers [61-66]. Four exercise categories can be distinguished based on the targeted skill. These skills are strength, dexterity, range of motion (ROM), and coordination. This is not an exhaustive list but a general categorisation. Table 4 shows the four categories as well as their relevance, limbs involved, and example exercises.

An exercise can target a combination of skills. For instance, exercises with the therapy or putty ball train finger strength as well as finger independence and alternating between making a fist and spreading the fingers trains range of motion as well as strength. This is partly because different skills interrelate. For instance, reduced strength can decrease muscle control and range of motion because strength is required to generate sufficient force for movements [58]. Similarly, dexterity is largely dependent on the control and coordination of fingers. So, an exercise that targets a specific skill can improve other skills as a by-product.

Table 4. Skill categories targeted by training with explanations, limbs involved, and exercises.

Skill	*Explanation*	*Limb/joint*	*Exercise example*
Strength	Weakness is a common impairment caused by stroke [8, 58, 67, 68]. It can affect the complete upper limb or specific muscles. It can occur in the hand or arm but also manifest itself as reduced grip strength [67, 69].	Arm Hand Finger	Weight training Therapy/putty ball
Dexterity/ fine motor skills	Loss of dexterity or fine motor skills is a frequent effect of stroke [58, 69]. It causes reduced control of hand and finger movements and force because of a decreased ability to activate individual finger muscles [67]. This can lead to issues with using fingers independently, extending them, and forming different finger postures [67]. Loss of dexterity can result in a reduced ability to reach, grasp, and hold objects [67].	Hand Finger	Finger opposition Finger extension Grasp and release objects (e.g. bottle or pen) Therapy/putty ball
Range of motion	Stroke can reduce the range of motion of joints, decreasing their ability to move. In the upper limb, the shoulder, elbow, and wrist are often affected [50, 59, 70]. Reduced range of motion of	Shoulder Elbow Wrist	Arm stretch Arm raise Wrist rotation Wrist curl Wrist extension/flexion

	the elbow can impair the ability to stretch the arm [48-50].		Finger spread
Coordination/ control	Stroke can impair motor coordination and control [71, 72]. Movements involving multiple muscles or joints require sufficient coordination, so a deficit can lead to difficulties forming and controlling movements [71]. Reduced control can lead to involuntary movements as well as slower and less smooth movements [71].	Arm Wrist Hand Finger	All exercises mentioned above

Coordination and control are required for any movement involving more than one muscle, which is nearly always the case [71, 73]. So, it plays a vital part in virtually any movement. This means most training exercises will involve the practice of coordination and control. Therefore, this skill will not be addressed separately because it is assumed to be targeted as a by-product of any developed ADL-based training. The focus will thus lie on these skills: strength, dexterity, and range of motion.

6 Design process

Now that the most suitable ADL has been identified as well as the central skills for the ADL-based training, the design process can begin.

6.1 Design process

To guide the design process two instruments are used, design guidelines and personas. The guidelines are design recommendations to ensure that the object meets important criteria, such as ease-of-use. The personas ensure that the training object is developed for stroke patients while taking their needs and goals into account.

After these tools are created, the ADL-based training object can be developed. The design phase consists of three stages: ideation, conceptualisation, and prototyping. In the ideation phase, various ideas for drinking-based training objects are brainstormed. In the conceptualisation phase, the most promising ideas are developed into concepts and evaluated to select the most suitable ones. These are then developed into working prototypes. Afterwards, the prototypes are assessed by stroke patients in a user evaluation.

6.2 Design guidelines

Guidelines are developed for the design of the training technology. Design guidelines are recommendations for designers and researchers on how to design something [74]. They function as a guide for the design of the interactive ADL-based training object.

Six guidelines have been formed based on a literature survey of studies [25, 27, 74-77] that proposed design requirements, criteria, or guidelines for technologies for post stroke upper limb rehabilitation. One of these studies formed recommendations for training devices in the home context [27], particularly relevant to this project. Others focused on robotic technologies [75], assistive technologies [25], or rehabilitation technologies to be used in clinics [76] or in general [74, 77]. Although these studies do not explicitly focus on technologies for interactive ADL-based training, they are still useful for formulating design guidelines.

Aside from the diversity in technologies, the studies used a variety of methods to establish guidelines. These include a literature search or review [27, 77], as well as interviews with stroke patients, caregivers, or physiotherapists [25, 75]. Some even employed a combination of a literature review and interviews [74, 76]. Overall, this variety can contribute to well-grounded design guidelines for an interactive training object that meets the goals and needs of stroke survivors.

Finally, note that this is not an exhaustive list of guidelines but an overview of the most relevant ones for prototyping interactive ADL-based training objects.

Ease-of-use

Usability plays a key role in rehabilitation technologies. Training devices should be easy to set up, operate, and understand [27, 74, 75]. The information it gives, such as feedback, should be clear [74]. Ease-of-use also refers to patients being able to perform the training at home without assistance from a therapist (after an explanation and instruction guide are provided) [75]. The object also has to fit in the home environment, not be too large, and be portable [27, 75]. Lastly, it is important to develop objects that are usable by both left and right side-affected patients [75].

Safety

It is important that the training object is safe to use. It should have no sharp edges, rough or slippery materials, pressure points or be uncomfortable to hold [25]. It needs to be robust and be able to endure pressure and weights [74]. Additionally, because the training centres around drinking it may not induce spilling or choking and the object should be waterproof.

Skill training

The training should have a positive impact on rehabilitation, namely improve or maintain abilities or reduce decline. To achieve this it has to train skills and movements used in daily activities, promote active participation of the impaired hand and arm, and stimulate repetition [75]. Ideally, the training targets one or more of the identified skills: strength, dexterity, or range of motion.

Difficulty level

Striking a balance between the abilities of the patient and training difficulty is key to rehabilitation. Training that is perceived too easy or too challenging can result in disengagement [27]. Naturally, patients differ in ability level and show progress over time. As they progress, the difficulty needs to match so they continue to improve skills [76]. Examples are increasing the intensity or frequency of exercises [76]. So, the training object should accommodate diverse levels of skill by enabling the adaptation of the difficulty level to the abilities and goals of individual patients [76, 77].

Feedback

Another key aspect of rehabilitation technology is feedback. Feedback should address the execution of movements as well as the performance of exercises [74, 76]. This can improve motor learning and enhance motivation and engagement [27, 76, 77]. Generally, positive feedback stimulates motivation, self-efficacy and compliance, whereas negative feedback encourages learning and skill improvement [78]. Feedback can be provided during or after an exercise [76]. If provided during the exercise, it is best not offered continuously but intermittently to prevent reliance on feedback [74]. Feedback is generally visual, auditory, or haptic [27, 74]. Apart from direct feedback, the performance of patients should be tracked over time to chart progress [74, 76]. Comparing past and present performances enhances motivation [27, 74]. This data can be provided to the therapist so they can asses the performance and tailor treatment to changing needs [76].

ADL-based training

An additional design guideline has been formulated specifically for this project. The training should be ADL-specific. In the present case it must involve the action of drinking or using a glass to ensure that the training is integrated into the drinking activity. This also implies that the training object should retain the function and form of a glass or cup.

These six guidelines are used in the three design phases to warrant the development of a useable and effective ADL-based training object.

6.3 Personas

Two personas have been developed to represent stroke patients. Personas are an important and common tool in design [79]. They are a fictional character based on research that represents the user and gives insights into their behaviours, goals, needs, and challenges [79]. They stimulate designing with the user in mind, targeting their needs and goals instead of designing based on assumptions [80].

In this project, two personas have been created based on the research on stroke patients from the Research Topics report (chapters 1, 2, and 4 [18]), the analysis of drinking (section 3.3 and 4.1), and the survey on drinking activities (section 4.2). This information was combined to draw up concrete personas to get a better picture of the life of individual stroke patients and their behaviours and goals. Two personas were created to reflect the diversity of patients. They represent two types of users: one with sufficient time for training but low motivation and one with high motivation but insufficient time for training. Both are included in Appendix 3.

7 Ideation

To develop a drinking-based training object, various glass, cup, and bottle designs are explored, keeping in mind the various hand and arm rehabilitation exercises that they will have to facilitate.

7.1 Glass designs

Several types of cups, glasses, mugs, bottles, and other drinking objects are investigated for a better understanding of glass design. The following designs are studied in the subsequent sections:

1. Regular glasses
2. Ergonomic glasses
3. Glasses for elderly and disability
4. Creative glasses
5. Smart bottles and cups
6. Smart glasses for stroke rehabilitation

7.1.1 Regular glasses

There exists a great diversity of glasses. Generally, a glass and its shape and material depend on the type of drink that is consumed. Survey responses on drinking activities (section 4.2) showed that people match their glass to their drink. For instance, tea is usually consumed in a glass or ceramics teacup. The design and material of a glass support its function. Hot beverages, for instance, are consumed from cups with a handle so users do not touch the hot surface. Table 5 shows an overview of common glasses categorised according to the consumed beverage.

Table 5. Different categories of glasses.

Category	*Beverage*	*Material*	*Shape*	*Image*
Water glass	Cold beverages (e.g. water, juice)	Glass Plastic	Smooth or edged textures for grip	
Teacup & coffee mug	Hot beverages (e.g. tea, coffee)	Glass Ceramics Porcelain	Handle Saucer	
Drinking glass	Alcoholic beverage	Glass	Often stemmed	
Disposable cup	Hot and cold beverages (e.g. soda, coffee)	Paper Plastic Glass Drink carton Metal	Lightweight Thin material	
Bottle & flask	Hot and cold beverages (e.g. water, coffee)	Plastic Metal	Lid or cap Thick material	

Although countless glasses can be designed differing in shape, colour, and size, they all consist of a limited number of design elements. Five of these can be distinguished: base, handle, saucer, lid, and stem. Most glasses show one or more of these elements. A regular water glass only contains a base, while a teacup consists of a base, handle, and possibly a saucer. A variety of materials can be used in glass design. Common ones are glass, ceramics, porcelain, plastic, metal, and paper or carton.

7.1.2 Ergonomic glasses

Glasses can be designed using ergonomic principles. Ergonomics focuses on reducing discomfort, fatigue and risk of injury, while optimising well-being [81, 82]. It considers how products fit those who use it, taking into account the required force, repetitive motions, and postures involved in a task [81, 82]. Ergonomics can be applied to the design of glasses to improve comfort [83, 84]. Frequently encountered ergonomic features are described in Table 6.

Table 6. Overview of ergonomic features in glass design.

Ergonomic feature	*Function and explanation*	*Image*
Grooves	Grooves guide the placement of the fingers and palm to form the correct grasp.	
Twin handles	User can hold both handles.	
Enlarged handle	The complete hand fits to hold the handle.	
Handle with holes	Handle has holes to place the fingers into for better support.	
Knob handle	Handle is shaped like a knob to provide better support.	
Handle design	Alternative handle shapes can provide better support for the fingers.	
Grip or anti-slip	Anti-slip material or shape can provide extra grip. This can be applied to the base or handle.	

7.1.3 Glasses for elderly and disability

Glasses designed for the elderly and people with disabilities have been studied as stroke patients are generally of older age and can experience difficulties with drinking. Such designs can inspire training exercises and useful features that reduce drinking issues.

Holt and Holt [57] identified four problems that may arise in (less-abled) elderly, as described in section 4.1.2. These include difficulty in grasping the glass due to reduced dexterity, lifting the glass because of reduced strength, bringing the glass to the mouth due to decreased range of motion, and higher risk of choking and spilling due to difficulty controlling the flow rate. Note that the first three issues were also mentioned in chapter 5 as the skills that upper limb rehabilitation often targets (dexterity, strength, and range of motion). Design for elderly and disability often addresses one or more of these issues. Table 7 presents an overview of design strategies targeting these issues in glass design, including examples.

Table 7. The four skills that may be impaired in elderly and design features that target them.

Issue	*Design feature*	*Explanation*	*Image*
Reduced dexterity	Enlarged handle	Makes it easier to grasp the handle as the complete hand can be used [57, 85].	
	Mouldable handle	Provides a personalised grip, fitted to the shape of the user's hand [85]. It can be a bendable or modular handle [85].	
Reduced strength	Twin handles	Distributes the weight of the cup over both hands [57, 85].	
Reduced range of motion	Nose cup	Has a cut-out slot for the nose so that the cup can be tilted further back. This is for people who have difficulty tipping their head back [57, 85].	
	Angled cup	Provides angled handles or a top edge that slopes away from front to back. It requires less raising the shoulders and tipping back the head [85].	
	Rotatable handle	Can be held without having to rotate the wrist [86]. The cup can be rotated by the other hand, thumb or lips [86].	
Risk of spilling /choking	Commuter lid	Has a flat lid with drinking hole to prevent spilling [85].	
	Lid with spout	Has a lid with a spout to drink from [57, 85].	
	Lid with straw	Has a lid with a straw to drink from. The straw can be enlarged to avoid lifting or angled to avoid tilting the head [85, 86].	
	Anti-spill insert	Restricts the liquid flow into the mouth [57, 86].	

7.1.4 Creative glasses

Innovative glass designs have been investigated for inspiration. Examples are shown in Figure 8. They include interesting handles, a squeezable bottle, and motivational feedback designs.

Figure 8. Examples of creative glass designs.

7.1.5 Smart bottles and cups

General-purpose smart bottles and cups have also been studied. They provide insights into interactive features and sensors that can be build into glasses, showing possibilities for interactive drinking technologies. There is a wide variety. A selection [87-93] is considered to identify common features, presented in Table 8. Figure 9 shows examples of integrating smart features into bottles and cups.

Table 8. Common features in smart bottles and cups.

Measure water intake (using weight sensor, accelerometer, or sip tracker)	Measure and display temperature of liquid
App tracks progress	Keep beverage warm
Personal goal setting in app	Bottle displays date, time, and weather
Reminders via app	Social element: see friends' progress
Reminders via bottle (LEDs, vibrations, message)	Built-in speaker
Bottle shows progress (LEDs, progress bar)	Location tracking

Figure 9. Examples of smart bottles and cups. The figures are taken from [88-93].

7.1.6 Smart glasses for stroke rehabilitation

Two smart glasses for post stroke hand and arm rehabilitation have been found during the research process. They are summarised below to gain insights into the training they provide and the sensors, feedback, and design elements that may be of importance to a drinking-oriented training object.

In several papers [24, 55, 56, 94], Bobin et al. described the development of the SyMPATHy smart glass, see Figure 10. Stroke patients can use the glass for drinking. It monitors the drinking activity and rehabilitation progress but does not provide rehabilitation exercises.

The smart glass monitors several elements, such as liquid level and tremor. The liquid level is detected by conductive electrodes placed inside the glass. The level is shown vertically on the glass with LEDs, see Figure 10. The orientation of the glass is measured using an inertial measurement unit (IMU) sensor. This measures if the patient holds the glass straight. LEDs at the top of the glass display colours according to the orientation, see Figure 10. Tremors (involuntary muscle contractions and relaxations) in the hand are measured using an IMU sensor [56]. The glass also measures grasp force (the pressure applied to the surface) by five pressure sensors (force-sensing resistors) placed in the shape of a handprint. The handprint has grooves which helps patients grasp the glass correctly. Using NFC tags, the placement of the glass on a coaster can be detected. A built-in speaker provides audio feedback when it is placed on the coaster. The recorded data is accessible to the therapist for monitoring and analysing performance and adapting rehabilitation exercises if needed.

Figure 10. SyMPATHy prototype with LEDs on the side indicating the liquid level and LEDs on the top indicating the orientation: a) glass held vertically (0-20°); b) glass tilted somewhat (20-50°); c) glass tilted (>50°). The figure is taken from [24].

Jayasree-Krishnan, et al. [95] have also developed a smart glass for stroke rehabilitation. They created a system involving a cup and interactive gaming environment on a computer, see Figure 11. It targets the activities of grasping, lifting, and tilting the cup. The user grasps and moves the cup to control virtual objects in the game. So, the smart cup trains drinking by executing exercises in a game environment rather than directly using a regular drinking activity.

To increase grip, rubber stickers are attached to the cup. A camera tracks the cup's location and orientation. It identifies if the cup is vertical, tilted, or horizontal. By grasping and moving the cup, the user grasps and moves a virtual object in the game (e.g. placing groceries on a shelf), see Figure 11. Instructions are presented on screen and the game contains multiple levels to keep it engaging.

A force-sensing resistor (FSR) on the cup monitors the grasp force applied by the thumb, see Figure 11. An Arduino processes this data and transmits it wirelessly to the game engine. At the start of the game, the grasp force of the unaffected hand is measured to set the baseline (i.e. optimal force). During the game, a progress wheel shows the grasp force of the affected hand relative to the optimal force. After completing the exercise, feedback is provided on the time taken. Data is stored and shared with the caregiver or therapist to monitor progress.

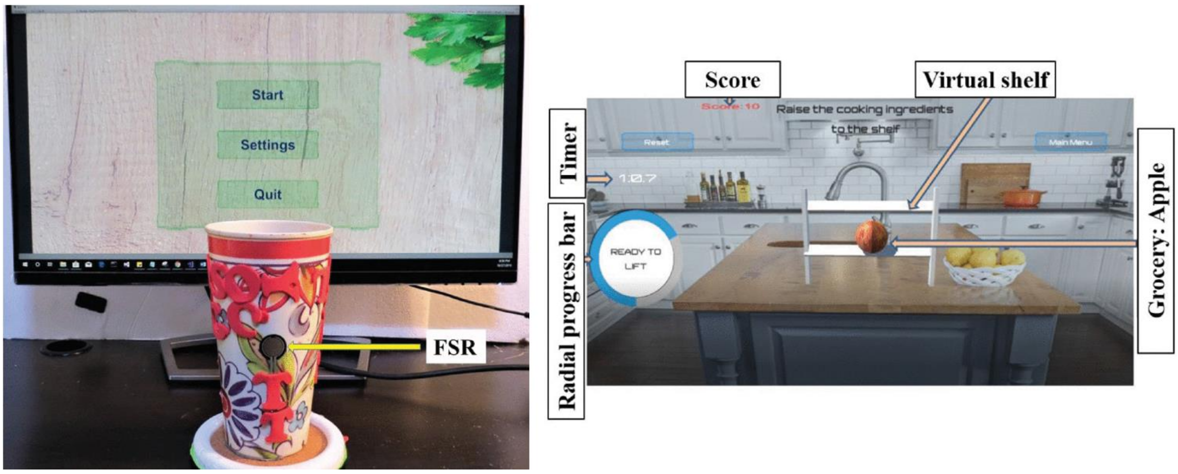


Figure 11. Left: Cup and gaming interface; Right: Gaming interface. The figures are taken from [95].

Both studies present smart glasses for stroke rehabilitation but they differ from the ADL-based training strategy proposed in this project. The SyMPATHy smart glass monitors elements related to drinking and rehabilitation progress but does not provide training. The second glass does provide training but without directly using the ADL. Still, both glasses provide insights into the integration of sensors and smart features and show the range of possibilities for linking stroke rehabilitation to drinking.

7.2 Idea generation

After the inspiration phase in which various glass designs and features have been investigated, idea generation could begin. The goal of this phase was to generate different exercises and designs.

Two approaches were taken to do so. First, the three skills that hand and arm rehabilitation training often targets (see chapter 5) were taken as the starting point: strength, dexterity, and range of motion. Exercises involving a glass that could address these skills were brainstormed. For instance, to train strength of the arm, weights could be applied to a glass to make it heavier. Second, the five key design elements identified in section 7.1.1 were taken as the starting point: base, handle, saucer, lid, and stem. The saucer category also includes a coaster and placemat, as these are elements that a cup can be placed on. Exercises that these elements could afford were considered. For instance, attachable handles with different shapes can practice different grasps. Images and features identified in the previous sections served as inspiration.

In the next step, ideas from both approaches were combined. The brainstormed exercises were categorised in terms of the design element they involve and the skills they target, resulting in 38 different training exercises. These are described in Annex 3. Some of the exercises simply target one skill, while others target all skills at once.

It was found that some design elements allow for a wide variety of exercises and can target each skill, while others only allow training one skill. For example, the base, handle, and lid afford a range of exercises related to different skills, while the saucer mostly affords training range of motion and the stem strength. Additionally, some exercises could be applied to different design elements, for instance the base and handle. Some training exercises even require a combination of elements. For example, a training that involves pressing both handles with sufficient force to open the spout lid incorporates both the handle and lid.

In the next phase, the large number of training ideas is narrowed down to a smaller selection for further development.

8 Conceptualisation

To develop an effective training object from the brainstormed ideas, a few steps are to be taken. Out of the 38 unique ideas, five promising concepts are selected for further development. These are presented to two clinicians with experience in the field of hand and arm rehabilitation for feedback. This is used to evaluate the concepts against the design guidelines which allows the selection of the training concepts with the most potential for ADL-based training.

8.1 Concept generation

Five concepts were selected from the set of ideas by combining separate ideas (e.g. combining similar exercises that can be applied to different elements of the cup or combining different exercises into one training concept). Furthermore, the design guidelines were used to evaluate the ideas and select the most promising ones. A consideration was to generate diverse concepts, targeting different skills and employing different design elements. This led to a varied range of five concepts, described in Figures 12-16.

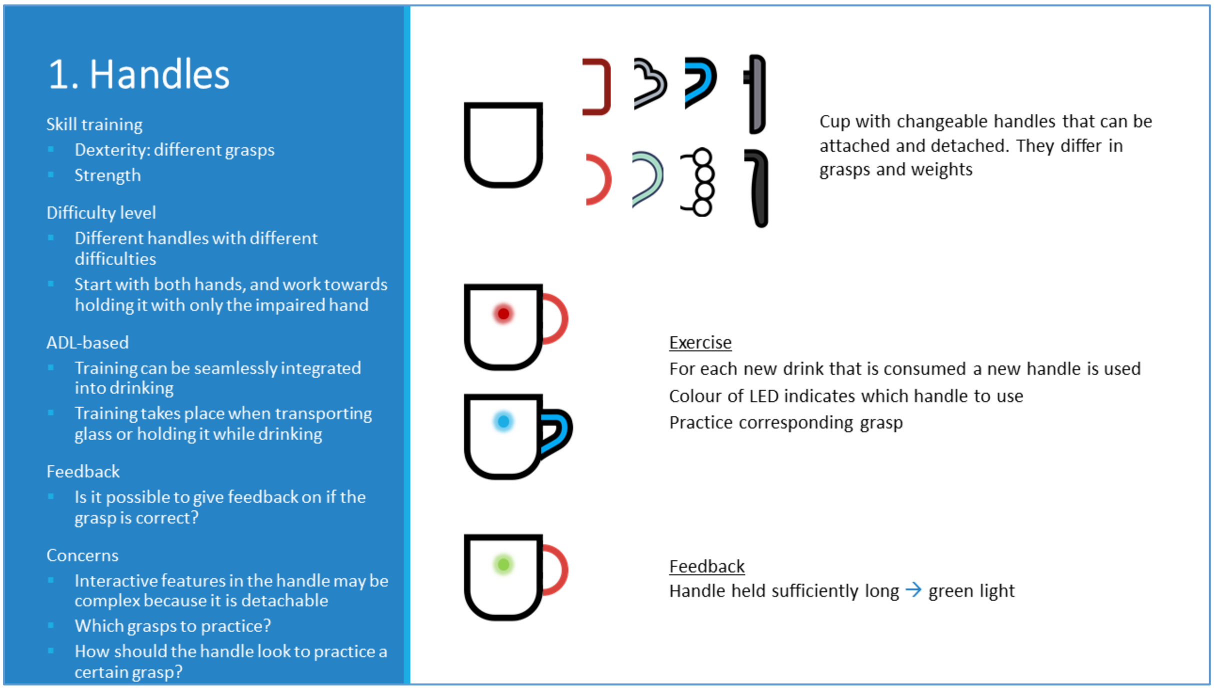


Figure 12. Description of concept 1: Handles.

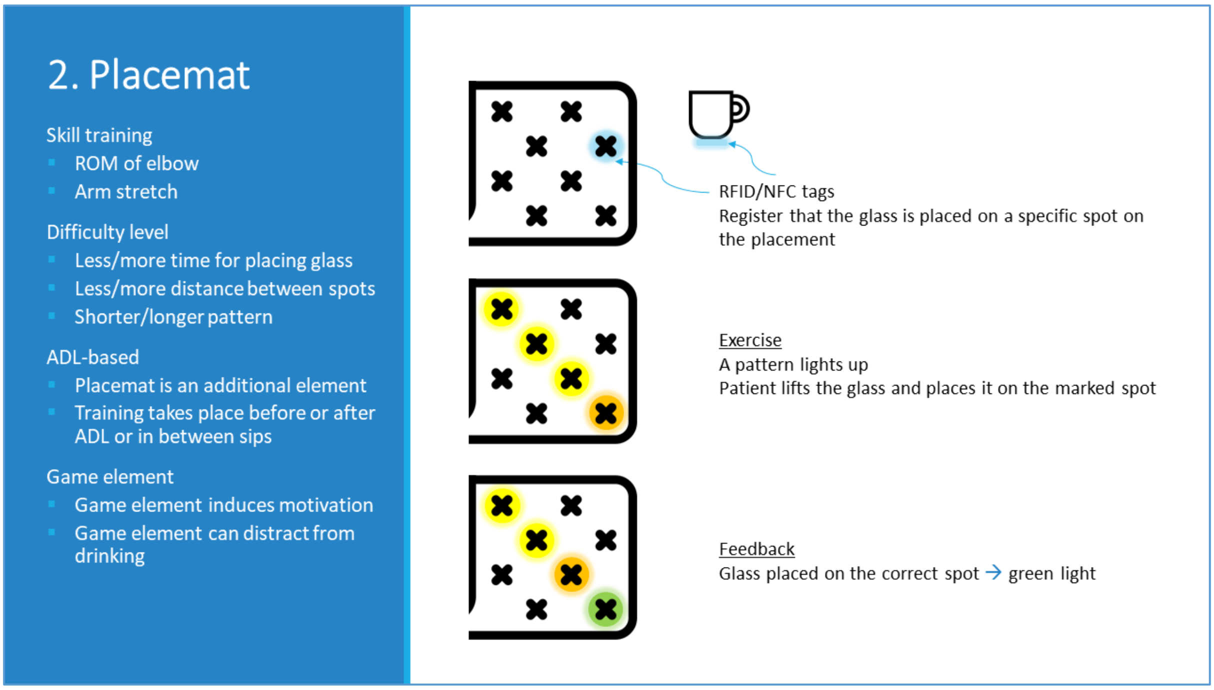


Figure 13. Description of concept 2: Placemat.

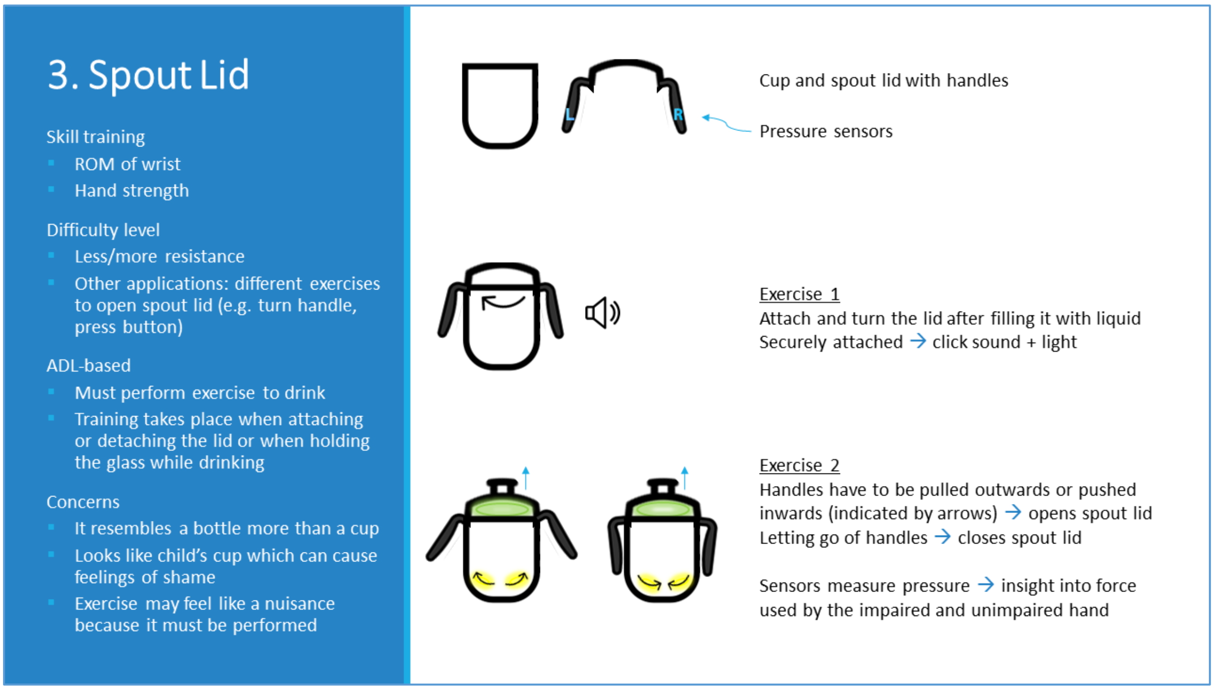


Figure 14. Description of concept 3: Spout Lid.

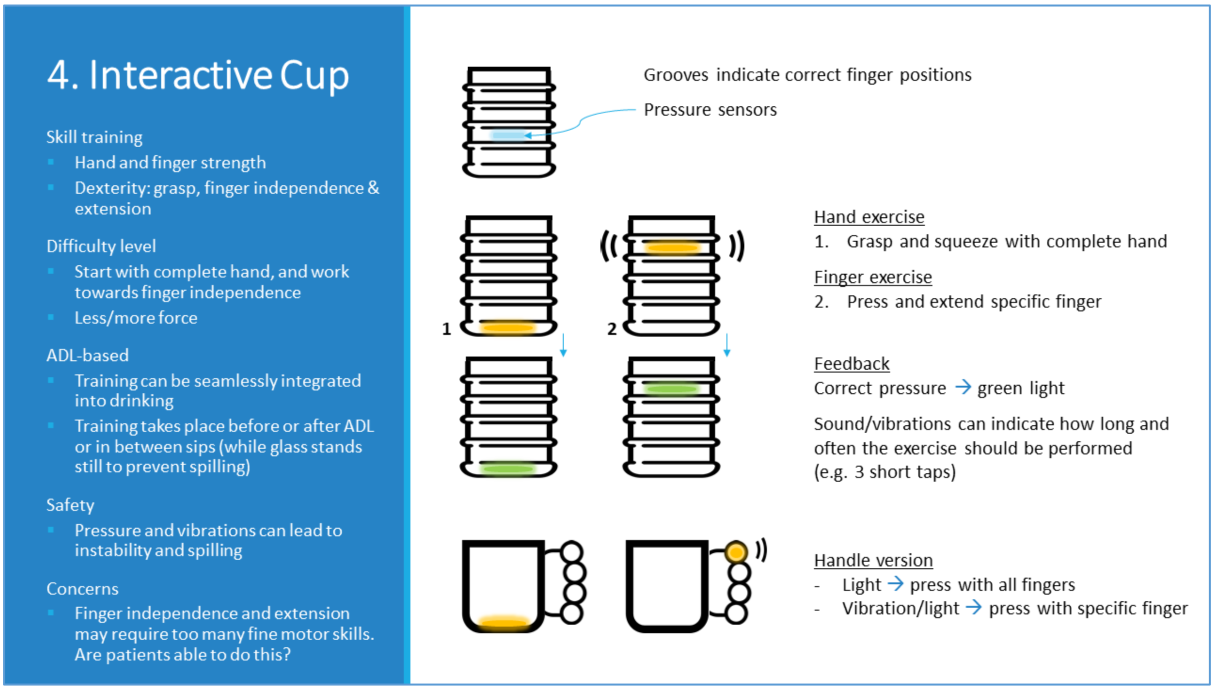


Figure 15. Description of concept 4: Interactive Cup.

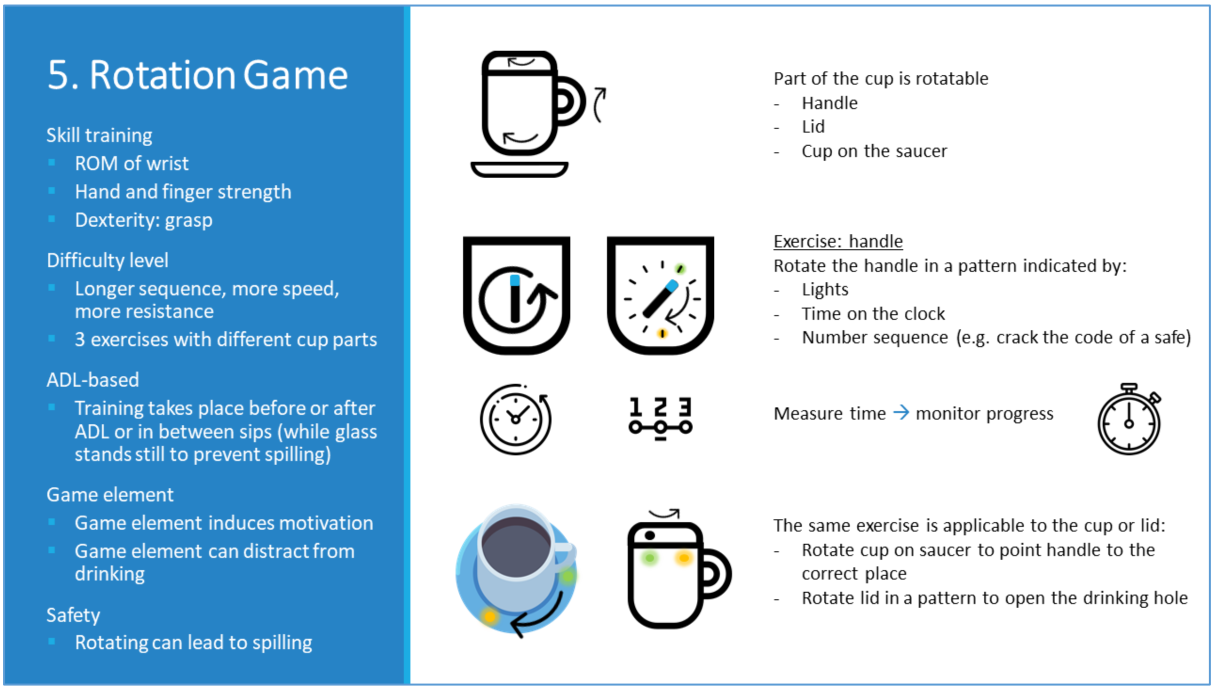


Figure 16. Description of concept 5: Rotation Game.

8.2 Evaluation of concepts

To determine which concepts are most promising, two clinicians were interviewed. Their input was used to evaluate the concepts against the design guidelines.

8.2.1 Interview methodology

Interviews with two clinicians were conducted to get feedback on the concepts and determine which fit best to hand and arm rehabilitation at home.

Both participants have extensive experience in the field of rehabilitation, having worked as physiotherapists with stroke patients. They currently work at Roessingh Research and Development, a research institute focusing on rehabilitation technology. The participants were recruited via this institute.

The interview plan was reviewed and approved by the Ethics Committee Computer and Information Science of the University of Twente. The sessions took place online on 5 and 6 April 2022 and lasted 30 to 45 minutes. They were conducted in Dutch and took place individually. The interviews were semi-structured, with open-ended questions. This enables following up on questions and diving deeper into topics [96]. The interviews were structured along the five phases proposed by Baxter, et al. [96]. The interview protocol, containing the prepared questions and contents, can be found in Appendix 4.

The interview started with an introduction during which participants were welcomed, given instructions, and briefly explained about the project and goal of the interview. Participants were informed that there were no right or wrong answers and that they could always ask questions. They were encouraged to be honest to reduce social desirability bias [96]. Next was the warming-up phase to make participants feel comfortable by asking easy questions to develop rapport. They were asked about their profession in the field of upper limb rehabilitation and how long they had been working in this field. The body of the interview started with a brief explanation of the development of the concepts. Next, the five concepts were presented using slides. Per concept, the participants were asked about their general thoughts on it, strong and weak points, and if it could provide an effective rehabilitation training. After all concepts were discussed, they were asked which ones they found most promising and to list them from most to least promising. When time allowed, additional questions were asked about developing effective training exercises. Afterwards, in the cool-off phase the interviewees were asked if there was anything else they would like to add. Lastly, in the wrap-up phase, participants could ask any remaining questions and were thanked for their participation. The interviews were audio-recorded and the transcriptions can be found in Annex 4 and 5.

The interviews were practiced with a pilot participant during which the concepts were explained and the prepared questions were asked. This was done to ensure that the concepts were clear and questions were interpreted as intended as well as to test the online environment in which the interviews were held.

8.2.2 Interview results

The feedback on the five concepts was analysed for evaluating them vis-à-vis the design guidelines. Moreover, the remarks by the experts that applied to multiple concepts or to training in general were analysed. These findings were used to select the most fitting concepts.

Feedback on concepts

The clinicians provided useful insights into the concepts, including their strong points, weak points, and possible improvements. An overview of the feedback per clinician and concept is provided in Appendix 5. Overall, both clinicians were most positive about the Placemat and then the Interactive Cup, and both disliked the Handles idea. Opinions were less pronounced for the Spout Lid and Rotation Game. The clinicians thought that the Placemat and Interactive Cup were nice ideas, targeted important skills, and offered a fun stimulation to train. They thought the Spout Lid and Rotation Game were rather complex with exercises not sufficiently related to drinking. According to clinician 1, the Spout Lid would serve better as a bottle for training outside the house. The clinicians stated that the Handles concept did not provide a useful skill training and could not be independently used by patients. Clinician 2 thought that patients may be less inclined to perform the Handles and Rotation Game training.

Evaluation of concepts against design guidelines

The feedback of the clinicians was used to evaluate the concepts based on the design guidelines (as presented in section 6.2). Table 9 shows this evaluation per concept, discussing the guidelines that are targeted well ('+') or poorly ('-').

Table 9. Evaluation of the five concepts against the design guidelines.

Guideline	Met?	Explanation
Concept 1: Handles		
Ease-of-use	-	The exercise is not easy to set up for patients independently. They likely require assistance with attaching and detaching the different handles.
Safety	-	The smaller handles may not provide sufficient stability for holding a large, heavy, or filled glass. The handle with separate units for the fingers is not safe because it is difficult to put the fingers into and out of it.
Skill training	-	The exercise does not focus on useful skills. It targets fine motor skills, which most patients lack. So, for most patients it would be too difficult to hold and use many of the handles. The few patients who can perform this training are so good that they hardly need it. It is also unclear which handles train which grasps.
Difficulty	+/-	The handles differ in difficulty level and the user can start with holding the glass with both hands and work towards using only the impaired one. However, the exercise exclusively targets patients with mild impairments but is too difficult for those with moderate impairments.
Feedback	-	It only provides feedback on how long to perform the training but not on correct execution.
ADL-based	+	The exercise stays close to the activity of drinking and can be seamlessly integrated.
Concept 2: Placemat		
Ease-of-use	+	The exercise is easy to set up and execute, only requiring the Placemat.
Safety	+/-	It can be safely used with an empty cup, but a filled cup may lead to spilling.
Skill training	+	It focuses on training range of motion, reach movements, and hand-eye coordination which are important skills. Additionally, it could measure and train smoothness of arm movements.
Difficulty	+	The exercise enables easy adaptation of the difficulty level in different ways. For instance, it could have smaller spots, more distance between subsequent spots, or less time to place the glass.
Feedback	+	It gives feedback on correct placement and potentially smoothness and time.
ADL-based	+/-	The exercise is not directly related to drinking and requires an additional element. As such, it can distract from the ADL. Still, patients get reminded to do the exercise when drinking and it can be done in between sips.
Concept 3: Spout Lid		
Ease-of-use	-	It is not easy to use as it consists of two separate complex exercises which must be performed in order to drink.
Safety	+	The lid prevents spilling if the movements are hard to execute.
Skill training	+/-	The rotation movement is useful, but the movements that the handles train are not.
Difficulty	+	The difficulty level can be changed by increasing the resistance and thus the required force.
Feedback	+	The pressure of both hands is measured and can be compared. When the exercise is done correctly, the reward is being able to drink.
ADL-based	-	It does not have the shape and appearance of a cup.

Concept 4: Interactive Cup		
Ease-of-use	+	The exercise is clear.
Safety	-	The exercise involves pressure and squeezing which can increase the risk of spilling.
Skill training	+/-	Strength and extension are useful exercises. It is good that it combines exercises for hand and fingers, but the finger exercises may be too advanced.
Difficulty	+	There are diverse ways to adapt the difficulty. The user can start with the hand exercises and work towards finger independence exercises and the required force can be increased.
Feedback	+/-	The feedback provides insight into the strength of the patient. However, vibrations should not be used as output because stroke patients can have impaired sensitivity.
ADL-based	+	This exercise can be seamlessly integrated into a glass and drinking activity.
Concept 5: Rotation Game		
Ease-of-use	-	The exercise is complex.
Safety	-	It can increase the risk of spilling due to the rotations (unless the lid is used).
Skill training	+	The rotation movement is useful to train.
Difficulty	+	The difficulty can be adapted by making a longer sequence, increasing the speed, or increasing the resistance.
Feedback	+	Feedback is provided about correct performance and time needed.
ADL-based	-	The exercise is not linked to drinking and trains movements unrelated to drinking. It does not use a regularly shaped glass but one that has added features.

Based on this evaluation, the Placemat meets the most guidelines, while the Handles concept meets the least guidelines. The other three concepts have similar scores, with the Interactive Cup performing slightly better than the other two.

General feedback

The clinicians also provided feedback that transcended the five concepts. Here, the most relevant remarks are discussed. Appendix 5 contains additional feedback.

One of the clinicians 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. Clinician 2 recommended the latter.

One clinician noted that some concepts focus on training actions that are not directly related to drinking. They referred to the Rotation Game but this also applies to the Spout Lid and Interactive Cup. This is not necessarily a downside, but clinician 1 recommended focusing on movements related to drinking. They also highlighted that some concepts clearly add an exercise or even a game. This is the case for the Placemat, Spout Lid, and Rotation Game. In contrast, the Handles and Interactive Cup concepts present more subtle exercises that directly involve drinking and can be seamlessly integrated into the ADL. They had a slight preference for 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.

Another consideration is whether the exercises remain interesting over time and keep stimulating patients to perform them. Perhaps interest in the Spout Lid and Rotation Game decreases over time, while irritation may increase because the exercises must be performed to be able drink.

Finally, one clinician mentioned that it is difficult to determine how long the exercises should be performed. Central to the ADL-based training concept is that there are several training objects at home. Clinician 1 explained that the total training time of these different objects should add up to about 30 minutes, so a few minutes (about 5) of training with the cup may already be adequate.

8.3 Concept selection

Based on the feedback of the clinicians and the evaluation of the guidelines, the concepts with most potential for rehabilitation training are the Placemat and Interactive Cup. Both experts saw most potential in these concepts as they focus on practicing important skills and provide a good reminder and stimulator for training. They had doubts about the other concepts. Additionally, these two scored best on the guidelines, particularly the Placemat.

Both concepts are further developed in the next phases of the design process. Two concepts are considered instead of one because both show potential while differing in an interesting way. So, continuing the design process with both concepts allows exploring their differences and determining which one provides the best training and is preferred by stroke patients. The key difference is that the Placemat presents patients with a clear exercise and involves a game element while the training of the Interactive Cup is more seamlessly integrated into drinking. The Interactive Cup more closely follows the principle of ADL-based training. It only involves a glass, whereas the Placemat adds an element, extending the exercise from the glass to the environment. The Placemat somewhat resembles a conventional interactive gaming exercise.

Overall, the Placemat is more conventional but according to the clinicians more likely to be an effective training object. In contrast, the Interactive Cup is a better representation of ADL-based training. This warrants further development of both concepts.

8.4 Updated concepts

Based on the interview feedback, both concepts are improved. An accelerometer is added to the Placemat to measure smoothness. As described in the kinematic analysis of drinking (section 4.1), arm movements of stroke patients are less smooth than that of healthy people when drinking [48, 49]. So it is useful to monitor and train this. Furthermore, the Placemat now only shows the next spot to place the glass instead of having the complete pattern visible during the exercise.

For changes to the Interactive Cup, the comments on the Spout Lid were also taken into consideration as these were similar to the Interactive Cup. The training concept is simplified by focusing on the complete hand instead of separate fingers. The training now targets squeezing and extending the hand, relinquishing the finger independence exercises as those are too complex and only appropriate for advanced patients. Furthermore, as extension is an advanced exercise, the emphasis is on squeezing so that exercise occurs more frequently. The implementation of the exercises into a handle is discarded as well as the use of haptic feedback. The improved concepts are described in Figure 17 and Figure 18.

An additional advantage of both concepts is that they train the cylinder grasp. This grasp is used to hold a regular glass by wrapping the hand around the base with the thumb in opposite direction to the fingers [30]. As discussed in the Research Topics report [18], this is one of the most common grasps used in ADLs, both in terms of time and frequency [30, 97, 98]. For instance, according Vergara, et al. [30] it is the fourth most used grasp, accounting for 12.3% of all grasps in frequency and 9.4% in time.

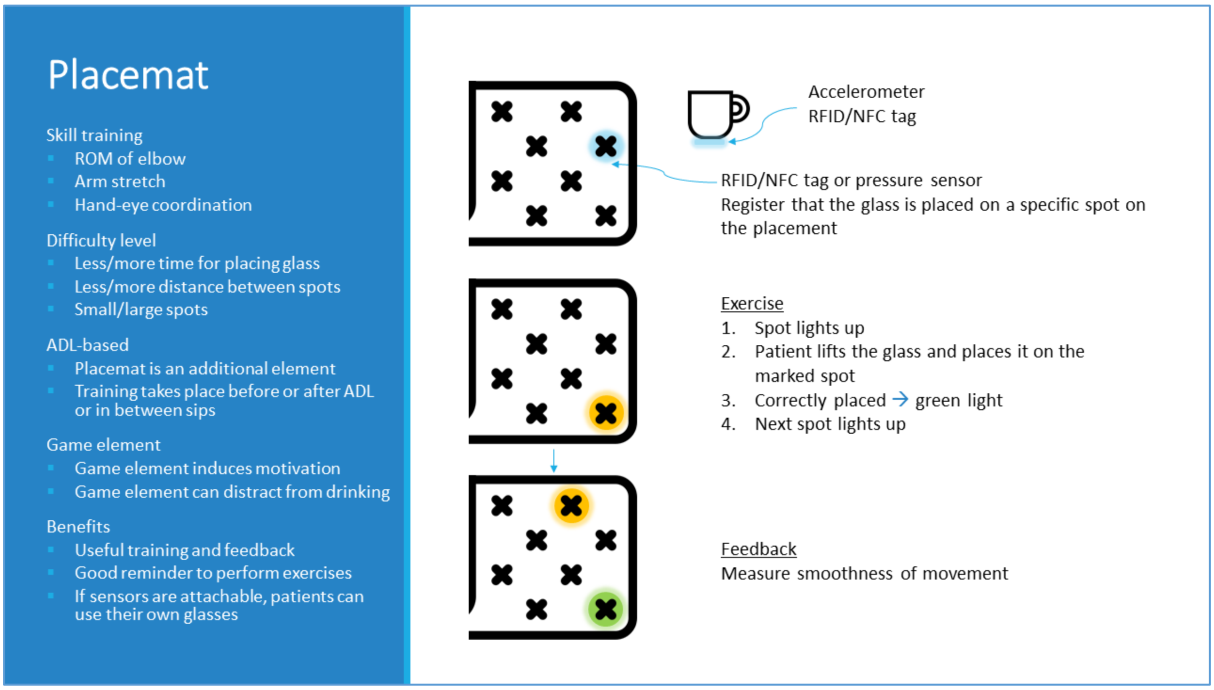


Figure 17. Updated Placemat concept.

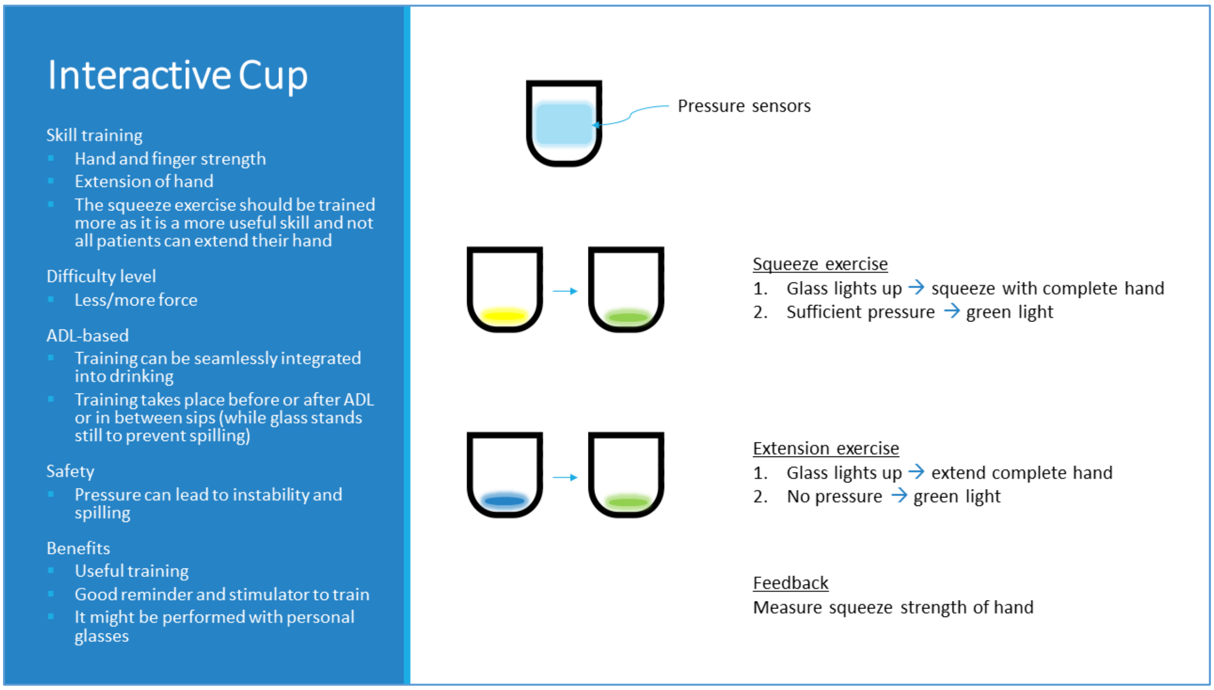


Figure 18. Updated Interactive Cup concept.

8.5 New design guideline

A new design guideline has been added based on the feedback of the clinicians. Clinician 2 recommended allowing patients to use their own glasses instead of providing a specifically designed glass, arguing that people want to use their own glasses for training and that different types of drinks are consumed from different glasses. This was also found in the survey on drinking (section 4.2). People consume different drinks and adapt their glasses to them, using different glasses in a day. So, ideally the training could be performed with different glasses. The clinician suggested to achieve that by providing a sleeve or cover containing the input and output elements.

9 Prototyping

The two selected concepts are developed into prototypes. Note that these are simplified due to time and equipment limitations. The following sections describe the prototypes in terms of hardware and functionality as well as the differences between the envisioned concepts and realised prototypes.

During the prototyping phase, input from supervisors and peers was frequently solicited to improve ease-of-use, clarity, and functionality. Furthermore, a usability test was conducted with peers to receive feedback and improve the prototypes.

9.1 Placemat prototype

9.1.1 Hardware

The Placemat consists of a wooden box and a sleeve that can be attached to a glass, see Figure 19. The box contains 11 microbits, which are programmable mini computers with a LED display, buttons, and sensors [99]. Two microbits allow users to set the settings with buttons, one for difficulty level and one to start or stop the training. The other nine detect if the glass is placed in one of the circles, using the built-in magnetic field sensor, and show feedback using the LED display. The microbits communicate wirelessly via Bluetooth. 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. The box is custom-built using a laser cutter. Circle outlines show where to place the glass and cut-outs show the LED display and buttons. The top is covered with plexiglass to make it easy to clean and reduce damage by spilling.

The sleeve is made of leather and contains a magnet. A Velcro strip allows it to be easily put around glasses differing in size or shape. The Python code used for the microbits is presented in Annex 6.

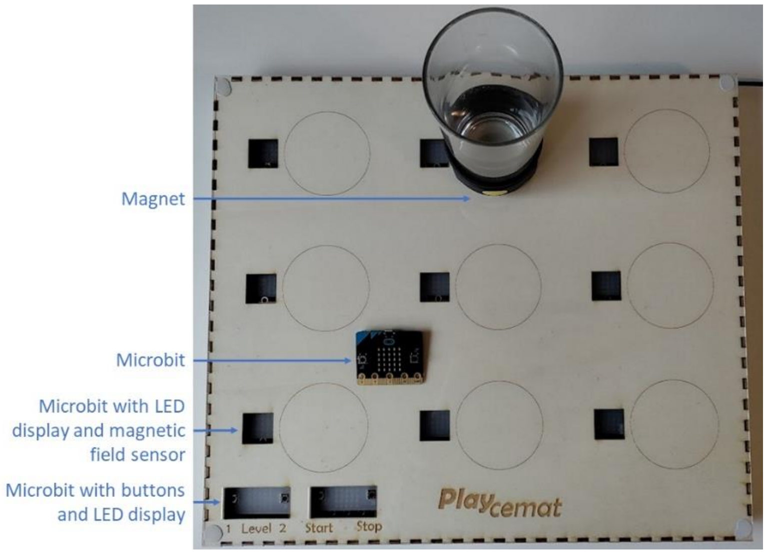


Figure 19. Placemat prototype.

Differences between concept and prototype

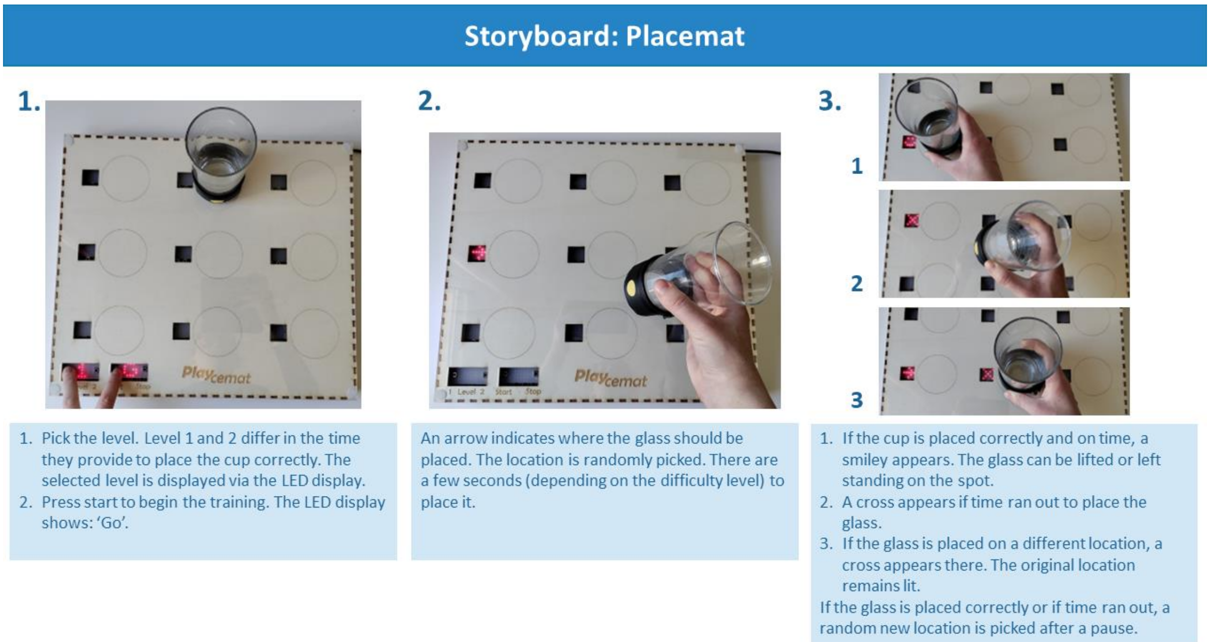
The prototype differs in some respects from the envisioned concept. The accelerometer to measure smoothness was not implemented. It was impossible to obtain a small enough accelerometer in the period available for prototyping. Another difference is that the difficulty level can only be adapted by changing the time available to place the glass correctly. Because of limited time the other two difficulty settings were not implemented, namely adapting the distance between two subsequent spots (to change the required range of motion) and the size of the spots (to change the required precision).

The use of microbits also caused deviations from the concept. Since the microbits contain magnet sensors, these were used instead of RFID tags or pressure sensors. The microbits contain LED displays which light up in one colour but can show different icons. Therefore, the Placemat now uses icons instead of colours for feedback. For instance, a smiley face is used to indicate positive feedback instead of green light.

Finally, as the concept description was not very detailed, additional features were implemented to improve ease-of-use and create a more comprehensive training. For instance, the exercise can be stopped manually and has short pauses between placing the glass and the next spot lighting up. The pauses differ in length (between three to seven seconds) to give a surprise element, keep it interesting, and prevent performing the exercise on autopilot. Furthermore, after completing the exercise, an overview of the performance is provided.

9.1.2 Functionality

The goal of the Placemat is to train range of motion of the elbow as well as hand-eye coordination. The idea is that the training and prototype are explained by a physiotherapist after which the patient can perform it independently at home. The physiotherapist could also receive the performance results and adjust the settings and difficulty level. The storyboard in Figure 20 shows how the Placemat works.



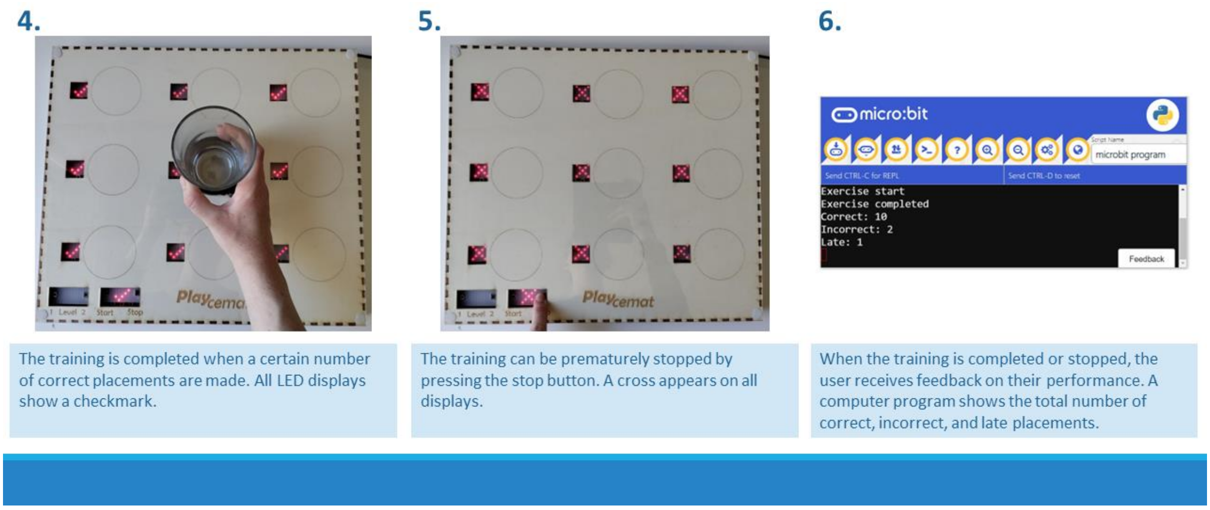


Figure 20. Storyboard explaining how the Placemat prototype works.

9.2 Interactive Cup prototype

9.2.1 Hardware

The Interactive Cup consists of a box with a processing unit and a sleeve that can be attached to a glass, see Figure 21. The box contains an Arduino Uno and breadboard and is linked to a laptop. The box has an on/off toggle switch and a turning knob to set the difficulty level, namely the required squeeze strength. The Arduino code is included in Annex 7.

The sleeve is made of leather and contains two pressure sensors (force-sensing resistors) and a LED strip. These are connected to the Arduino via a wire. The sensors measure the strength by which the user exerts force onto the glass with their hand. The glass has a cylindrical shape to enforce a cylinder grasp. For such a grasp, the thumb provides the largest portion of grasp force followed by the middle finger [95]. The sensors are therefore located on opposite sides 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 indicate which exercise to perform and to give feedback.

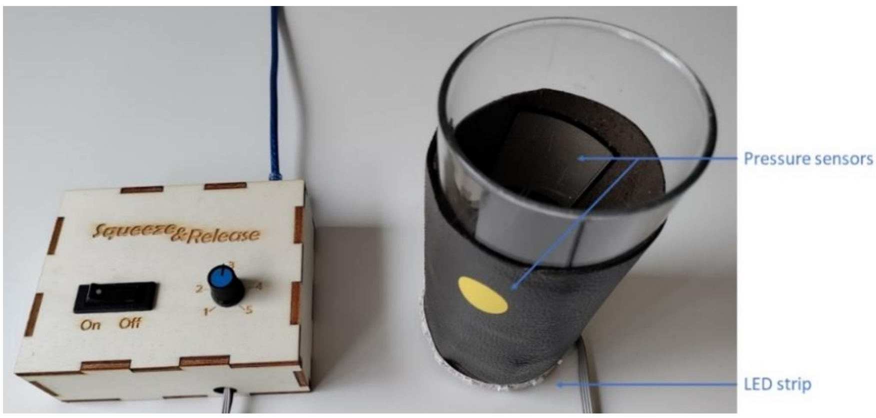


Figure 21. Interactive Cup prototype.

Differences between concept and prototype

One element from the concept was not realised in the prototype. The glass does not function wirelessly. A wire is necessary to connect the LED strip and sensors to the processing unit.

Features additional to the concept were implemented to improve the training. These are similar to the ones added to the Placemat prototype, namely manually stopping the training, presenting a performance overview after the training on a laptop, and creating pauses. These enable the user to take a short break between exercises.

9.2.2 Functionality

The goal of the Interactive Cup is to train hand and finger strength and extension. The idea is that the training and prototype are explained by a physiotherapist, after which the patient can perform it independently at home. The physiotherapist also sets the difficulty level with the knob, which can be adapted based on the performance results. The storyboard in Figure 22 shows how the Cup works.

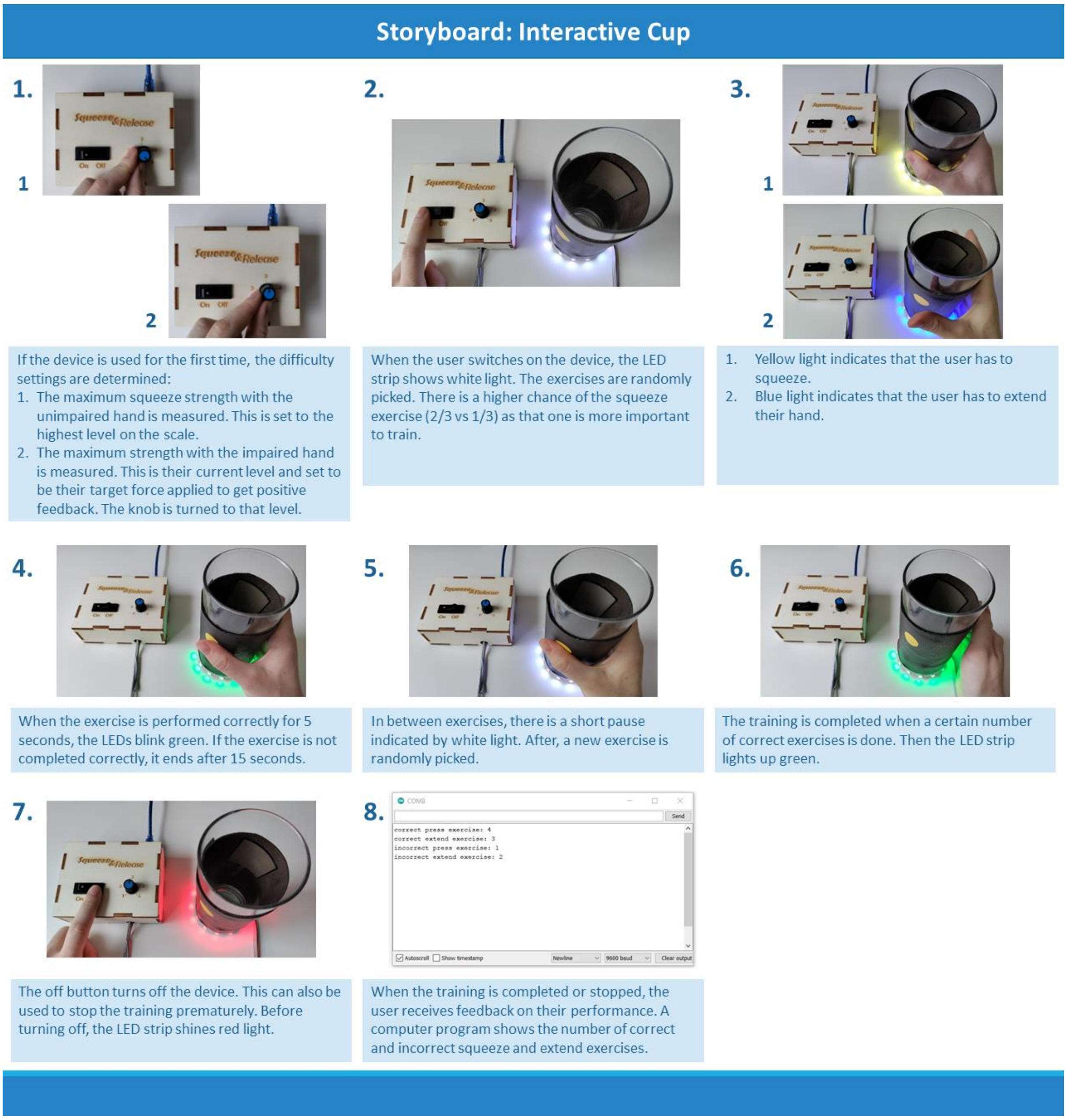


Figure 22. Storyboard explaining how the Interactive Cup prototype works.

9.3 Usability test

A usability test was conducted with healthy subjects to get feedback and discover any issues. This would allow improving the prototypes before presenting them to stroke patients. This test also served as a practice round for the user evaluation and enabled testing if the explanations and questions were clear and interpreted as intended.

The user tests were conducted with three participants on 19 May 2022 and lasted about half an hour. They were conducted in English and took place in-person and individually. They were held at a project room in a university building. The participants were briefly explained about the goal and nature of the test. Next, the prototypes were explained and they were asked to perform the exercises. Afterwards, questions were asked about the prototypes and training. The interview was semi-structured, with both open and closed questions, relating for instance to the ease-of-use, difficulty, feedback, and appearance. An overview of questions and responses is presented in Annex 8.

Based on the issues participants encountered and feedback they provided, adjustments were made. Table 10 shows the issues and changes for both prototypes.

Table 10. Issues encountered in the usability test and the improvements made.

Prototype	Issues	Improvements
Placemat	The magnet sensor did not always register that the glass was placed at the correct spot.	The magnet sensor's sensitivity was increased.
	The time to place the glass correctly at difficulty level two was too short.	The time was increased from two to three seconds.
Interactive Cup	The meaning of the differently coloured lights was unclear. This was especially the case for the feedback light which changed both in colour and brightness.	Lights and feedback were simplified: - White light indicates a pause. - Yellow light indicates the user has to squeeze. - Blue light indicates the user has to extend their hand.
	The white light was too bright.	The brightness was reduced.

After incorporating these adjustments, one new participant was asked to test the prototypes. The lights of the Interactive Cup prototype were deemed clear. Based on their input, a green blinking light was added to indicate positive feedback when the squeeze and extend exercises were performed correctly. The storyboard of the Interactive Cup already contains these adjustments.

10 User evaluation

After the prototypes have been developed and tested on usability, they are evaluated by members of the target group, stroke patients who have or had mild hand and arm impairments. The goals of the user evaluation are to let end users asses the prototypes so they can be improved and to determine the potential of ADL-based training. This chapter describes the method and results.

10.1 User evaluation methodology

Three stroke survivors evaluated the prototypes. Each had experienced or was currently experiencing hand and arm impairments due to stroke, but they differed in various respects, for instance in how long ago the stroke occurred, their abilities, impairments, and recovery process. This reflects the diversity between patients. For example, participant 1 is fully recovered, participant 2 receives treatment and shows progress, and participant 3 no longer receives training but is not fully recovered. None of them suffered severe motor or cognitive impairments at the time of the evaluation. Table 11 shows relevant characteristics of the participants. Two participants were recruited via the Roessingh Centre for Rehabilitation and the third was recruited directly via the researcher of this project, being an acquaintance.

The plan for the user evaluation was reviewed and approved by the Ethics Committee Computer and Information Science of the University of Twente. The sessions took place from 24 to 27 May 2022 and took one hour. They were conducted in Dutch and took place individually. One session was held in a project room in a university building. The other two were conducted at the participant's house at their request. In one session, the participant's partner was present and gave some additional remarks.

The user evaluation was semi-structured, with mostly open-ended questions. This has the benefit of easily following up on questions and giving participants the opportunity to explain their ideas [96]. The user evaluation was structured along the five interview phases proposed by Baxter, et al. [96] as explained in section 8.2.1. They were held in accordance with a predetermined protocol which contained prepared explanations and questions. The protocol is presented in Appendix 6.

The session started by informing the participants about the project and the nature of the evaluation session. They were asked to read and sign the consent form and encouraged to be honest and ask questions if they had any. Next, questions were asked about the participant and their stroke. The body of the evaluation concerned the prototypes. Each prototype was presented and explained, after which the participant performed the training. They were asked various questions about the prototypes, for instance about the strong and weak points, usability, difficulty, and feedback. Some applied to both prototypes, while others were specific to a prototype. Next, some overarching questions were asked. These included if they preferred a prototype and what their thoughts were on ADL-based and drinking-based training. Afterwards, the participants had the opportunity to add something or ask questions if they wished. Lastly, they were thanked for their participation and given a gift voucher of €10.00. The sessions were audio-recorded and the transcriptions are included in Annex 9-11.

Table 11. Overview of characteristics related to the participant, stroke, and stroke effects.

Characteristic	*Participant 1*	*Participant 2*	*Participant 3*
Age	50	64	64
Gender	Male	Male	Male
Stroke	Dec 2020 (1.5 years ago)	Sept 2021 (8 months ago)	Nov 2011 (11 years ago) Nov 2012 (10 years ago) June 2014 (8 years ago)
Affected side	Left	Left	Right
Dominant side	Right	Right	Right, but switched to left due to the stroke
Initial effects	Paralysis on left side, including arm, hand, leg, and mouth	- Paralysis on left side, including arm, hand, leg, and mouth - Different voice	- Paralysis on right side - Speech impairment - Short term memory loss - Reduced skills in upper limb
Current condition	Almost completely recovered	- Mostly recovered - Reduced sensation and tingling feeling in the left side - Reduced hand and arm abilities, e.g. less strength - Experiences more difficulties when tired, e.g. with walking, talking, and muscle control	- Somewhat recovered - No more progress - Reduced hand and arm abilities, e.g. tremor, less strength, control, and fine motor skills
Rehabilitation training	Completed training	Physiotherapy twice a week	Completed training
Motivation to do exercises	High	High	High initially, but declined when progress was no longer visible
Drinking	No difficulties, can drink normally with the impaired hand	- Can grasp a glass and drink with the impaired hand - Walking with filled glass is hard without spilling - Less strength, precision, control, and sensation	No longer drinks with the right hand, but with the left. Same for filling the cup and using the tap

10.2 User evaluation results

Information gathered during the user evaluation was analysed. Firstly, feedback on the prototypes was studied which included various points of improvement. The feedback was used to determine to what extent the design guidelines were implemented in the prototypes. Secondly, feedback applying to both prototypes or rehabilitation training in general was analysed.

10.2.1 Feedback on prototypes

The user evaluation provided insights into the prototypes, their advantages, disadvantages, and improvement points. A complete overview of the feedback is provided in Annex 12, in which the feedback is categorised per participant and question. A summary of this is presented in Appendix 7.

Overall, the participants responded positively to both prototypes. They considered them well-developed concepts and easy to use and understand. They appreciated that both provided clear feedback and that the difficulty level could be adapted to their abilities. All participants preferred the Placemat prototype because of the game elements which made it more fun, varied, motivating and challenging, even over time. They also thought it provided a more useful training, targeting important skills such as hand and arm movements, hand-eye coordination, and cognitive skills. The Interactive Cup was deemed too simple and lacking a playful element which could quickly reduce motivation and interest. Two participants also questioned the usefulness of the training. Although they acknowledged the importance of training strength, squeezing and extension, they found it unintuitive to do this with a glass. Their main concern was that it lacked functional exercises related to drinking or a glass. Two participants indicated that they would perform the Interactive Cup training if recommended to them and the third would only do so if functional exercises were added. In comparison, all participants would be willing to perform the Placemat training.

10.2.2 Implementation of design guidelines

Based on the feedback of the participants, the application of the design guidelines (section 6.2) in the prototypes is evaluated. Table 12 describes this per guideline.

Table 12. Evaluation of the implementation of the design guidelines into the prototypes.

Guideline	Evaluation
Ease-of-use	The participants thought both prototypes were easy to use and understand. They only require attaching the sleeve and could be independently used at home. They also stated: - The feedback from the displays of the Placemat was intuitive. Using common icons made it easy to understand how the exercise works, but the Placemat was large and high, the LED displays were difficult to see for people performing the exercise with their left hand (as they are placed left of the circles), and the magnet sensors were not reliable enough. - The differently coloured lights of the Interactive Cup were clear, but it could be tiring and uncomfortable to squeeze the glass for extended periods. The glass was not wireless which reduces the usability.
Safety	Although all participants thought both trainings could be performed safely, even if the cup contained liquid, they pointed out that: - The Placemat should be fully waterproof. - Squeezing the Interactive Cup might lead to spilling and breaking the glass.
Skill training	- The Placemat provided a useful training of important skills, including range of motion, hand and arm movements, hand-eye coordination, and cognitive skills. - The Interactive Cup provided a less useful training. Although the targeted skills were important, they were not functionally related to drinking.
Difficulty level	Both prototypes enabled adjusting the difficulty level of one variable (time or strength) to the patient's abilities using a button or knob. The participants suggested adding more difficulty settings.
Feedback	Both prototypes provided direct visual feedback indicating correct or incorrect performance. Feedback on the overall performance was provided at the end of the training session but was not tracked across sessions. So, it did not show progress over time.
ADL-based	Both prototypes involved a glass and related to drinking, but the participants indicated they could also be performed separately from drinking. They also stated that: - The Placemat added an additional element that was not part of regular drinking activities. - The exercises of the Interactive Cup were not functionally related to drinking.
Personal glasses	Both prototypes had a sleeve enabling users to use their own glasses.

The feedback showed that all guidelines were implemented to some extent in the prototypes. The participants provided various suggestions for improvement, for instance regarding ease-of-use and safety. Some guidelines were implemented in similar ways in the prototypes. For example, they both enabled adjusting the difficulty level of a variable, provided direct and overview feedback, and had an attachable sleeve. This resulted in similar feedback for both prototypes. There was one major difference. The training provided by the Placemat was considered beneficial whereas the Interactive Cup training was considered less beneficial as it was not functionally linked to drinking.

10.2.3 Recommended improvements

Various points of improvements were suggested in the evaluation (see Appendix 7 and Annex 12 for more details), which are summarised below.

Placemat

1. Ease-of-use
    a. The device should be less high to better resemble a placemat and not force users to lift their arm too much.
    b. The LED displays should not be positioned to the left but below the circles to be visible when users perform the exercise with their left hand.
    c. The magnet and magnetic field sensor are unreliable. It may be better to use a pressure sensor. This means it is no longer required to use a sleeve with magnet.
2. Safety: The buttons and LED displays of the 'start/stop' and 'level' microbits should be waterproof so the training can be safely performed with a filled cup.
3. Skill training: Smoothness of arm movements can be measured and trained by adding an accelerometer and providing feedback on it. This feature was also recommended by both clinicians and included in the Placemat concept.
4. Difficulty level
    a. The time to place the glass correctly can decrease and distance between subsequent locations can increase with rising difficulty levels. In later rehabilitation stages, the precision with which patients place the glass can be trained. The difficulties would then be speed: low/high; distance: low/high; and precision: low/high.
    b. The difficulty level can also be increased by filling the cup with liquid. An additional advantage is that this makes the glass heavier, thus training strength.
5. Feedback
    a. More intuitive colours should be used for feedback, such as a green smiley and red cross, instead of using the same colour.
    b. Instead of showing the number of correct, incorrect, and late placements, one score reflecting the overall performance is more insightful and easier to interpret. This score should be recorded and an app should enable users to monitor their performance over time via this score.
    c. The performance on individual locations of the Placemat should be recorded and provided to the physiotherapist so they get a better grasp of the areas that require more training.
6. Game element: The game element can be increased by adding existing games such as tic-tac-toe or memo or adding new games. For instance, the LED displays could show images related to a topic the user likes and they have to place the glass on a specific subsection (e.g. only yellow flowers). These games could be played alone or against a computer or family member.

Interactive Cup

1. Ease-of-use: All electronic elements should be contained within the glass to make it wireless. This is most likely not possible for an attachable sleeve, so it is recommended to make it a specifically designed training glass with a processing unit at the bottom.
2. Skill training: Aside from squeezing and releasing, the cup should provide exercises that are more closely related to drinking or using a glass. These can include grasping a glass, lifting it,

rotating it, and emptying it. This requires new sensors, such as an accelerometer and weight sensor. The physiotherapist will inform the patient which exercises are relevant to them.
3. Difficulty level: The required squeeze force can increase and the duration and frequency of pauses can decrease with rising difficulty levels.
4. Feedback: Instead of showing the number of correct and incorrect exercises, a score reflecting the overall performance is more insightful. This makes it easier to keep track of progress than the number of correct exercises. This score should be recorded and an app should enable users to monitor their performance over time via this score.

10.2.1 General feedback

Some feedback transcended the two prototypes and applied to both or to rehabilitation training in general. These topics are described in the following sections.

Training with non-dominant side

Drinking is commonly done with the dominant hand but can be performed with the non-dominant hand, as the survey results showed (section 4.2). This was also expressed by the participants whose non-dominant side was most affected by stroke. They were willing to perform the exercise and drink with the non-dominant hand if it could help towards progress.

Training moment

The participants differed in how they would integrate the training into drinking activities. Participant 1 preferred to do it before drinking, so drinking forms the reward. Participant 2 recommended using an empty cup before drinking in earlier rehabilitation stages. When progress is made, a filled glass could be used and sips could be taken as a reward. According to participant 3, the training should take place while drinking to better resemble the realistic drinking setting. All participants stressed that both trainings could be performed safely with a filled glass.

Personal glasses or designated training glass

Participant 2 had a clear preference for using personal glasses, arguing that as training takes place at home, it should teach using your own equipment. Another advantage is that this allows practicing with glasses of varying weights and shapes which require different grasps and movements. The other participants had no preference.

Functional skill training

Two participants highlighted the importance of functional training. They thought drinking-based training should be directed at improving functions related to drinking. They explained that while the Placemat does this, the Interactive Cup does not as we do not normally squeeze glasses. They suggested adding exercises to the Cup related to drinking, like rotating or filling the glass. The two participants indicated that functional training is more motivating as it is clear how the exercise helps executing regular tasks. Participant 2 also considered functional training to improve independence.

Difficulty level

All participants mentioned the significant differences in skills between early and later rehabilitation stages. As patients advance in the rehabilitation process, their abilities advance as well. Participant 3 emphasised the large differences in impairments and progress between patients. Therefore, they all stressed the importance of adapting exercises to different levels of skill. There should be a balance between the skill of the patient and the difficulty of the training, so the exercise is sufficiently challenging to be stimulating but not too challenging to become frustrating or confronting.

Direct and progress feedback

All participants emphasised the importance of direct feedback and progress feedback. Direct feedback shows if an action or exercise is correct, while progress feedback shows development over time. All participants wanted progress to be shown in an app. They all highlighted the importance of visually seeing your development, as this is motivating. Participant 2 explained this is helpful because it is difficult to notice your own improvement and remember how your performed before. The participants also wanted feedback to be available to the physiotherapist so they get a better grasp of the development and which muscle groups should receive more attention.

Game element

The three participants valued game elements in the prototypes. The playful way of learning with the Placemat was found to be motivating and challenging. Participant 2 indicated that game elements add variation, train cognitive skills, and keep the training interesting over time. Two participants even suggested adding more game elements to the Placemat. Participant 1 considered game elements unnecessary as they would want to perform the training anyway.

Social comparison

Participant 1 considered it useful to have an app showing your own progress as well as that of other patients, as this could be motivating. However, the other participants strongly advised against this, stressing that training should not encourage social comparison. Participant 3 pointed to the fact that every patient's rehabilitation process is different and comparing oneself is not beneficial. Each participant emphasised that any competition should be against your previous self and stimulate improving on past performances instead of competing against others.

ADL-based training

Each participant saw benefits in the ADL-based and drinking-based rehabilitation training. Two mentioned that many ADLs, and drinking in particular, are routine-based which means it is likely that the training becomes part of the routine. This way, the ADL is a reminder to train. According to participant 1, this reminder function can be particularly beneficial for patients with cognitive impairments. Participants 2 and 3 considered as a benefit of ADL-based training that it enables functional training of the skills used in the ADL.

Although participant 2 expressed enthusiasm for performing ADL-based training, the other two had more reservations. Participant 1 mentioned that because of their high motivation, the training did not need to be integrated into an ADL. Patients who are motivated to improve hand and arm functions would perform the training regardless of ADL integration, grasping any opportunity to improve. Still, participant 1 acknowledged that for patients with less intrinsic motivation it may be helpful. Participant 3 considered that although the concept was nice, they switched from being right-handed to left-handed many years ago and would not switch back now to perform the exercise and drink with the impaired hand. They thought training was not useful because progress was no longer possible.

11 Discussion

This chapter describes the lessons learned in this project. It discusses relevant findings on ADL-based training, recommends guidelines for the development of (ADL-based) rehabilitation technologies, reflects on the used methods and their limitations, and offers directions for further research.

11.1 ADL-based training

The potential of ADL-based training for home rehabilitation has been explored in this project. This section discusses the implications of the benefits and concerns identified in this research. It also describes two directions that can enhance ADL-based training.

This project set out to explore the development and design of interactive ADL-based training objects in the context of hand and arm rehabilitation of stroke patients at home. While home rehabilitation plays an increasingly more important role in stroke care, it is characterised by low adherence which reduces treatment efficacy. ADL-based training is a novel strategy that aims to counter this issue by integrating training into daily activities, thus potentially reducing the motivation and barriers associated with training and improving training outcomes and adherence. This project explored the possibilities of ADL-based training to contribute to filling this gap in literature and rehabilitation practices.

Through the design of two working training prototypes, this project shed light on how rehabilitation exercises can be integrated into daily activities. It has shown that this is possible for the ADL of drinking and that ADL-based training can offer a viable rehabilitation strategy that directly uses ADLs as training interventions. This strategy differs from current rehabilitation technologies as these focus on monitoring or assisting ADLs rather than training them, such as the SyMPATHy glass [24]. It also differs from current training practices that often provide exercises that indirectly rather than directly target the execution of ADLs, such as the VR-based training cup [95]. So, this project contributes to the current body of knowledge by laying the foundations of a rehabilitation approach that uses ADLs as training interventions.

11.1.1 Benefits

This study indicates that ADL-based training has various advantages. For example, the user evaluation participants argued that most ADLs are routine-based, making it likely that the training becomes part of the routine. This is supported by Neibling, et al. [27] and Kytö, et al. [26] who 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. So, ADLs provide good reminders to train routinely, which may be especially helpful for patients with cognitive impairments.

Another benefit participants recognised is that ADL-based training lends itself particularly well to functional training. This is supported by stroke professionals who explained that ADLs at home provide functional and meaningful training opportunities that can be performed throughout the day [9]. Finally, linking rehabilitation technologies to daily activities was also recommended by Vourganas, et al. [10], as it can increase motivation, engagement, acceptance, and adherence.

11.1.2 Possible concerns

ADL-based training is not only associated with benefits. The user evaluation provided a nuanced perspective as the participants also raised concerns. One participant stated they would perform the training before drinking or even separately from drinking and suggested using different objects than a glass for the Placemat training. This indicates that the training may not be integrated into the ADL as intended. This project has not studied how the prototypes are implemented by patients and if they perform them as part of drinking.

The user evaluation highlighted the diversity between stroke patients. The ADL-based training concept may not be applicable to all. One participant endorsed the concept while the others had more reservations. Findings from the evaluation indicated that it may be most suitable to patients with lower intrinsic motivation as it reduces the required motivation and training barriers. However, it may be less helpful for those with high motivation because they are sufficiently motivated to train regardless of whether it is integrated into ADLs. On the one hand, the ADL-based concept can still offer them benefits, such as functional skill training and the clear application of training to real-life activities. On the other hand, the integration could hinder or distract from the ADL or vice versa. The target group that can benefit most from ADL-based training should be studied further.

11.1.3 Directions for ADL-based training

Based on the findings, there are two promising avenues that can enhance ADL-based training: gamified and seamless ADL-based training. Both come with distinct characteristics, target groups, and advantages. Interestingly, the two avenues seem incompatible with each other. Game elements make the training more visible whereas the seamless strategy focuses on integrating the training intuitively and almost unnoticeably into ADLs.

Gamified ADL-based training

The first strategy focuses on incorporating game elements into ADL-based training. This was identified as a potential strategy because the user evaluation participants appreciated the game elements in the prototypes. They explained that these add variation, improve cognitive skills, and make training more fun and motivating even over longer periods of time. This is in line with prior studies [13, 75, 76] which found that game elements create more engaging, motivating, and challenging training experiences. So, ADL-based training could be enhanced by including game elements or games. The Placemat fits this strategy as the participants already thought it had game elements, such as the smiley face reward.

The gamified ADL-based approach may be particularly relevant for motivated stroke patients. They are already sufficiently motivated to train and do not necessarily require the integration into ADLs to reduce training barriers. Instead, the game elements can improve their experience and make ADL-based training more engaging.

A downside of the gamified approach is that diverges from the ADL-based concept. It emphasises the gaming experience but de-emphasises the connection to the ADL. The challenge, therefore, is to incorporate game elements into the training without distracting and separating it from the ADL.

Seamless ADL-based training

The second direction, which has been identified as promising by Stefess, et al. [17] as well as the interviewed clinicians, is to ‘seamlessly’ integrate training into ADLs. Seamless refers to the training providing an intuitive interaction, fitting with the context, and blending in with the ADL [17]. An example is having to hold an electric toothbrush with sufficient force. Only then it functions. Holding it with less force, turns it off. The difficulty level (i.e. required strength) can be seamlessly adapted to the patient's abilities via machine learning instead of requiring the patient to set the level.

The Interactive Cup best resembles the seamless concept. Rather than presenting an obvious training task it blends in with the ADL and can easily be performed during it. Although the skills it trains are not functional to drinking, thus lacking an intuitive interaction, this training can be adapted or applied to more fitting objects that require squeezing (e.g. bottles and jars to squeeze out the contents). This would make the squeezing training more intuitive.

The seamless approach may be most suited to patients with low motivation. For this group, training barriers may be too high for conventional exercises, but perhaps not for seamless exercises. As seamless training only minimally deviates from the regular ADL, it reduces training efforts to a minimum. This may, for example, be an appropriate strategy for patients who no longer show progress. One of the participants reported having no motivation to train because of lack of progress. However, training can still be beneficial for preventing decline as one of the clinicians explained. The seamless approach may be beneficial to this group as it requires less effort.

A downside of this approach is that it may not provide effective training. The training should be both seamless and train skills. So the challenge is to modify the ADL in such a way that it remains fundamentally the same while also providing sufficient training.

The user evaluation participants preferred the Placemat over the Interactive Cup. Although the game element played a role in this, it cannot be concluded that they preferred the gamified approach over the seamless approach as this was not explicitly tested and the prototypes differ in more respects. Both approaches can be further explored, compared to each other, and tested with the mentioned target groups.

11.2 Recommended design guidelines

This study has implications for the design guidelines presented in section 6.2. Based on the user evaluation results, most guidelines remain the same, some are modified, one is removed, and a new one is proposed. This results in recommended guidelines for future works in the field of interactive (ADL-based) rehabilitation technologies. They are listed in Table 13 and explained below.

Table 13. Overview of recommended design guidelines.

Recommended design guidelines
Ease-of-use
Safety
Difficulty level
Functional skill training
Direct and progress feedback
ADL-based training
Avoid social comparison

11.2.1 Reflection of design guidelines

Ease-of-use, safety, and difficulty level

Based on the user evaluation, the guidelines on ease-of-use, safety, and difficulty level remain as presented in section 6.2. The 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. [25] and Pickrell [74]. As outlined in section 6.2, the difficulty level of the training should be adaptable to the skills of different patients as well as to the progression patients make over time to ensure a balance between skill and difficulty. This is supported by the user evaluation participants, the clinicians, and literature [27, 76, 77]. So, it should be easy for therapists or patients to change difficulty settings or alter the rehabilitation technology to support individual needs [16].

Functional skill training

This guideline is modified in two ways based on the user evaluation. Firstly, the skills to be trained are not limited to the three discussed in chapter 5 (strength, dexterity, and range of motion). They can also include hand-eye coordination and cognitive skills. Secondly, the participants emphasised that the training should be functionally related to the ADL. Originally, the idea was that there did not have to be a direct link. The training could target a skill required for a different ADL, as is the case for the Interactive Cup. However, the participants and one clinician argued that the drinking-oriented training should focus on improving skills related to drinking, like wrist movements. The participants considered functional training more motivating because of the clear connection between the training and execution of real-life tasks, which is confirmed by Kytö, et al. [26] and Bach-y-Rita, et al. [100].

To give an example, if a patient has difficulties performing an ADL, like combing their hair, then the training the comb provides should train the ADL, thus improving their performance. This functional training concept resembles task-oriented training, which is a common training principle that focuses on repetitive training of functional, i.e. skill-related, tasks or subtasks [76, 77, 101]. This has been shown to have a positive effect on hand and arm function in stroke patients [77].

Direct and progress feedback

Based on the user evaluation findings, it is recommended to provide both direct feedback and progress feedback. This distinction is made because they serve different goals. Direct feedback immediately shows if an action or exercise is performed correctly which stimulates learning [10, 27, 76, 77]. Progress feedback enables patients to see how they develop over time which improves motivation. This is supported by literature [27, 74]. Both types are relevant to home rehabilitation because they motivate patients and help them perform exercises correctly in the absence of a therapist who would otherwise provide this. The participants recommended providing direct feedback via the interactive training object and progress feedback via an app. They suggested sharing feedback with physiotherapists, as recommended in some studies [76, 102].

ADL-based training

As the focus of this project is on ADL-based training, this guideline remains important but the concept, potential concerns, and two future directions should be further explored to determine if ADL-based training is beneficial and should be recommended.

Personal glasses

One of the clinicians suggested that patients should be able to train with their own glasses. However, this was not confirmed by the user evaluation participants. Hence, this guideline is excluded. Instead, it is recommended to consider the technical feasibility. Training objects that require various sensors and output elements, like the Interactive Cup, are difficult to integrate into an attachable sleeve. In such cases, a specifically designed glass is more feasible. In other cases, like the Placemat, it can be easier and more beneficial to develop a sleeve and allow users to train with personal glasses.

Avoid social comparison

The input from the participants has led to the formulation of a new guideline, namely avoiding social comparison. Although Neibling, et al. [27] stated that social interaction, for instance competition between patients of similar abilities, can increase engagement, the participants strongly advised against this. They argued that training should not promote comparison to others, as this may not be constructive, but should focus on comparing one's own past and present performances. This is in line with a design criterion for stroke rehabilitation technologies proposed by Pickrell [74].

To conclude, this project contributes seven design guidelines. They lay the foundation for the development of interactive ADL-based training objects and offer a guide for transforming daily activities into rehabilitation activities. As the guidelines are broad and supported by literature on stroke rehabilitation technologies in general (see section 6.2), they may also be more universally applicable to the design of rehabilitation technologies.

11.3 Limitations

The methods used in this project are characterised by some limitations. Overall, the involvement of stroke patients was limited. They were only involved at the end of the design cycle to provide feedback on the prototypes. They could have been involved earlier in the process to better understand their needs and wishes. For instance, the context of drinking was studied with healthy individuals. This may have given an incorrect representation of the ADL as drinking may be experienced differently by stroke patients and be associated with different settings or actions. Furthermore, stroke patients could have been involved in the ideation phase through a co-design session to gather their input on skill training and object design and implement this in the design process.

To guide the process, broad design guidelines were used rather than specific requirements. This was done because this study centred around the development of training concepts and these could be realised in diverse ways, largely dependent on access to available technology. A downside of this is that broad guidelines do not offer a clear tool for evaluating the prototypes. The specificity of requirements is better suited for this. For the purposes of creating prototypes the guidelines provided sufficient direction, but if they are further developed, requirements are necessary to ensure the training objects meet important criteria and can be 'objectively' assessed.

Next to the guidelines, personas were formed to guide the design. However, they were not actively used throughout the process, for instance to ensure that the concepts or prototypes fit the needs and goals of patients. They could have been better utilised to improve the design. Still, the process of creating the personas was insightful. Translating abstract stroke-related facts into concrete patients provided a better grasp of how stroke can affect a person, their activities, and surroundings.

The design circle was limited to one iteration, which meant the prototypes remained simplistic. For example, not all elements of the envisioned training concepts were implemented. The prototypes could be further developed and improved based on the feedback of the participants. This would entail a more iterative design approach and evaluating the prototypes with end users after each iteration. This way, the prototypes would be better adapted to their needs.

The user evaluation showed two important limitations. Three participants are too few to provide a good representation of the target group. Moreover, one test session in an experimental setting rather than a longer testing period in a more natural context is insufficient.

Lastly, this project had a limited scope. It explored how training can be integrated into ADLs but did not test the rehabilitative impact of ADL-based training and how people use it at home. The concept is about patients having multiple ADL-based training objects at home providing them with diverse exercises throughout the day. However, this project involved one ADL and two objects so it was not possible to accurately test the participants' perceptions and use of ADL-based training. Furthermore, this research is based on the assumption that ADL-based training requires less time, motivation, and effort compared to conventional training and can thus improve training adherence. But this assumption was not tested.

11.4 Recommendations for future work

The findings and implications of this study allow for recommendations for further research endeavours. It is particularly relevant to study the implementation, training efficacy, suitable target group, and future directions of ADL-based training.

It is important to understand how the prototypes and ADL-based training objects are adopted by stroke patients at home. How do they integrate the exercises into their daily routines? Do they continue training over time? This could, for instance, be tested by providing stroke patients three different ADL-based training objects, each linked to a specific ADL, and letting them use these at home for several days. Testing with a large number of participants in the home environment over a longer time period provides more representative results. Additionally, this enables investigating the assumption underlying this research, namely that ADL-based training reduces the efforts associated with training and improves adherence. This assumption should be tested to determine if ADL-based training can address the issue of low adherence to home rehabilitation any better than conventional strategies.

As the main goal of rehabilitation is to improve functional outcomes or prevent decline, clinical evaluations are required to determine the rehabilitative effect. The treatment efficacy partly depends on the training duration. The duration of ADL-based training follows the time spent on the ADL rather than strict guidelines. The advantage is that this poses less time constraints but the disadvantage is that ADLs may not provide sufficient training to have a positive effect.

It is also important to refine the target group. Findings from the user evaluation indicate that ADL-based training may be most suitable to patients with low intrinsic motivation and less suitable to those with high motivation. ADL-based training should be studied with a large number of patients, including those with low and high motivation, low and high availability of time, and those who can still improve and those for whom training can only prevent loss of skills. This way, the group that can benefit most from ADL-based training can be determined.

The training concept can be taken into two promising directions, gamified and seamless ADL-based training. The former focuses on enhancing the ADL-based concept by improving the experience and motivation via game elements. The latter focuses on reducing training efforts by creating an intuitive training that blends in with the ADL. As they are associated with different benefits and challenges it is useful to explore both. It is particularly relevant to study their target groups as it seems the gamified approach is suitable to motivated patients and the seamless approach to less motivated patients.

Overall, future works can investigate these directions to determine the potential and efficacy of ADL-based training, compare it to conventional strategies, and explore new avenues. This contributes to a better understanding of ADL-based training, which is needed before it can be recommended as a rehabilitation strategy.

12 Conclusion

This Graduation Project built on the Research Topics report [18], and introduced and explored the concept of ADL-based technologies for hand and arm rehabilitation after stroke. Home rehabilitation plays an integral part in stroke care but is faced with a key issue. It is characterised by low adherence which reduces the efficacy of treatment. Therefore, this study explored a novel rehabilitation strategy that could tackle this issue. By making use of training opportunities present in people's daily lives, ADL-based training can potentially reduce the time, motivation, and barriers associated with training, thus enhancing training adherence and outcomes.

Through the design of two interactive ADL-based training objects for drinking, the Placemat and Interactive Cup, this project illustrated the possibilities of translating daily activities into rehabilitation activities to improve hand and arm functions. It explored the potential of using ADLs directly as rehabilitation interventions. While current practices focus on exercises that indirectly target ADLs, this study illustrates that ADLs themselves offer functional and meaningful training opportunities. Additionally, it highlights that rehabilitation technologies do not have to be limited to monitoring or assisting ADLs but can be used for training ADLs. By showing the potential of interactive ADL-based interventions, this study contributes to filling the gap in literature and current rehabilitation practices.

This study laid the foundations for ADL-based rehabilitation by offering design guidelines. These are based on the user evaluation and rehabilitation literature. They are ease-of-use, safety, difficulty level, functional skill training, direct and progress feedback, ADL-based training, and avoiding social comparison. It is particularly important that ADL-based training improves functions related to the ADL. These guidelines provide a tool for transforming daily activities into rehabilitation activities. Future works are recommended to take them into account when developing ADL-based training objects. As the guidelines are broad, they may also be applicable to rehabilitation technologies in general.

The user evaluation findings indicated that ADL-based training offers a viable option for rehabilitation training and has various benefits, such as the integration into routines, increased motivation, and functional skill training. However, the participants also raised concerns. Because of the limited scope of this study, these concerns were not fully explored. For instance, it is unclear how patients adopt the training at home and which patients can benefit most from it. Other directions to be investigated are whether ADL-based training reduces efforts associated with training, improves adherence, and has a positive impact on treatment outcomes. Based on the present work alone, it is not yet possible to draw conclusions on this.

This research identified two directions that can enhance ADL-based training. The 'gamified approach' uses game elements to improve the motivation and training experience. The 'seamless approach' creates intuitive training experiences to reduce the training barriers to a minimum. The former seems most suitable to motivated patients and the latter to less motivated patients. This project paved the way for ADL-based training on which further works can build by investigating these two avenues as well as the possible concerns. This contributes to a better understanding of the potential and efficacy of ADL-based training, which is needed before it can be recommended as a rehabilitation strategy.

If further research demonstrates the positive impact of ADL-based training on hand and arm rehabilitation and training adherence, this could lead to a shift in home-based rehabilitation practices. Training would no longer require setting aside time, training at a specific location, and high intrinsic motivation. Patients simply need to perform their regular activities and at the end of the day they have executed a diverse range of exercises. If successful, this strategy could be applied to rehabilitation more broadly, for example hand and arm impairments caused by other medical conditions or different stroke-induced impairments. ADL-based training could bring about a paradigm shift in the field of home rehabilitation.

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Appendices

Appendix 1: Justification of excluded ADLs

Criteria were set up to determine the most viable ADLs for developing training opportunities. From the top ten ADLs, 'eating with knife/fork' and 'cup to mouth' met most criteria (see Table 2 and Table 3) and were thus considered for the next stages of the project. The other eight met less criteria and were excluded. Below follows an explanation per ADL as to why it is excluded due to the criteria it did not meet.

1. 'Holding object while walking' may not be performed for long periods of time at home. This ADL is also not associated with specific daily-used objects which makes it difficult to design a training object that integrates smart technology.
2. 'Keyboard work' is not necessarily performed by any stroke patient for long durations or high frequencies on a daily basis. It is also possible that keyboard work is not performed at home but rather at work. Next to that, it may require a high level of attention and focus. This may make it difficult to perform a training task at the same time without distracting or hindering the original ADL.
3. 'Taking money from purse' is an ADL that is generally performed outside the home and is associated with short durations and low occurrence frequencies. It may therefore not occur frequently enough and for sufficiently long durations at home to provide an effective training. In addition, it requires some attention to make sure the right amount of money is collected, making it more challenging to perform a training task simultaneously.
4. 'Open/close clothing' is associated with short durations and may not occur frequently enough to provide an effective training. Next to that, this ADL is associated with a variety of objects. It can be done in many ways with various fastening objects, such as a zipper, button, belt, and drawstring. This makes it more challenging to design a specific training object that integrates smart technology.
5. 'Grooming' represents a broad category of ADLs. This means it is unclear which specific grooming activities stroke patients want to train on. Furthermore, many activities that belong to grooming were measured separately in the study of Timmermans, et al. [28], such as wash and dry body, open/close clothing, tying shoelaces, putting arm in sleeve, and brushing teeth (see Figure 1). So, it is unclear which activity (or activities) grooming refers to, which objects are associated with it, and if it is performed sufficiently long each day.
6. 'Writing' is generally only performed by the dominant hand. So, it is not an applicable training activity for patients with impairments in the non-dominant hand. Furthermore, not all stroke patients may write frequently or long enough for this ADL to provide an effective training. Writing can also require a lot of attention, making it challenging to add a training activity without distracting or hindering the execution of the ADL.
7. 'Holding rake/broom/spade' may be a gender or age-specific activity and is not necessarily performed by any stroke patient on a daily basis for a long period of time.
8. 'Arm in sleeve/reach high/sewing' are three different activities combined into one category. The activities may not be performed frequently or long enough each day. Furthermore, sewing is not necessary performed by any stroke patient and can be gender-specific. Arm in sleeve and reach high are not associated with objects, thus making it difficult to integrate technology.

Appendix 2: Survey on drinking activities

Table 14 shows the variables together with their explanations and examples as used in the survey on drinking activities. Participants filled in all variables for each of their drinking activities.

Table 14. The 17 variables with explanations and examples included in the survey.

Variable	*Explanation*	*Example*
Type	Which drink is consumed?	Herbal tea
Time	Record start and end time	14:30-14:45
Amount		300 ml
Location		Living room
Social setting	Who are present?	Three friends
Activities	Which activities co-occur during drinking?	Reading a book; talking
Focus	Is the primary focus on drinking or the co-occurring activity?	Focus on talking
Goal		Relaxation; hydration
Cup type	Which type of cup/glass is used?	Glass teacup
Hand	Which hand is used?	3x both hands; 7x right hand
Grasp - *picture*	How are you holding the cup? *Please take a picture of this.*	3x both hands around the cup; 7x by the handle
Lift	How many times do you lift the cup?	Occasional sips: 10x
Objects	Which other objects are used?	Teaspoon, honey pot, book
Mealtime	Consumed during a meal or in between?	In between meals
Frequency	How often does this drinking activity recur?	Afternoon tea recurs daily
Mood		Relaxed
Experience of time	E.g. in a rush, taking a long time	Taking my time, no rush

Appendix 3: Personas

Two personas were created to guide the design process. Two were formed to reflect the diversity of stroke patients. Each reflects a different type of end user. Willem (Figure 23) represents a user with sufficient time for training but low motivation. Annette (Figure 24) represents a user with insufficient time but high motivation.

Figure 23. Persona of a patient with sufficient time for training but low motivation.

Figure 24. Persona of a patient with high motivation but lacking time for training.

Appendix 4: Protocol for the concept interviews

Phase	*Estimated duration*	*Contents*
Introduction	5 min	1. Hallo, welcome. Thank you for participating in this study. 2. I'll briefly explain the goal and content of this interview. 3. I'm currently doing the Graduation Project of my master Interaction Technology at the University of Twente. 4. We are developing interactive objects that can help people who have experienced a stroke with hand and arm rehabilitation. We are specifically looking at daily-used objects so that the training can be integrated into daily life. This way it requires less time and motivation. For this research, we consider the activity of drinking, so we are looking at trainings related to drinking from a glass. 5. The purpose of this interview is to receive feedback - from you as an expert in the field of upper limb rehabilitation - on five training concepts I developed. 6. If there is any time left, I would like to ask some general questions about the development of rehabilitation exercises. 7. I want you to know that you can be honest during this session and that there are no right or wrong answers. If you have a question, feel free to ask it at any time. 8. Do you already have a question or is everything clear so far?
Warm-up	2 min	1. What is you occupation in the field of rehabilitation? 2. How long have you been working in this field?

Body of the interview	20 min	3. Then we can now continue to the concepts. I'll first explain the process using some slides. The slides also make it easier to explain the concepts.
		4. First, I studied which skills rehabilitation exercises often target, namely strength, dexterity (fine motor skills), and range of motion. Afterwards, I looked at various glass and cup designs and brainstormed ideas for exercises and designs. I then chose five concepts based on a few criteria.
		5. Now I will briefly present and explain each concept and ask some questions about them:
		    1. First impressions?
		    2. Good points?
		    3. Potential problems?
		    4. Points of improvement?
		    5. Does this provide a useful training?
		6. Could you list the five concepts from most to least promising? Are there any concepts that immediately strike you as showing a lot of potential or showing no potential?
		7. Next follow the more general training questions:
		    1. How long/often should a training be performed to have beneficial effects?
		    2. I found three important skills that are targeted with hand or arm rehabilitation. Are these correct or am I missing an important skill?

Cool-off	3 min	1. Is there anything else related to drinking or training that we have not discussed yet but that you want us to consider? 2. Is there anything else you want to add or emphasise?
Wrap-up	1 min	1. Then I have asked all my questions. 2. Do you have any questions for me? 3. I want to thank you for participating and helping me with my research. This was extremely useful and provided a lot of insights. 4. Thank you and have a nice day!

Appendix 5: Additional feedback from the concept interviews

Feedback on concepts

The interviews with clinicians during the conceptualisation phase resulted in useful feedback on the five concepts. This could be categorised into three themes: positive points, negative points, and suggested improvements. Table 15 shows the feedback per concept and clinician.

Table 15. Feedback per concept, divided into positive, negative, and improvement points.

	Clinician 1	Clinician 2
Concept 1: Handles		
Positive	The two handles with cylinder grasps are useful.	- Nice to use handles to stimulate exercises. - Feedback colours are nice and clear.
Negative	- It focuses too much on fine motor skills and involves difficult grasps. - Most patients won't be able to perform this exercise. And those who can are so good that they need the training less. It is only executable for patients with mild hand impairments.	- It requires switching handles, which is hard for patients. So they need help. The exercise is not independently executable. - It requires a specific mug. But people may want to use their own cups, and different drinks are consumed from different kinds of glasses. - Some handles are not applicable for training. The small ones don't provide enough stability and the separate rings are difficult to put fingers in and out. - The cup may not be used much. - It is unclear which handle trains which grasp.
Improve	- Ensure the cup is held with the unimpaired hand, e.g. with CIMT or forced-use. - It should focus on holding it with one or both hands around the glass instead of handles.	
Concept 2: Placemat		
Positive	- This is a really nice idea. - It focuses on training useful skills, reach and workspace, and does that well. - This is clearly an exercise. But it is integrated into daily life so it is still a strong concept.	- This is a nice and simple idea. - It trains rich movements and hand-eye coordination, which is a good training. - It gives useful feedback on placement and potentially smoothness. - Good reminder and stimulator to train when drinking. - Easy to do as it only requires the Placemat.
Negative	It is not directly related to drinking but extended to the environment.	It adds a separate element to drinking.
Improve	Smoothness is a central parameter for measuring progress in hand and arm function. So an accelerometer could be included to measure this and monitor progress.	- It can have different sizes or differently sized spots to account for differences in abilities. - The tags should be attachable so patients can use their own cups. - Don't show the full pattern, but only one spot.
Concept 3: Spout Lid		
Positive	- Doing an exercise to be able to drink is nice. - This could be nice for a bottle for training outside the house.	- The exercise involves a reward: being able to drink. - Lid prevents spilling if movements are complex. - Turning the lid is a good exercise.
Negative		- It is clearly an exercise object. If people want to drink, they may not first want to do an exercise. - The movements the handles train are not useful. - It is a complex exercise.
Improve	- It is a bimanual training, but unimanual is better. By making it a smaller cup, one hand is used to exert pressure onto the bottle or handle. This would open the spout lid.	- It is a bimanual training, but unimanual is better. It should be a smaller cup managed by one hand to train squeezing the cup with the hand or handle with the thumb. This results in liquid coming out or opening the lid.

	- It could be a bottle for on the go training so training is location-independent. - It could look more like a bottle.	- It can be simpler: a cup with pressure sensors and a green light when the patient exerts sufficient force. An additional advantage is that the patient knows they hold the glass securely. - It should look like a take-away cup, so it is less like a cup for children or people with disabilities.
Concept 4: Interactive Cup		
Positive	- The exercise for the complete hand is good. - It combines exercises for the complete hand and for separate fingers.	- This is a nice idea. - Extension is a useful training. - It reminds and stimulates training in a fun way.
Negative	- Vibrations are not a good output because stroke patients can have impaired sensitivity. - The training, especially the separate finger exercises, are only for patients with more skills.	Extension is an advanced exercise. So it may only be applicable to patients with more abilities.
Improve	- Music could be used for feedback. Music or sounds are generated when squeezing the glass. But this could be annoying or distracting. - Extension should be trained with the complete hand.	- It involves a dedicated mug. Instead it could be a rubber sleeve that can go onto different cups so patients can keep using their own mugs. - To train extension the cup should not be too wide. - Training should focus mostly on pressure and then on extension, but it should not train different grasps, because people use one grasp for holding a cup.
Concept 5: Rotation Game		
Positive	The focus on the rotation movement is good as it requires two hands.	- The rotation movement is useful to train. - The lid is useful as it prevents spilling. - This is really a game.
Negative	- It trains actions unrelated to drinking. - This is a clear exercise added to the object.	- There is a risk of spilling. - The technical feasibility may be low. - There is a risk that the cup will not be used.
Improve	- Training rotation is illogical as it does not fit with a glass (but with a jar). It should train movements linked to drinking. - Ensure that patients perform the exercise with the impaired hand.	The handle rotation element must be secure so it does not rotate when patients lift or hold the cup.

General feedback

The clinicians also provided feedback that applied to more concepts or to training in general. Below, some important findings are discussed.

Training elements:

- An important movement for drinking, which could be considered for training, is wrist pronation and supination.
- The exercise could be extended to the activity of filling the cup with liquid. This requires two hands, one for fixating the glass and one for filling it.
- It is important that there is variation in the training. Not every exercise or movement should be exactly the same. Variation causes a better learning effect.

Differences in skills:

- Some stroke patients may not be able to make progress anymore. In such cases, training still plays a significant role in maintaining abilities and preventing decline.
- Extension is complex. People who can extend the hand and fingers early on in the rehabilitation process have a better prognosis of recovery.

Design:

- It should be ensured that the exercise is performed with the impaired hand, not the unimpaired hand. This can be done through design, e.g. by making a shape in the cup for the thumb on one side and the other fingers on the other side. This shape makes it comfortable to use impaired hand and uncomfortable to use the unimpaired hand. This does mean making separate objects for the left and right hand.
- Technical feasibility of the concepts should be considered. It is important to make a product that is affordable and does not require difficult equipment. The technology has to be implemented in a small cup without making it too heavy.

Appendix 6: Protocol for the user evaluation

Introduction

1. Hello, welcome. Thank you for participating in this study.
2. I'll briefly explain the goal and content of this interview.
3. I'm currently doing the Graduation Project of my master Interaction Technology at the University of Twente.
4. We are developing interactive objects that can help people who have experienced a stroke with hand and arm rehabilitation. We are specifically looking at daily-used objects so that the training can be integrated into daily life. This way it requires less time and motivation. For this research, we consider the activity of drinking, so we are looking at trainings related to drinking from a glass. For this, I made two interactive training prototypes.
5. The purpose of this interview is to receive feedback on the prototypes to find out if they provide a useful training and are user-friendly. Based on this, we will improve them.
6. I want you to know that you can be honest during this session and that there are no right or wrong answers. If you have a question, feel free to ask it at any time.
7. Do you already have a question or is everything clear so far?

Warm up: Questions about stroke and motor abilities

1. What is your age?
2. When did you have a stroke?
    a. I.e. which phase (acute, subacute, chronic) are you in?
3. Which side is the most affected side due to stroke?
    a. Is that the dominant or non-dominant side?
4. What were the effects of the stroke on your upper limb motor functions and abilities?
    a. Do you know if you have a mild, moderate, or severe arm or hand impairment?
    b. Did you experience any other cognitive or motor difficulties?
5. Are you currently still doing rehabilitation exercises?
6. How is drinking currently for you?
    a. Do you experience any issues? If so, which?

Body of the interviews: Prototypes

1. Then we can continue to the prototypes.
2. I'll first explain them, after which you can try both training prototypes. Then we will discuss them and I'll ask some questions.
3. As the training takes place during drinking, I would like you to imagine yourself in that situation. For instance, what and where do you drink, what are you doing?

Prototype 1: Placemat

Explanation

- The goal of the Placemat is to train range of motion of the elbow and arm as well as hand-eye coordination.
- The idea is that the training and prototype are explained by a physiotherapist after which the patient can perform it independently at home. The physiotherapist could also receive the performance results and decide on the settings and difficulty and when they should be changed.

The prototype works as follows:

1. You can pick a level and press ‘start’ to begin or ‘stop’ to stop.
2. An arrow indicates where the glass should be placed. There are a few seconds to place it correctly, then a smiley appears.
3. If you are too late or place it on an incorrect spot it shows a cross.
4. A random new location is picked after a short pause.
5. After placing the glass, you can lift it or leave it standing there.
6. It tracks the correct, incorrect, and late placements and shows this as feedback.
7. The exercise ends after a certain number of correct locations or if you press stop. Then the feedback appears.

Questions for both prototypes

1. What do you like about it?
2. Did you encounter any problems or difficulties?
3. What are improvement points?
4. Is the exercise
    a. Understandable?
    b. Easy to use?
5. When would you perform this exercises: before, after or in between drinking? And why?
6. Do you think this exercise can be performed safely with liquid in it?
7. Do you think this provides a useful training that can benefit rehabilitation?
    a. Do you think this training might be useful for your day-to-day activities?
8. Do you think you would perform this rehabilitation training at home?
9. How would you like to receive the feedback?
    a. Where
        i. On a pc screen, app, on the product, or other?
    b. When
        i. Immediately after the exercise?
        ii. Overview of progress over time?
10. Would you like to be able to use your own cups and glasses (e.g. with a sleeve/cover) or get a designated cup for this training?

Questions for Placemat

1. What do you think of the feedback?
    a. Right now you see this on the computer. But the idea is that it appears on the Placemat. So at the end of the training you see how many are placed correctly, incorrectly, and too late. The therapist would also receive this and also see this per location (to see which locations go well or not which helps in determining which areas need more training).
        i. Is it easy or difficult to interpret this feedback?
        ii. Do you think the location feedback is useful or unnecessary? Do you want both you and the therapist to receive the information?
        iii. Would you like to be able to track your progress over time?
2. What do you think of the two difficulty levels?
    a. Right now it only differs in time: is that useful?
    b. But there are other ways to change the difficulty.
        i. Less/more distance between subsequent locations: would that be useful?

    ii. Spots with small/large size. This focuses on the precision of placing the glass: would that be useful?
  c. The difficulties could then be as follows:
    i. Levels 1-3 for speed and distance, and turning precision on/off
    ii. Speed: low or high; distance: low or high; and precision: low or high
    iii. Would this be useful?
3. We could add a smart meter to the cup, which would measure smoothness of the arm movement? Do you think that would be useful?
  a. How would you like to receive feedback on this?
4. What do you think of adding a social element to the training?
  a. For instance that you compete with someone based on speed or play tic-tac-toe?
  b. Would this help in keeping you engaged with the training or not?
5. Right now the Placemat ‘enforces’ the training and there is negative feedback. But training could take place differently. For instance, that no arrows light up and that there is no negative feedback, but that you can place your glass wherever you want whenever you want, and then it lights up/gives a smiley. This would not enforce but invite you.
  a. Which kind of exercise would you prefer?
  b. And which one do you think you would actually perform?

Prototype 2: Interactive Cup

Explanation

- The goal of the Interactive Cup is to train hand and finger strength and hand extension.
- The idea is that the training and prototype are explained by a physiotherapist, after which the patient can perform it independently at home. The physiotherapist also determines and sets the level with the turning knob and can adapt this based on the performance results they receive.

The prototype works as follows:

1. First the settings are determined:
  a. The patient squeezes with the unimpaired hand, this sets the difficulty level five.
  b. The patient squeezes with the impaired hand, this is their current level. So this forms their strength goal. The turning knob is turned to that difficulty level.
2. The device can be turned on or off.
3. The glass lights up when it is turned on.
4. There are two exercises:
  a. If it lights up yellow: the patient has to squeeze.
  b. If it lights up blue: the patient has to extend their hand.
5. It shortly blinks green if the patient performs it correctly.
6. In between the exercises, there is a short pause indicated by white light. Afterwards the new exercise is randomly picked.
7. The training is completed after a certain number of correct exercises.
8. It records the number of correct and incorrect exercises for both the squeeze and extend exercises, which is provided as feedback when the training is completed or stopped.

Questions for both prototypes

- See above

Questions for Interactive Cup

1. Are the lights and what they mean clear? Is it easy or difficult to interpret this information?
    a. I.e. exercise indicator, exercise feedback, pause light.
2. Is the length of the exercise sufficient/too long?
    a. i.e. if it is too long it can be tiring or difficult?
    b. Would it be useful to let the length depend on the difficulty level?
3. Do you think the extension exercise is useful/too hard?
4. Feedback
    a. Is feedback on the number of incorrect and correct squeeze and extend exercises enough or do you want to know how hard you squeezed?
    b. The feedback could also show your average or maximum strength value relative to the goal. This could for instance be a percentage or a meter on the box that shows it in real-time.
    c. Would you like to see an overview of progress?
5. Pauses
    a. Are the pauses in between exercises sufficient/too long; too frequent/infrequent?
    b. Right now there is always a pause in between two exercises.
        i. Do you think this is nice or could it be without the pauses?
        ii. Or sometimes a pause but not always (i.e. pick randomly between white, blue, yellow)?
        iii. Are the transitions doable: squeeze-to-release and release-to-squeeze?
        iv. The number and duration of pauses could be implemented as difficulty level:
            1. Level 1: always a long pause after an exercise
            2. Level 2: frequent pauses
            3. Level 3: occasional and shorter pauses
            4. Would that be useful?

General training questions

1. Do you prefer one of the two training prototypes? And why or why not?
2. What do you think of linking the training to the activity of drinking?

Cool off

1. Is there anything else related to drinking, rehabilitation training or the prototypes that we have not discussed yet, but that you want to mention?
2. Is there anything else you want to add or emphasise?

Wrap up

1. I have asked all my question.
2. Do you have any questions for me?
3. I want to thank you for participating and helping me with my research. This was particularly useful and provided a lot of insights.
4. You will receive a digital gift voucher of €10.00.
5. Thank you and have a nice day.

Appendix 7: Feedback from the user evaluation

Table 16 presents a summary of the feedback given in the user evaluation. It is structured along six emergent theme.

Table 16. Overview of feedback per prototype and categorised into six topics.

Topic	Placemat	Interactive Cup
Ease-of-use	Overall, the participants found the Placemat easy to understand and use. But there could be improvements: - It could resemble a placemat more, so thinner and more flexible. It is too high now, requiring lifting the arm more. - If the exercise is performed with the left hand, the hand is in front of the LED display. The displays should be positioned below the circles. - The magnet and magnetic sensor are not reliable enough. The sensor does not always register the magnet and is influenced by nearby electronic devices. The user has to pay attention to hold the glass so that the magnet points to the sensor. A different sensor or placing the magnet on the bottom of the glass can help.	Overall, the participants found the prototype easy to understand and use and thought the lights were clear. There could be some improvements: - It could be wireless. - It may be tiring to squeeze really hard for a long time. - A glass less wide would be more comfortable to squeeze. - Squeezing hard in a glass is unintuitive, especially when it contains water.
Safety	All participants indicated that the training could be performed safely with liquid in the glass, but the start, stop and level buttons should be waterproof.	Although all participants indicated that the training could be performed safely with liquid in the glass, two participants thought people may not want to squeeze hard because they do not want to break the glass or spill.
Skill training	- All participants thought it provided a useful training of important skills: hand-eye coordination, cognitive skills, and hand and arm movements, e.g. grasping and placing. - All participants indicated that they would perform this training at home if recommended by their physiotherapist. - P1 suggested that it should not only focus on training speed, but also on the smoothness and stability of movements. In the beginning movements are more uncontrolled and jerkier. A score can be given for this to see progress. - P1 also suggested that other objects could be used as a glass is easy to pick up. These could have different shapes and weights to train other skills like dexterity and strength.	The opinions of the participants differed. - P1 thought strength and extension were important to train. - P2 thought it trains important cognitive skills because you have to respond with different actions to the different colours and thought grasping was useful. P2 argued that people who are at home are further along in their rehabilitation process and need to practice more than just squeezing and releasing. So the exercise should be more challenging by adding exercises that are functional to drinking and using a glass, e.g. grasping, lifting, rotating, placing, filling, emptying, or rinsing it, walking with a full cup, and wrist motions and coordination. This means other sensors should be added. - P3 suggested adding similar exercises as P2. P3 thought squeezing, extension and strength were useful to train but not with a glass. Instead it should focus on training functions related to a glass. - P1 and P2 indicated that they would perform this training if recommended by their physiotherapist. P3 would only use it if functional exercises would be added.
Difficulty level	- All participants thought it was useful to change the time to place the glass correctly and the distance between subsequent locations depending on the difficulty level. - Their opinions differed on measuring precision. P1 and P3 thought precision would be important to train because you should be able to accurately place an object and this requires good coordination. The combination enables people to	- All participants thought that it was useful to change the squeeze strength and pauses depending on the difficulty level. The need for pauses depends on the rehabilitation stage. So the frequency and duration of pauses should change with the difficulty level.

	become fast and precise. P3 argued that it should not be the focus initially but when a patient is further in the rehabilitation process. P2 found precision less useful to train from a functional point of view but thought precision information may be relevant for physiotherapists. - Two participants also suggested that the difficulty could also be increased by filling the cup with liquid (empty, half full, full). This also makes the glass heavier, which trains strength.	- P2 suggested to change the difficulty by adding different exercises, such as wrist motions or lifting the glass.
Feedback	- P1 mentioned that instead of the number of correct, incorrect, and late placements, it should provide one overall score. One score is easier to understand. P1 also suggested to give a score for the time you take and smoothness of the movement. These could be presented as three scores or combined into one value. This could be provided in an app to track progress. P1 liked the smiley faces as positive feedback as they feel like a reward. - Two participants thought it would be useful if the physiotherapist received information on performance on the different Placemat locations so they get a better understanding of which areas and muscles should be trained more. But they would not need to receive it themselves. P3, however, wanted to receive the location-specific feedback themselves. - P3 suggested that the feedback could be clearer by adding intuitive colours (green and red) or sounds.	- Two participants stated that instead of the number of correct and incorrect exercises, a score representing the squeeze strength could be more insightful. A score makes it easier to keep track of development than the number of correct and incorrect exercises. - P2 mentioned that some patients exert uncontrolled pressure. If they squeeze too hard, it could light up red to make them aware and stimulate them to relax their hand.
Game element	- All participants appreciated the game element and thought that made it fun, motivating, and challenging. - Two participants made suggestions for enhancing the game element: - You could play tic-tac-toe or memo against a computer, family member or a patient. This trains cognitive skills and competition can be motivating. - The LED displays could show numbers, and the user should place the glass in the right order (1, 2, 3) or they could show images of something the user likes, e.g. cars, and they have to place the glass on the images or on a subsection (e.g. only the red cars). This adds variation, can keep the training interesting for a longer period of time, and trains cognitive skills.	P3 disliked that it lacked a game element. It could be more playful.

Annex

Annex number	*Annex name*	*File/folder name*
1	Research Topics	Annex1_Research_Topics.pdf
2	Survey	Annex2_Survey
3	Ideation	Annex3_Ideation.xlsx
4	Transcript Interview Clinician 1	Annex4_Transcript_Interview_Clinician_1.doxc
5	Transcript Interview Clinician 2	Annex5_Transcript_Interview_Clinician_2.doxc
6	Code Placemat	Annex6_Code_Placemat
7	Code Interactive Cup	Annex7_Code_Interactive_Cup
8	Usability Test	Annex8_Usability_Test.xlsx
9	Transcript User Evaluation 1	Annex9_Transcript_User_Evaluation_1.doxc
10	Transcript User Evaluation 2	Annex10_Transcript_User_Evaluation_2.doxc
11	Transcript User Evaluation 3	Annex11_Transcript_User_Evaluation_3.doxc
12	User Evaluation Feedback	Annex12_User_Evaluation_Feedback.xlsx