Master Thesis

TumbleTooth, an ADL-based home rehabiliation aid for hand-stroke patients.

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Abstract

Following initial recovery, stroke patients tend to lose their motivation to perform exercises at home. This thesis investigates how to seamlessly integrate the exercises into an object of daily living in an at-home setting. Through the Self Determination Theory (SDT) and Health Belief Model (HBM) we managed to present an overview of the health behavior of stroke patients. Subsequently, we identified a design gap in the current related work. Based on observations, 'Brushing teeth' was identified as the most promising activities of daily living (ADL) in this context. After that, we classified suitable exercises and a proper design features list. This resulted in TumbleTooth. TumbleTooth is a toothbrush with a rotating head to encourage wrist movement. A user evaluation indicated that the concept seemed to seamlessly promote exercises. However, this must be reconfirmed in a longitudinal test. The findings of this thesis demonstrate a successful seamless ADL-based hand exercise object for stroke patients.

Acknowledgments

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Furthermore, words cannot express my gratitude to the two (former) stroke patients who assisted me during my thesis. Their openness to their experiences gave me an invaluable understanding of the struggles they face daily. They, and to extend all stroke patients, have my utmost respect for keeping hope and motivation while handling such an intense disease.

Finally, I would like to thank my parents, for proofreading this thesis, their love, and their unconditional support of my university journey.

Contents

List of acronyms

ADL	activities of daily living
PSD	Persuasive System Design
HBM	Health Belief Model
SDT	Self Determination Theory
BCTs	Behavioural Change Techniques
HCI	Human Computer Interaction
DRM	Day Reconstruction Method
MPU	Motion Processing Unit
IDE	Integrated Development Environment
NASA	National Aeronautics and Space Administration
CIS	Computer and Information Sciences
MoSCoW	‘Must have’, ‘Should have’, ‘Could have’, and ‘Will not have’
MQTT	Message Queuing Telemetry Transport
Li-Po	Lithium Polymer
b-ADL	basic activities of daily living
i-ADL	instrumental activities of daily living
a-ADL	advanced activities of daily living
CET	Cognitive evaluation theory

Introduction

0.1 Problem statement

An irregular blood supply to the brain is known as a stroke [1]. Globally, stroke affects 1 in 4 people above the age of 25 during their lifetime [2], making it a leading cause of disability in adults in many countries [3]. Many individuals who experience a stroke survive it, but they face lasting consequences like disabilities and physical limitations [3], [4]. Particularly a loss of motor functions in the face, hand, arm, and leg on one side of the body [4]. Recovering from a stroke is a complex and lengthy process, accompanied by a significant decrease in the patient's quality of life [5]. Patients can lose their motivation and patience, and their mental health decreases immensely [6].

Once a patient survives the initial stroke, they go through a rehabilitation process [3]. At rehabilitation facilities, experts make a plan for the patients, specifically to let them regain their bodily functionality [3]. Physiotherapists often supervise and help the patients through the process [3]. At some point in the rehabilitation journey, patients continue their rehabilitation exercises at home [3]. However, this phase tends to be difficult for patients. Patients often tend to lack the motivation to perform exercises in this phase [7].

Rehabilitation at home often comes with additional (smart) interventions that patients can use, such as a therapy ball [8], therapy putty [9], or for instance, the Neofect Smart Board [10]. However, these interventions require a high cognitive load from the users. Moreover, the objects demand motivation from the patients. Interactive objects like the Neofect Smart Board [10] require a significant amount of additional space as well. Patients who already lack the motivation to keep doing these exercises are not likely to make use of these large objects [11], [12].

A possible solution is to integrate their exercises into their daily lives, rather than passively 'asking' patients to do the exercises. This method is also known as ADL [13]. This thesis is based on two projects at the University of Twente that have such an approach. The projects looked into creating an ADL based object that induces motivation in users to start doing their rehabilitation exercises [13]. However, at the end of the research, it was theorized that another factor could influence the usage of the products as well. It might have been possible that solely ADL-based design does not create a seamless experience.

Both projects do not have a clear definition of seamlessness. Based on research, it is possible to state the characterizations seamlessness has [13]. Moreover, it became clear that it is not possible to create a 100% seamless object [13]. Therefore, researchers urge to create a design that has a mix of seamlessness characterizations and seamfulness characterizations [13]. Seamfulness is another definition, specifically one somewhat the opposite of seamlesnness in terms of characterizations [13]. See Table 1 and Table 2 for the components of these concepts. To make something as seamless as possible, the design should still have seamful features [13].

Based on other findings it is clear that users need to be involved in the design process. Currently the two other projects [14], [15] do not do this, and it influences their designs [13]. Moreover, they do not use persuasion design methods like the Persuasive System Design (PSD). Besides, implicit interactions can be interesting as well [13]. This might have the potential to create a design that induces motivation in the patient to do the exercises they need to do.

Table 1: Characterizations of full seamlessness objects, taken from the Research Topics report [13]

Characterizations of seamless objects
It promotes simplicity
It is easy to use for the user
It enables consistent interaction
It is designed for low cognitive thinking
It facilitates everyday usage
It is part of a set, mentally or physically
It should be embedded in a specific environment or context well-known to the user

Table 2: Characterizations of full seamfulness objects, taken from the Research Topics report [13]

Characterizations of seamful objects
It enables design for/with uncertainty
It empowers individual assumptions about the concept
It is configurable
It should have recognizable visible and computational features

Based on all this information, this thesis focuses on creating a mix between a seamless and a seamful ADL-based object. Users are involved in the design process early on and the design is built upon a persuasive design method [13].

The main research question of this thesis gravitates toward the following:

> ***'To what extent can we design an object of daily living that seamlessly promotes hand-rehabilitation exercises in an at-home setting?'***

Several sub-research questions look into different aspects to answer the main research question.

According to the PSD, persuasive design requires a better understanding of the motivations, needs, struggles, and interests of stroke patients. For this purpose, a few research questions fixate on getting to understand the user better. Other different sub-research questions are based on seamless features, seamful features, implicitness, related work, and the prototype. Furthermore, for the development of a high-fidelity prototype, it is necessary to know what kind of technologies the related work focuses on. See table 3.

Table 3: Research questions regarding understanding stroke patients.

Research questions context
‘What are the factors and beliefs that influence the behavior of stroke patients?’
‘What daily activity is most fitting to integrate an exercise for stroke patients?’
‘What daily object is most fitting to that activity or integrating an exercise for stroke patients?’
‘What exercise can be incorporated (into this activity or with this object)?’
‘What are the boundaries of implicitness?’
‘What kind of implicit interactions take place in current work?’
‘What is the opinion (of stroke patients) on the final concept?’
‘Is the interaction of the prototype understandable?’
‘What seamless and seamful features do we have in the final concept to create a meaningful experience?’

0.2 Structure report

This section outlines the structure of the report. First of all, we need more information on the context, which is covered in the first chapter. The second chapter dives into the related work in this context. Chapter three presents the observations of stroke patients at their homes, and chapter four dives deeper into the daily activity of brushing teeth. Subsequently, chapter five offers information on the exercises of stroke patients. The sixth chapter explains the features needed for the design. Chapters seven and eight present the design methodology for developing the prototype, and the ideation process, while the ninth focuses on prototyping. Chapter ten is dedicated to presenting the user evaluation methodology and results. Chapters eleven and twelve show the discussion, and conclusions respectively.

Chapter 1

Understanding the user context

Before it is possible to make a design, it is necessary to understand more of the design context. In this case, the context of a stroke patient. This chapter tries to answer the sub-research question:

- ‘What are the factors and beliefs that influence the behavior of stroke patients?’

Literature research revealed that using the concepts PSD, HBM, and SDT provide comprehensive insights for this specific context [13]. PSD is a method to design for persuasive technology. HBM and SDT combined give a clear indication of factors that influence the behavior of a stroke patient [13]. Figure 1.1 shows the overview of the PSD model in combination with the other concepts. The following section starts with the PSD model.

1.1 Persuasive System Design

It is important to understand the context of the users [13]. With the help of PSD, it is possible to create persuasive technology with a step-by-step process.

The PSD consists of three phases;

- Understanding key issues behind persuasive systems.
- Analyzing the persuasion context.
- Design of the qualities of the system.

1.1.1 Understanding key issues behind persuasive systems

The first phase of the model involves the same issues, namely that technology should be open, unobtrusive, easy to use, useful, incremental, direct and indirect, need consistency, need commitment, and is never neutral [13].

The next step is phase two, ‘Analyzing the persuasion context’. The following sections dive into this phase. See Figure 1.1 to refer back to the entire structure of this chapter.

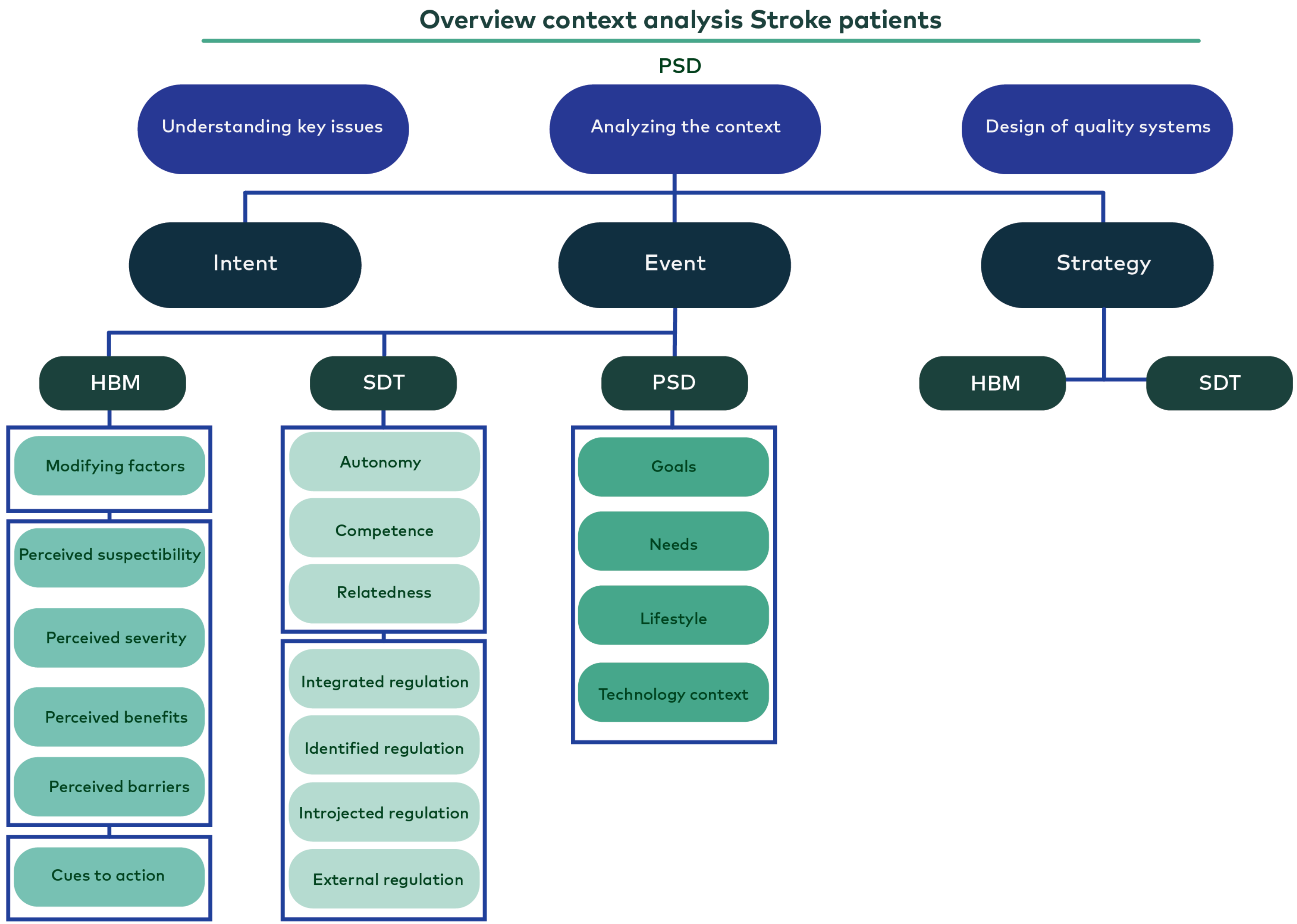

Figure 1.1: Overview of the use of different concepts in the PSD model.

1.1.2 Analyzing the persuasion context

This phase includes three steps, namely, figuring out the **intent**, **event**, and the **strategy**. The intent part is rather short, but the event section and strategy section need more explanation. The event part can be explained by answering questions set up by the PSD model. However, this does not give a full picture in a health domain setting [13]. Therefore, the event part consists of two more concepts that explain this step, namely the HBM and the SDT [13]. Figure 1.2 shows the context of the event of the stroke patient and the relationships between the concepts HBM and SDT. This chapter explains the figure in later sections.

1.1.3 Design of system qualities

After the analysis of the user context is clear, the persuasive technology receives requirements it needs to adhere to. This phase shows all the features the technology/design should have in an ideal situation. After that, the designer implements the design. Researchers in the PSD give examples of different cases of persuasion technologies with design principles, such as primary task division, dialogue support domain, system credibility section, and the social support category [16]. The next sections start with the steps of the second phase.

1.1.4 Intent

In the **intent** step, the intent and identity of the convincing party are established, as well as the type of change in the persuasive technology. In this context, the intent is endogenous [16], since the designer tries to change the behavior of the user, and autogenous [16], as the user wants to change their behavior with an easy tool. The change type concentrates on the behavior change of the user.

1.1.5 The event

The next step illustrates a better understanding of the **event**. In this part, the context of the usage should become clear. This is the part that needs a grander analysis. The PSD model gives some understanding, but it is not complete. HBM and SDT give more insights into the context. The following sections explain the answers to the models and theory in more depth. HBM and SDT do not give answers to all the categories mentioned in the PSD model, but they give a coherent view. So for this step, we also look at these two models. Figure 1.2 shows the relation between the HBM and SDT model for this specific context. The next section starts with terms the HBM and SDT do not cover.

Persuasive System Design - event

The PSD model urges to give answers on some topics that the HBM and SDT do not answer, so, therefore, the following sections look into that.

Goals

The main goal of stroke patients is to restore as much functionality as possible. Stroke patients want to rebuild their lives and create a high quality of living [17]. In the study of Nasr et al., the users stated plain goals, like seeing progress in their hand functionality, performing daily activities, and personal goals relevant to their passions [18].

Needs

Nasr et al. [18] discovered with their research important aspects that stroke patients need in a possible rehabilitation prototype. The researchers stated that; the system should have high usability, be able to train for stroke rehabilitation, prompt feedback on performance, and insinuate motivation in the users. Preferably, the object is also compact [18].

Niemi and colleagues [19] express that stroke patients prefer to receive reassurance, accommodated training, provided information about their condition, and mental help. The social aspect of these characteristics is an important need for stroke patients [20].

As mentioned above, stroke patients have a hard time performing independent activities. A need for this user group is to improve the capabilities in daily activities [20].

Lifestyles

Hafsteinsdottir and Grypdonck [21] discuss interviews with stroke patients at a maximum of 72 hours after the initial stroke. This research shows that the lifestyles of stroke patients are uncertain and anxious in the first days. Patients are aware that their limbs are losing functionality. Soon after the diagnosis of the stroke, the patients seek out help. Afterwards, they start the rehabilitation process.

During the rehabilitation process, stroke patients want to retrieve any possible functionality. Preferably the functionality of the pre-stroke situation [21].

Stroke patients may fear experiencing another stroke [21]. Moreover, the mental health of stroke patients tends to decline as well. Stroke patients miss out on social events, lose basic functionality, and face other obstacles in this new lifestyle [6], [21].

Morone et al. [22] showcase ADLs where stroke patients experience the most difficulties, and what activities have the highest recovery. According to their results, patients have the highest restoration in their “bowel and bladder function, transfers, and walking”. The lowest return tends to lie in “bathing, dressing, grooming, and climbing stairs” [22].

Technology context

Levanon [23] states that technology in this context has its advantages and disadvantages. Technology can enhance the experience of the hand rehabilitation process. However, it is not a complete replacement for the classical approach [23].

The researcher states that technology can provide feedback, motivation, and flexibility. There is a possibility that technology can easily adapt to different scenarios and is accessible at home. On the other hand, unfamiliarity with technology can lead to frustration. Some patients do not appreciate using technology in general. And most importantly, social contact is lacking [23]. According to Levanon [23], technology should be seen as an additive to hand rehabilitation.

The research of Hover et al. [12] and Stefess and colleagues [11] indicate that stroke patients value intuitiveness, ADL-based training, skill training, progress feedback, direct feedback and task-specific training in rehabilitation products. Hover et al. [12] indicate that independent use is a must for participants, as is the ease of use.

Participants from Hover et al. [12] stated that the difficulty level of the exercises should be adjustable. Moreover, the object should be small, safe to use, have a high production quality, and have a possibility for both hands. Researchers argue that an object in the same context should have a co-design-based intervention to avoid pitfalls. Moreover, they argue that a seamless design could help with the ADL-based idea.

The researchers urge that gamified elements are in contrast to the seamlessness feature and should therefore be avoided [12].

The next sections explain the context from the stroke patients with the HBM.

Health Belief Model

The HBM is a model to explain the care and change of health-related behaviors [13]. The model consists of three parts, namely **modifying factors, individual beliefs** and **action** [13]. This section briefly discusses the modifying factors of the user. Then the individual beliefs of the user and actions the user can take. Individual beliefs involve perceived susceptibility, perceived severity, perceived benefits, and perceived barriers. Each section explains what these concepts entail. The action part mainly focuses on cues to action. This section goes through each of these concepts and explains in more depth what exactly occurs. Again, see Figure 1.1 to get a clear image of the context overview. The following sections cover the HBM in the event part of analyzing the context.

Modifying factors

Modifying factors are based on demographic variables and psychological characteristics from the user [24]. Demographics, such as the greater likelihood of obtaining a disease, can already influence the health behavior of a user.

If one of the biological parents got a stroke, the chance is more likely that the offspring gets a stroke as well [25]. Once a person is older, it is more likely to get a stroke [2]. Overall, 56% of all the currently living stroke patients are women [2].

All the following risks affect the global burden of stroke by 87%. There are metabolic risks (high body mass index, high cholesterol), behavioral factors (bad diet, smoking, lack of an active physical lifestyle), environmental risks (air pollution), and high systolic blood pressure [2]. 89% of all stroke deaths worldwide occur in low- to middle-income countries [2].

As can be seen in Figure 1.2, modifying factors influence perceived susceptibility, perceived severity, perceived benefits, and perceived barriers [24]. So, for example, when a person has a parent who had a stroke, that person can have a higher perceived susceptibility that they get the disease. Or, they might have more perceived barriers, as they experienced the disease first-hand.

Perceived Susceptibility

Perceived susceptibility, indicates the expectation of how likely it is to get a certain illness [26]. For a stroke, this number is relatively high. One in four after the age of 25 gets this disease [2]. The older a person is, the more at risk they are. When a person is 65 years old, there is a 75% chance that a stroke occurs [27].

Perceived Severity

The term perceived severity focuses on the severity of the possibility that the individual can acquire a disease [26]. This can refer to the medical, clinical, and social consequences. For a stroke, the severity is considered as high.

Stroke patients perceive a high number of consequences in their daily lives. Stroke patients tend to be unable to participate in social activities, family life, and in sexual activities [20], [28]. In addition, their financial needs are not always met and their physical well-being is at a very low point. Of all the consequences, their physical abilities are affected in the most extreme way [20], [27]. Stroke patients often tend to lose functionality in their motor functions and other bodily abilities [2].

Stroke patients also suffer consequences on an emotional level. Loss of dependence, having a sense of loss, and not being able to recover at the expected pace, create a negative impact on their lives [27]. And this probably influences their mental well-being, since stroke patients tend to be more susceptible to depression and anxiety [6].

Perceived Benefits

Perceived benefits refer to the influence the anticipated benefits have on the behavior change of the individuals [26]. If individuals can determine the benefits if they take action, this might change unwanted unhealthy behavior in their lifestyle.

The perceived benefits in this regard are to rebuild the life of the patient and thus restore their affected functions [17]. As mentioned in other research, patients want to be able to regain pre-stroke functionality and regain independence. If patients learn how to cope with their current state, this tends to create a higher quality of life, according to Buono et al. [27].

Perceived Barriers

The term perceived barriers refers to the concept when individuals fixate on the negative sides of health-related behavior [26]. First of all, stroke patients can fixate on the difference between their rehabilitation expectations and the actual outcome. This can lead to a disappointed feeling [27].

Additionally, for patients, it can be difficult to see actual progress in their functionality. Another barrier is that patients tend to lack the motivation to perform exercises outside rehabilitation centers [7]. One of those barriers tends to lie in the fact that they have to accommodate extra time and space.

Moreover, stroke patients rely on quite some aspects of help from their family, friends, or spouses [20]. This can become a burden to their caregivers but is also perceived by the patient as a barrier, since they lose their independence [20].

Cues to Action

The last term of the HBM, cues to action, describes suggestions that provoke actions [26].

According to Buono et al. [27] and Masterson-Algar et al. [17], patients who accept their current state and abilities tend to be more motivated and experience a higher quality of life. According to Buono et al. [27], patients who tend to perform “active- and task-oriented coping strategies” are more likely to have a positive outlook on their life. Furthermore, social support tends to provoke actions. Continually adapting the goals of the patient helps with a higher quality of life.

The work of Masterson-Algar et al. [17] shows that patients benefit from coaching sessions with an ex-stroke patient coach. This helps patients in numerous ways, such as receiving helpful guidance and creating support to achieve their goals.

According to Nasr et al. [18], patients are motivated if they can regain control (with the help of rehabilitation systems).

Conclusion Health Belief Model

Based on different parts of the HBM, it becomes clear that the user perceives barriers and that the severity of the disease is rather high [2], [6], [20], [26]–[28]. The perceived benefits turn out to be major, as it could help the patient retrieve physical functionality (partially) and maintain current functions. This research should take into account the **task-oriented training strategy** and **objectives of the object should be adaptable** for the design [27].

Before it is possible to relate the HBM and the SDT, the next sections dive into the SDT.

1.1.6 Self Determination Theory

SDT is a theory of human motivation. The theory tries to give an understanding of how the three SDT establishments relate to the physical and mental well-being of an individual [29]. In combination with the HBM it gives an overview of the context of stroke patients.

SDT is based on autonomy, relatedness, and competence. If these three conditions are satisfied, a person is more likely to change their health behavior. The SDT explains that people can also have intrinsic and extrinsic motivations to perform the behavior [13]. Based on this, the following sections go into the autonomy, relatedness, competence, and extrinsic and intrinsic motivations.

Patrick and Williams [30] state examples to obtain greater motivation in patients in the health domain. The findings of Patrick and Williams give direct answers as to what one should do to induce autonomy, relatedness, or competence in the patient. This is why their findings dominate the following sections.

Autonomy

The autonomy of a person concentrates on the need to be able to feel like making choices, and the willingness to perform the behavior [30]. Supportive behaviors consist of recognizing the expectations and sentiments of patients. This can be done by; “supporting patients’ choices and initiatives; providing a rationale for advice given; providing a menu of effective options for change; minimizing control and judgment; and exploring how relevant health behaviors relate to patients’ aspirations in life [30], [31]”.

Relatedness

Relatedness discloses the need to be accepted and to relate to others in a social context [30], [32]. According to Patrick and Williams, relatedness aims to instigate confidence in patients. Especially if the patient was unable to meet their goals. A practitioner should give an understanding of the challenges the patients perceive. The researchers give an example that people around them should actively listen to their problems [30].

Competence

Competence involves the need to believe in one’s ability to successfully achieve desired outcomes [30]. Competence can be met by affirming that patients can flourish. This can be done by changing the perspective of a failure, coming up with a plan based on the functionality of the patient, granting unprejudiced comments, diagnosing hurdles, and focusing on expanding on the qualifications [30].

Intrinsic and Extrinsic motivation

A person might believe in a goal because they find it important, this is known as intrinsic motivation [30]. On the other end of the spectrum, motivation can come from external factors (extrinsic motivation). Patrick and Williams comment briefly on the intrinsic and extrinsic motivations. According to them, when individuals put their attention to mainly extrinsic hopes, autonomy and relatedness tend to be lower. According to Patrick and Williams [30], and Yoshida et al. [33], SDL-based inventions in the health domain show that intrinsic aspirations have changed health behavior effects on a long-term bias.

However, it is possible for different forms of regulations to exist side by side [30]. The design could involve extrinsic motivation, but it is of course still possible that the user already has some internal motivation to finish the tasks. A combination is an ideal situation.

Figure 1.2 illustrates that intrinsic and extrinsic motivation are both influenced by the autonomy of a person [34]. Intrinsic motivation is on the other hand more influenced by competence, and can also influence competence the other way around. Extrinsic motivation is also influenced by relatedness.

The following four sections dive deeper into the different integrated motivation methods that are useful in the health domain. Figure 1.2 only shows the integrated and identified regulation. The conclusion of the SDT explains this in more depth.

Integrated regulation

One extrinsic motivation method is known as an integrated regulation [30]. According to Ryan and Deci [34], this form is known as the fullest form of internalization. Integrated regulation tends to be the most autonomous one of the extrinsic motivation methods. In the health domain, it focuses on integrating the behavior into the patient's daily life and aims attention to understanding the value of the activity [30], [35].

According to Ryan and Deci [34], the essence of this method lies in actively reflecting and changing the values, or attitudes, the person used to have.

As can be seen in Figure 1.2, Integrated regulation is mainly influenced by the autonomy of a person. As far as was found, it does not seem to be influenced by relatedness and competence.

Identified regulation

Another possible route is to focus on identified regulation. This is a form where people understand the profit of a behavior, and solely do it for personal benefits [34]. Ryan and Deci [34] give an example of a girl who refuses to drink alcohol since she understands that it is bad for her health. She still refuses to drink, even if no one is watching her.

Figure 1.2 shows that identified regulation is also influenced by autonomy. While it is less influenced by autonomy than integrated regulation, it is still the case [34].

Introjected regulation

Introjected regulation is a direction that could help as well. This is a somewhat more external form of regulation, where someone feels the need to perform a behavior because of guilt or obligation [30], [34].

External regulation

External regulation is the most external form of all the previously mentioned regulations. This behavior occurs when an individual wants to acquire a reward or omit a punishment [30],

[34].

Conclusion Self Determination Theory

Patrick and Williams [30] give an extensive overview of how to reach relatedness, autonomy, and competence. The researchers urge that the focus should lie on intrinsic motivation, but also have some combination with extrinsic motivation.

The extrinsic regulation and introjected regulation might be useful courses of action. However neither external regulation nor introjected regulation influenced the health behavior of patients that were experiencing illnesses [34]. The patients who experienced high forms of autonomy and self-regulation tended to perform more of the correct health behavior. Ryan and Deci [34] do not give concrete examples of stroke patients, so therefore the external regulations can still be interesting. It is entirely possible that external regulations do not help in this context based on related work.

This report takes the advice from Patrick and Williams. This report aims at combining intrinsic and extrinsic methods. Overall, it seems that patients should receive support, an appropriate goal plan, and an understanding of their situation. Integrated and identified regulation might help the most in this specific scenario, and changing intrinsic motivations can help the patient with a long-term bias. On the other hand, the object made for this context could perhaps use more external regulation.

1.1.7 Health Behavior Model and Self Determination Theory

As can be seen in Figure 1.2, it is possible to relate the HBM and the SDT to see how they can influence each other. The relations between the concepts are established based on the definitions of both sides, not on previous research. This section explains Figure 1.2 in more detail.

Perceived susceptibility does not seem to influence any of the SDT parts. This is because it mainly involves how likely it is someone gets the disease. Perceived severity, on the other hand, can influence the autonomy, relatedness, and competence of a person. The autonomy is influenced by the emotional impact of the disease, the relatedness is influenced by the social impact of the disease, and the medical impact influences competence. Perceived benefits also affect the autonomy, relatedness, and competence. Maintaining functionality shapes the autonomy of a person, and regaining functionality does the same for the competence of a person. Possible perceived benefits could for instance be social support from others, and that can influence the relatedness.

Perceived barriers also affect autonomy, relatedness, and competence. Autonomy is influenced by being stuck in a certain mindset, while relatedness can be influenced by other people. Especially once a person needs to depend more on someone for help. It might be possible that partners get frustrated after a while to deliver help, and that might result in the sick person not feeling accepted by others [3]. Perceived barriers can influence competence as well if someone does not experience any progress.

And finally, cues to action can influence all three items of the SDT. Adapting goals can influence autonomy, social support can impact relatedness, and task-oriented exercise can influence competence [27].

1.1.8 Conclusion of the motivations, wants, and needs

With the help of the HBM, SDT, and PSD, the motivations, wants, needs, and problems have a clearer image. All in all, the models give insights into the design of the final concept. Figure 1.2 shows the most important points of each of these approaches.

As for the HBM, it became clear that the exercises should be active, and task-oriented. Moreover, the possible system should be adaptable to different goals, and rehabilitation systems should help patients who struggle. With the HBM, it became clear that social support is a crucial factor to enable patients to take action.

1.2 Strategy

To get a clearer image of the persuasion strategy, let us take a look at the relationships between the previously two mentioned models and the motivations.

1.2.1 Relations between SDT and HBM

Figure 1.2 shows the relationships between the two models in the context of stroke patients.

Siegert and Taylor [36] describe the motivational aspects of SDT in the rehabilitation setting. According to them, autonomy involves making sure that a rehabilitating patient should be able to make their own goals. According to the concept of autonomy [34], some other aspects influence this as well. Since only truly emotional and self-influencing thoughts have an impact on autonomy, some forms of perceived severity, perceived barriers, perceived benefits, and cues to action have a relationship with autonomy. These are; 'emotional impact', 'stuck in mindset', 'maintaining abilities', and 'adapting goals'. See Figure 1.2.

Siegert and Taylor [36] comment that relatedness should concentrate on the social needs of a patient. Therefore, the following characterizations of HBM have an influence on relatedness; perceived benefits, perceived severity, and cues to action. This is based on 'social support' and 'social impact'. See Figure 1.2.

And finally, the two researchers Siegert and Taylor [36] declare that competence is influenced by mainly correctly performing ADLs, and mobility. Based on that notion, it can be said that competence has some relations with perceived severity, perceived benefits, perceived barriers, and cues to action [34]. Therefore, competence is influenced by 'medical impact', 'Regaining functionality', 'no progress', and 'active and task-oriented exercises'. See Figure 1.2.

As can be seen in Figure 1.2, intrinsic, extrinsic, integrated regulation, and identified regulation are all related in some way to the autonomy of SDT [34], [37]. Ryan and Deci [34] state in earlier work that integrated regulation is the highest form of autonomous motivation.

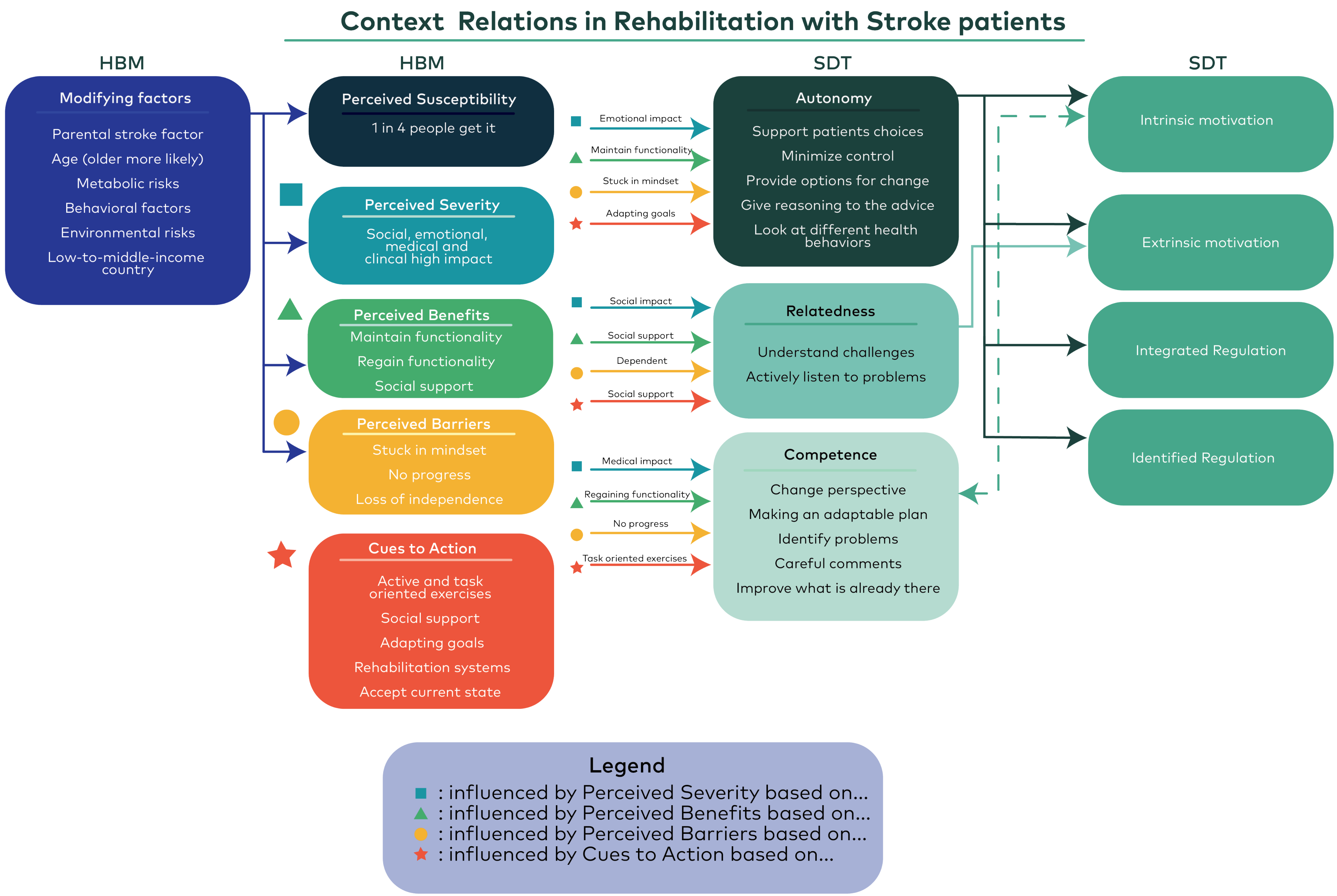

Figure 1.2: The relationships between HBM, SDT, and motivations in the context of rehabilitating stroke patients.

McLachlan et al. [38] state that extrinsic motivation mainly depends on other influences, like approval from peers. This can be seen as relatedness, so, therefore, relatedness influences extrinsic motivation. This can be seen in Figure 1.2 as well.

Cognitive evaluation theory (CET) is a mini-theory to understand factors that influence intrinsic motivation [34]. The theory explains that competence and autonomy should both be met to preserve intrinsic motivation. Moreover, if competence is negatively or positively influenced by a factor, this affects intrinsic motivation accordingly [36]. According to Siegert and Taylor [36], intrinsic motivation can increase perceived competence.

1.2.2 Conclusion

Based on the analysis of the context from the previous section, it is possible to come up with an approach.

As to answer the question:

- 'What are the factors and beliefs that influence the behavior of stroke patients?'

Figure 1.2 gives an overview of answers to this question.

A potential strategy could be to include all the elements mentioned in the conclusions from the previous sections. This might become too complicated since this focuses on a multitude of requirements.

Ryan and Deci [34] give numerous examples in the health domain where if patients received autonomy-supportive help, they were more likely to change their motivation and do a wanted behavior. If the patients reach competence as well, they are also more likely to do exercises regularly.

Based on what Ryan and Deci [34] said, it is the most profitable in this context to aim for autonomy and perceived competence. According to Schunk and Zimmerman [39], forms of internal extrinsic motivations are often combined with intrinsic motivation to create a wanted effect. Based on that, a combination of Intrinsic motivation, and Integrated Regulation or Identified Regulation could be the best course of action. The HBM and SDT give some examples of how to achieve autonomy and competence as well.

Chapter 2

Related work context

2.1 Understanding related objects

This chapter presents information on interactions of related work. This is a Persuasive Technology concept that can help to guide to a seamless experience [13]. In this case, specifically implicit interactions. Implicit interactions enable products/systems to interact with users [40]. Implicit interactions aided in creating seamlessness in the eventual design. Identifying interactions of related work revealed gaps in this study area. This constructed design opportunities. Therefore, the first section goes into implicit interactions. After that, the following sections put the related work into the perspective of the Implicit Interaction Framework.

The research questions that were answered in this chapter are;

- “What are the boundaries of implicitness?”
- “What kind of implicit interactions take place in current work?”

2.2 Implicit interactions

Seamless design could benefit from implicit interactions. However, the question remained what an implicit interaction represented. According to Serim and Jacucci [41] there are multiple definitions for implicitness in the Human Computer Interaction (HCI) domain. In their research, they explained the differences several researchers use in the field. The different forms of implicitness the researchers described about were; unintentional, unawareness, implicature, unconsciousness, and attentional background. This report concentrates on attentional focus since the prototype should be seamlessness, which is based on low cognitive thinking. Therefore, the next sections discuss the Implicit Interaction Framework.

2.2.1 Attentional Focus

Ju and Leifer [40] concentrated on the attentional focus implicit interactions need. According to Ju and Leifer [40], there were several forms of implicit interactions.

Ju and Leifer [40] made a distinction between foreground and background interactions. Foreground interactions need the user's attention, background interactions evade the user's attention [40]. They stated that interactions commenced by users create reactive interactions, and interactions started by systems are proactive interactions. With these principles, the researchers derived a concept, namely the Implicit Interaction Framework. Figure 2.1 shows the Implicit Interaction Framework. The framework makes a difference between foreground-background and reactive-proactive interactions. Foreground interactions tend to appear in the foreground of the attentional span of users. Background interactions do not take attention from the user. Reactive interactions require users to act, Proactive interactions are initiated by the system.

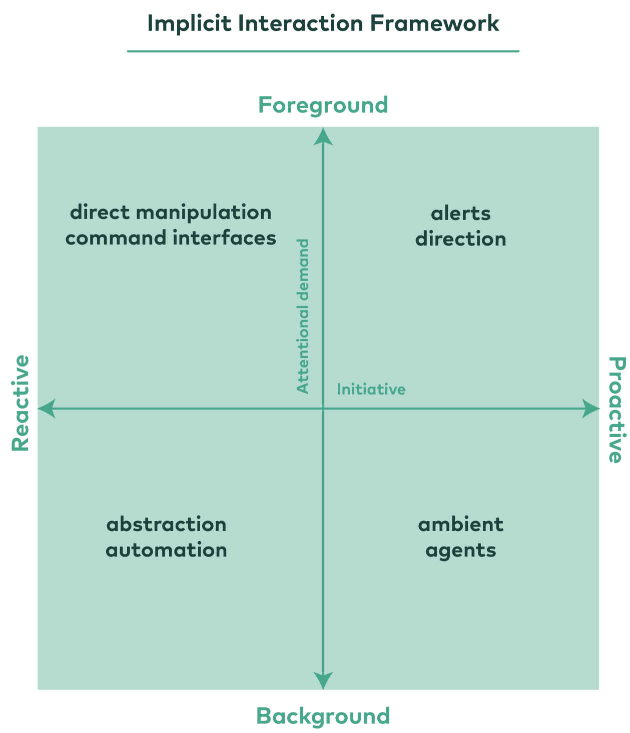

Figure 2.1: Implicit Interaction Framework. Framework taken from Ju and Leifer [40]

Related work in Implicit Interaction Framework

For the sake of this research, the related work was put in the Implicit Interaction Framework. As mentioned by Schmidt [42], implicit and explicit interactions can coexist, and this was the case for all these objects. It was not possible to state for every interaction if it was implicit or explicit. Therefore, the objects were regarded as a 'whole'. The placing of the objects was an indication, rather than an exact answer. Figure 2.2 shows the related work in the implicit framework. As can be seen, a circle indicates roughly where the objects are located in the framework.

In the related work, there were five different groups.

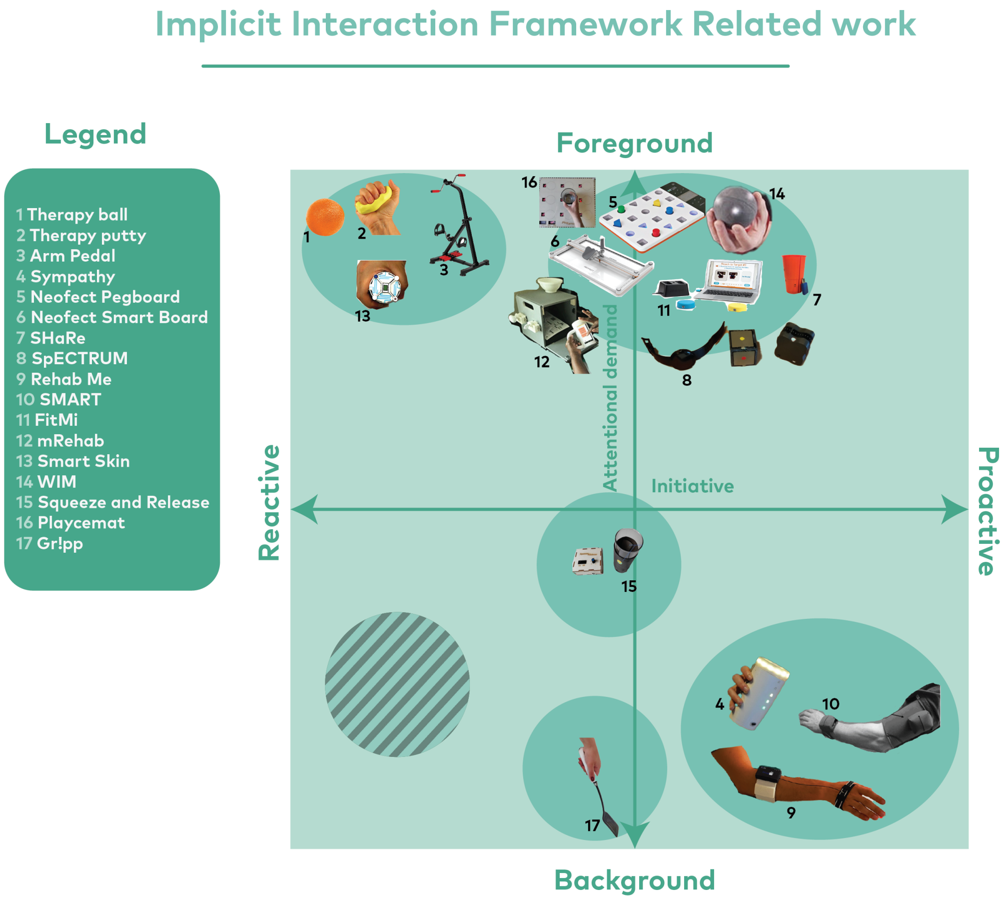

Figure 2.2: Related work in the Implicit Interaction Framework

The first group contained reactive and foreground-centered objects. These objects did not give feedback to the user. This included the therapy ball [8], therapy putty [9], arm pedal [43], and Smart Skin [44].

The second group was spread in the middle of reactive and proactive. These devices gave indications and alerts to the patients on what to do. The users needed to actively use the devices. Moreover, the gadgets required some attention. These devices were, PlayCemat [15], Neofect Pegboard [45], Neofect Smart Board [10], SHaRe [46], WIM [47], SpECTRUM [48], FitMi [49], and mRehab [50]. See Figure 2.2 where this group lies.

The third group involved tracking devices that can collect data on the performance of a patient. These objects operated in the background. They required the user to act, but are more on the proactive side compared to the other two groups. Rehab me [51], SMART [52], and Sympathy [53] were such systems.

The fourth group involved objects that give indications of what users should do. But they acted in the background of the attentional demand. The system did not act on its own but is neither proactive nor reactive. The system was integrated into a daily activity. This system was Gr!pp [14]

The fifth group presented the object Squeeze and Release [15]. Just like the previous group, the object was neither proactive nor reactive, but somewhere in the middle. The system gained more attention from the user than the previously mentioned group. It was integrated into a daily activity. Therefore, it lies more in the background.

The other black-green textured circle indicated the area of interest for this report. There seemed to be a clear gap in this area in this context. An object in this area could reach the goal of seamlessness interactions.

Conclusion related work

As can be seen, there were reactive objects that appeared to be in the background. The differently textured circle indicated the area of interest. The concept should lay in the background. Figure 2.2 shows that most of the ADL-based objects (namely Sympathy [53], Gr!pp [14], and Squeeze and Release [15]) appeared to be in the background. None of these objects was extremely in the background and on the reactive side. Therefore, the idea was to create a prototype in this area.

As for the answers to the sub-research questions, the boundaries of implicitness occurred in different forms based on unintentional, unawareness, implicature, unconsciousness, and attentional background. As for what kind of implicit interactions transpired in current work, Figure 2.2 gives an overview of the implicit interaction in the Implicit Interaction Framework.

Chapter 3

Observations

As a previous study stated, co-design is a fruitful method to create a design [11]. Currently, there were quite some studies that indicated which activity users would like to perform exercises with [15], [54]. However, Hover [15] mentioned that one of the limitations involved not having users in the design phase. Therefore, this thesis involved users and investigated which ADL is the most fitting. The goal was to find the most fitting ADL and to understand what activity the participants would prefer. This was done through sessions that occurred at the homes of the participants. All the activities were audio recorded. Each session took about two to three hours, with breaks in between.

The research questions that are answered in this chapter are;

- "What daily activity is most fitting in this context?"
- "What daily object is most fitting to that activity or context?"

3.1 Participant characteristics

The participants had no cognitive impairments, hand function to some extent, and were stroke survivors. The last stroke ranged from half a year to five years ago.

These observation sessions were approved by the Computer and Information Sciences (CIS) Ethics Committee of the University of Twente. The ethical application request number was 230219. Appendix A shows the consent form and the information letter from these observations. Additionally, a follow-up feedback session for these participants was approved. Two former stroke patients participated in the observations. The participants were 50 years or older and both suffered a stroke around 2 to 3 years ago. Both participants had their right hand affected, and for both, this was the dominant hand.

Participant 1 had regained most of his functionality in his affected hand. He was highly motivated and had a short rehabilitation process. He no longer needs therapy.

Participant 2 had no functionality in her hand and had very low motivation. She still followed group therapy and used her affected hand where possible.

3.2 Methodology

During the observations, the following ADLs were investigated: 'Eating', 'Household appliances and daily technology', 'Personal grooming', 'Dressing', 'Doing housework', 'Drinking', and 'Preparing food'. The choice was based on research from Hover [15] and findings from Timmermans and colleagues [54]. See Appendix B for the rating and motivation of the ADLs.

During the sessions, the participants performed these ADLs. After each ADL the participants filled in a survey taken from Day Reconstruction Method (DRM) [55] and the National Aeronautics and Space Administration (NASA) task load index [56]. Based on the answers, a short unstructured interview transpired after each ADL. See appendix C, 'During observations' for the questions. Periodically, the researcher inquired participants if they desired a break.

DRM is a method to evaluate the feelings that occur during daily activities [55]. DRMs seemed like a valuable way to scientifically determine which ADL fits best. This research only used the last survey from packet 3 [57].

The NASA task load index could help with understanding which activities might be more or less fitting [56]. Temporal demand and frustration were left out. Temporal demand was not of interest to this research, and the DRM included frustration.

The participants decided which ADL they wanted to perform. During the sessions, the participants thought aloud while performing ADLs. While they performed the tasks, the researcher asked questions and wrote down notable moments or quotes.

After the ADLs were completed, the researcher asked the participants additional questions. Appendix C, 'After the observations' shows this semi-structed interview.

In the end, the researchers thanked the participants and rewarded them.

3.3 Findings

Please note that participant number 1 performed all the ADLs, except for the grooming. Participant number 2 did all the ADLs except for household activities. The next sections explain the findings of the observations.

3.3.1 Similar observations

During the observations with participants 1 and 2, both participants wanted a rehabilitation object integrated into a difficult activity. For them, the exercise would only matter if they could see improvement in the struggling activity. For participant 1, this was the case for using the remote controller. For participant 2, this was the case for all the activities.

Both participants saw the value in doing an exercise while waiting. Most of the waiting time occurred in the kitchen for participant 1. Participant 2 commented that she often has to wait due to her disability throughout the day. In that case, she wanted an exercise while watching the television.

Participant 1 liked the idea of having some kind of visual feedback, to indicate how well he is performing. He wanted to have a professional take a look at his progress over time. Participant 2 wanted feedback but was unsure of what form that could take. She said that the feedback should be adaptable, based on whether she has a bad or good day.

3.3.2 ADLs from observations

Based on the observations, it was possible to determine a fitting ADL. This was done with the previously used table. In this case, the table got 'Safety' added as a criterion. See Figure 3.1 for the rating of the ADLs based on the observations. The final ADL had at least a + in 'Low mental workload' and 'Safety'.

The top two ADLs were: Brushing Teeth and Watching Television. Both of these ADLs scored high. Both of them had a low mental workload, room for exercise, and were safe for the users, compared to the other ADLs.

ADL	Duration	Frequency	General population	Home	Either hand	Specific object/environment	Low mental workload	Room for exercise	Safety	Score
Brushing teeth	+	+	+	+	0	+	+	+	+	8
Drinking	+	+	+	+	+	+	+	+	0	8
Housework	+	0	+	+	+	+	0	0	+	6
Tea/Coffee	+	+	+	+	0	+	0	0	-	4
Dishes	+	-	+	+	-	+	-	-	-	-1
Eating with cutlery	+	+	+	+	+	+	-	0	+	6
Prepare food	+	+	+	+	+	+	-	-	-	3
Dressing	+	-	+	+	+	0	-	-	+	2
TV	+	+	+	+	+	+	+	+	+	9
Washing oneself	+	+	+	+	+	0	0	+	0	6

Figure 3.1: Rating the ADLs based on the observations. The + states that it was fitting, the 0 indicates that it was unsure or might be fitting, and the - shows that this label did not occur.

3.4 Limitations

A limitation was that only two participants aided with these observations. This likely created a bias towards the preferred ADLs. Moreover, one of the participants did not want to brush their teeth in front of the researcher.

While this number was limited, the two participants showed the boundaries of this context. Participant 2 was heavily impacted by the stroke. This resulted in understanding the severity of the disability. Based on that, it was easier to determine the most fitting ADL, since on 'bad' days other stroke patients might be more like participant 2 than participant 1.

Participant 1 showed on the other side of the boundaries. Participant 1 was minimally affected by the stroke. It became clear that certain ADLs fit better, and he made comments as to what makes sense for him to improve on.

3.5 Conclusion

To answer the sub-research questions:

- "What daily activity is most fitting in this context?"
- "What daily object is most fitting to that activity or context?"

We discussed the options in this section. Looking at the observations, two ADLs seemed to be the most interesting. This was the Brushing Teeth and Watching Television ADL.

Brushing teeth was a fitting ADL because it takes place in a standard setting, everyone performs the activity, it has a low mental workload, there is room for exercise, and the activity is safe.

Watching Television was a fitting ADL because most people do it, it takes place in a standard setting, it requires a low mental workload, there is more than enough room for exercise, and it is safe.

These two ADLs were different. For one, the Brushing Teeth ADL made sense to perform an exercise during the activity, since the activity itself is rather short. It was an activity that one must perform every day, in a standardized setting. The participant is actively performing this activity, and it comes naturally to most people. That was a reason to integrate an exercise into this activity. An active activity was more in line with the current objective of this thesis.

Watching Television, however, is a leisure activity. It can take a long time, and as participant 2 indicated, this is an activity that she performs when she needs to fill up time. This would be considered as some kind of 'waiting' activity. This was not completely in line with the initial objective of this project. It was an experience that was less focused on doing something. It was about experiencing media and being a passive bystander. Watching Television might become too much of a distraction for users.

Therefore, brushing teeth fell more in line with the project, and was the ADL this research focused on. Based on that, the second sub-research question could be answered as well. In this case, the daily object most fitting for that activity was a toothbrush.

Chapter 4

Brushing teeth

Since the ADL was chosen, this chapter looks into the ADL in more detail. This chapter tries to find design opportunities and inspiration for the ideation process. Because of that, this chapter looks at different aspects of brushing teeth. First, the chapter indicates how one should brush their teeth. After that, field observations occurred. After that, the current state of the art for toothbrushes was analyzed.

4.1 Brushing teeth

Brushing should be done twice a day, for at least two minutes. When brushing with a hand brush, the toothbrush should be held at a 45-degree angle. The brush should cover a part of the gum. Brushing should be done gently.

A brush should move back and forth in short strokes. Brushing could be done in different sections. It is important to brush each tooth to get rid of any bacteria and plaque. The toothpaste should have fluoride to ensure that the teeth become clean. Preferably, a toothbrush is replaced every three months [58]–[63]. Figure 4.1 shows how someone should brush their teeth correctly.

4.1.1 Field observations

Four simple field observations were held to understand the design context. Four different people participated. The participants were filmed and informally interviewed while they brushed their teeth. Two participants were right-handed, and two participants were left-handed. Two participants were male, and the others were female. Participant 2 used an electrical toothbrush, the others used regular hand brushes. The age of the participants ranged between 20 and 26 years old.

During the observations, participants 1, 2, and 3 varied in their grasp. The medium wrap, Thumb 3 finger extensions, and the light tool grasp occurred frequently. Participant 4 only used a medium wrap and an adducted thumb grasp. Moreover, participant 1 used an index finger extension for a brief moment. See Figure 4.2 for all the different grasps.

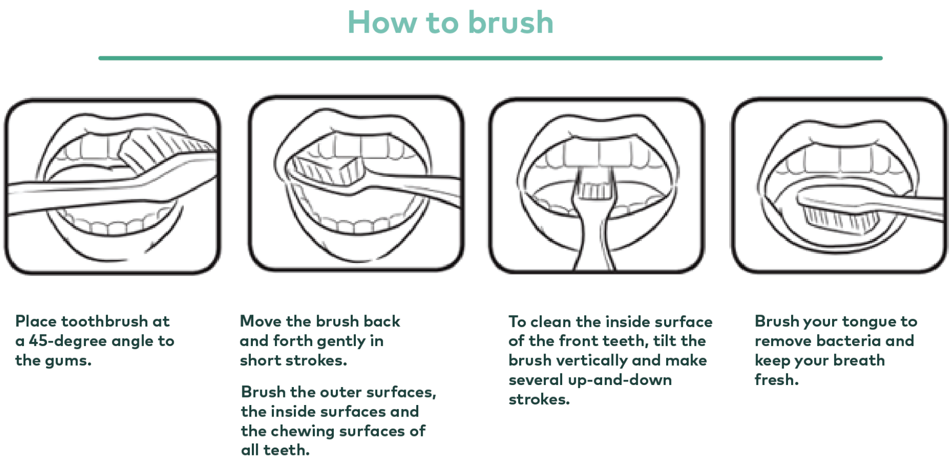

Figure 4.1: How to brush your teeth correctly, image taken from ADA [63]

Participant 4 had less different grasps because of the shape of the electric toothbrush. As can be seen in Figure 4.2, the electric toothbrush was bigger and sturdier than the regular hand brushes. All the participants made wrist motions while they brushed their teeth. None of the participants changed hands during the activity.

During the observations, the users did not tend to stay in one place while brushing their teeth. They tend to wander around for a bit. Moreover, most of the users tended to watch their mobile phones. Some stated that they use the mirror, while others said that they never look at it while brushing. All of them stated that they often tend to lose track of time and continue to brush their teeth for much longer than two minutes. Three users used their dominant hand to brush their teeth, the user with the electric toothbrush did not.

As for the setting, the participants have similar settings. All of them have a mirror and a place for their dental hygiene items, together with other cosmetic creams and self-care products. The participants all had a sink as well.

Conclusion field observations

It became clear that the shape and functions of the toothbrush impacted the different grasps a person performed. The participants used different grasps while brushing their teeth, and manipulated their wrists in various motions.

4.2 Toothbrush state of the art

Toothbrushes come in different forms. This report makes a distinction between regular brushes and brushes for individuals with restricted hand movement.

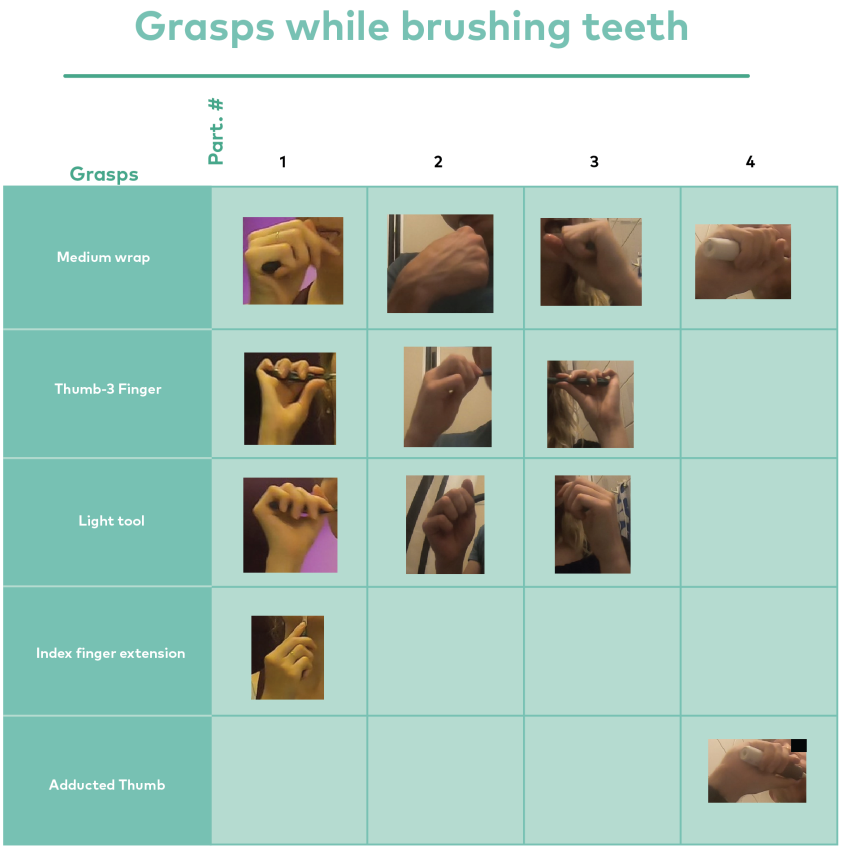

Figure 4.2: Different grasps during the toothbrush observations

4.2.1 Regular brushes

Regular brushes had a separation between hand brushes, electric toothbrushes, sonic toothbrushes, and hands-free toothbrushes. See Figure 4.3.

A regular toothbrush, or a manual toothbrush, is the most basic form of a toothbrush. An electric toothbrush is electrically powered to rinse the teeth more effectively. A sonic toothbrush has the same principle as an electric but is faster and quieter. Finally, a hands-free toothbrush requires only minimal movement from the hand of the user. For each of these brushes, there are some variations in the bristles and handles.

Effectiveness

Deery et al. [64] stated that the effectiveness of a manual and an electric toothbrush have no significant difference. The researchers stated that a specific type of electric toothbrush reduced plaque. However, the researchers were unsure if that was significant enough to be more effective. Re et al. [65] on the other hand, indicated that a sonic toothbrush seemed to be more effective than a manual toothbrush.

Singh [66] argued that their hands-free toothbrush created a 'clean' feeling for the users.

Regular toothbrushes

Toothbrush	Material	Form	Specialties
Regular hand brush 	Plastic Wood Bamboo Silicone	Different angles Small long rod form	-
Electric toothbrush 	Plastic	Thick long rod form	Requires less movement from user than regular
Sonic toothbrush 	Plastic	Thick long rod form	Is quicker with removal from plaque than electric
Hands-free 	Plastic	Mouthguard with circular form	Requires very minimal movement from user

Figure 4.3: Regular toothbrushes

Yet, the researchers did not support that conclusion with findings. Moreover, research suggested using hands-free U-shaped toothbrushes was the same as not brushing [67]. Other experts stated that this tool is not effective in cleaning teeth [68], [69].

4.2.2 Toothbrushes for people with restricted finger movement

Figure 4.4 shows different toothbrushes that are used by individuals with restricted hand movement. The figure shows customized handles, customized bristles, electric toothbrushes, and additive features.

Dickison and Millwood [70], Colvenkar et al. [71], and Pasiga and Dewi [72], made customized handles for people with restricted hand movement. The designs varied from plain balls to organic forms. All concepts focused on letting the user hold the toothbrush, without making it fall.

The customized bristles involved toothbrushes with curved bristles [73]. The bristles were curved so that they could touch each side of a tooth.

The electric toothbrush was recommended after a stroke because of its ease [74]. During the user observations, participant 2 could only use an electric toothbrush. A manual was too hard to grasp.

The 'additive features' category involved a toothbrush with an extra handle. The handle toothbrush [75] could not fall from the user's hand.

Restricted hand movement toothbrushes

Toothbrush	Material	Form	Specialties
Customized handle	Plastic Silicone Household items (tennis ball, towel)	Easily grabable handle, often imprints of fingers or organic form	Handle is added to grab and hold it easily
Customized bristles	Plastic	Thin long rod form	More bristles are added so user does not need flexible wrists
Electric toothbrush	Plastic	Thick long rod form	Requires less movement from user than regular and is easier to grab
Additive features	Plastic	Thick long rod form with strap	Makes sure toothbrush does not fall off

Figure 4.4: Toothbrushes for people with restricted finger movement

Conclusion on restricted hand movement toothbrushes

The current state of the art gave inspirational features for the ideation phase. Especially the form of the handle, the different kinds of bristles, and the additive features.

Chapter 5

Exercises stroke patients

This chapter tries to answer the following sub-research question:

- ‘What exercise can be incorporated (into this activity or with this object)?’

Naturally, it was necessary to know which exercises the patient did. This chapter looks at current exercises for hand-stroke patients. Additionally, the preference for exercises on different levels was explored.

5.1 Exercises

Since it was clear what the context is of the user group, it is possible to dive deeper into certain aspects. The following sections discuss different hand grasps and exercises.

One of the previous works this research was based on gives an overview of different hand exercises for stroke patients [15]. The exercises involved different categories, namely; Strength, Dexterity, Coordination/Control, and Range of Motion. This thesis used these categories.

Strength aims to regain power in the affected limbs. Stroke patients tend to lose grip strength in their limbs, for instance in their arm and/or hand [3], [76].

Dexterity implies the loss of fine motor skills in limbs. Often, the fine movement of the hand and the fingers becomes difficult for the patient [76]. Holding, reaching, and extending are challenging.

Range of motion dives into the ability to move the joints in certain directions [77]. In this context, the stroke can influence the movement of the shoulder, elbow, and wrist.

Coordination/Control covers all the control the patient has after a stroke [78]. Movement always concerns numerous muscles, therefore all the exercises from the other categories can influence this skill.

For each exercise, a ‘Level of Difficulty’, ‘Opportunity of transferability’, ‘Duration’, ‘Either hand’, and ‘Specific Object/Environment’ was added, to see if the exercises were transferable in possible ADLs.

The levels were divided into two sections, namely; orange exercises and pink exercises. This concept was taken from one of the exercise brochures. Orange exercises are movements for patients who regained most of their functionality. Pink exercises involved people with some functionality in their limbs [79]. Stroke patients urge to be able to change the difficulty level of a rehabilitation object [13]. Therefore, this information was sorted out. The level of difficulty was taken from what the provider of the exercise deemed as a beginner or advanced level. The brochures had a third level, which included exercises for patients who have no functionality in their limbs. Since this group does not belong to our user group, the appendix does not show these exercises.

As for the 'Opportunity of transferability', the exercise had to feel natural and be applicable in an ADL. The 'Duration' and 'Either hand' indicated if the exercise fitted, as did the 'Specific Object/Environment'.

Appendix D shows all the exercises taken from different sources [80]–[83]. The appendix shows the exercises on different levels, and in what category they belong. The pink levels mainly focused on strength and fine motor skill exercises. The orange levels were focused on exercises in fine motor skills.

5.2 Preference Exercises

Basteris and Amirabdollahian [84] noticed that patients with severe disability preferred exercises based on wrist motions. Stroke patients with milder disabilities wanted to train their hand functionality.

Timmermans and colleagues [54] stated that patients wished to train in fine motor skills, like grasp and manipulation.

5.3 Requirements exercise

Langerak et al. [85] studied the requirements for arm-hand stroke exercises that need to take place at home. The researchers looked at the features of a rehabilitation system, and the requirements for exercises. The researchers showed a table of what each exercise should have.

It was possible to state the following; the researchers explained that it is essential to use repetitive exercises that are task-oriented. The researchers urged that the patients must be able to choose between exercises and the intensity of the said exercise [85].

5.4 Conclusion

Based on this, the exercises should be adaptable to the user and have the ability of personification regarding the exercises. Moreover, preferably the exercise focuses on fine motor skills. Severely impacted patients should be able to focus on regaining control and dexterity exercises. More abled patients could focus more on position and manipulation exercises. This is the answer to the sub-research question.

Chapter 6

Features and Behaviour Change Techniques

Based on the information gathered, a list was made of wanted features and wanted Behavioural Change Techniques (BCTs). This chapter explains the features and the BCTs

6.1 List of features

Earlier work [13] discovered key features in the works of Stefess [11] and Hover [12]. Chapter 1 found two features based on the SDT and HBM, namely 'Adaptable goal', and '(Autonomy) Supportive' [27], [34].

Additionally, Langerak and colleagues [85] displayed features for a home-based rehabilitation device. The researchers presented a list with 33 features based on the 'Must have', 'Should have', 'Could have', and 'Will not have' (MoSCoW) technique. This thesis only focused on the must-have features. Most of the must-have features were integrated into the previous list [13]. However, the blended care features and exercise features from Langerak et al. [85] were missed in the initial list. The blended care features were not applicable in this context, therefore they were disregarded. The exercise features are; 'Shows the exercise' and 'Supplies the exercise' [85]. These features were added to the list. In an ideal setting, the system could supply an exercise. Additionally, the system shows how to perform the exercise correctly. This makes the whole experience more pleasant for the user [85].

Figure 6.1 shows the final list of all the recommended features based on literature and related work. The ideas from the brainstorming session were set against this list to determine which ideas were the most promising.

6.1.1 Seamlessness

'Seamlessness' appeared on this feature list. The seamlessness characterizations were based on; simplicity, ease of use, consistent interaction, low cognitive thinking, facilitating everyday usage, being part of a set, and being embedded in a specific environment well-known to the user [13]. These features were set against the designs later on. If there was a possibility for one of these, the design had a possibility for seamlessness.

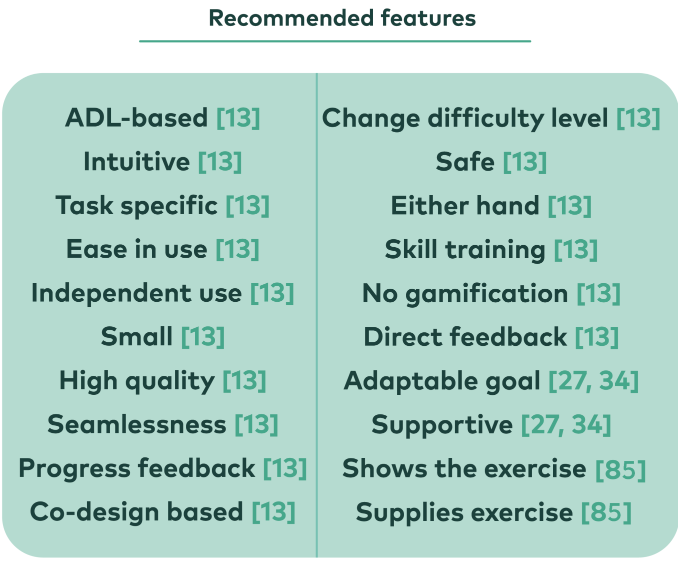

Figure 6.1: Recommended features based on previous work, the HBM and the SDT and the work of Langerak et al. [13], [27], [34], [85]

6.1.2 Seamfulness

Previous work stated that a design should aim for a mix of seamfulness and seamlessness [13]. However, seamfulness is not on the list of recommended features. This is the case since it was difficult to adhere to both of these concepts at the same time. Moreover, the characterizations of seamfulness were hard to measure. Studies did not indicate how to measure seamfulness [13]. Moreover, this design aims for a high level of seamlessness, and a low level of seamfulness. It is not possible to achieve 100% seamlessness, but it might be that remaing features are seamful. To make it less complex for the participants, no questions were asked about seamfulness. The design was later rated against this feature by the researcher.

6.2 Behavior Change Techniques

Five BCTs were deemed as suitable in this context [13]. This list involved: ‘Goals and Planning’, ‘Feedback and Monitoring’, ‘Associations’, ‘Repetition and Substitution’, and ‘Self-Belief’. Moreover, ‘Associations’ and ‘Repetition and Substitution’ relate to a concept of seamlessness, so these BCTs get extra attention [13]. For the concepts, we concluded if one or more of the BCTs were integrated.

Chapter 7

Design methodology

The background information was clear, so it was possible to start with the design of the concepts. To start, an ideation session was held with multiple students. After that, the most promising ideas were further defined. The BCTs were declared and possibly added to the concepts. Consequently, the ideas were compared to a list with recommended features, see the previous chapter. Based on this, a selection of ideas got feedback from users and experts.

Two (former) stroke patients and two experts gave feedback on these concepts in a semi-structured interview. The ideas were adjusted, or eliminated. After that, the most promising ideas were put in the Implicit Interaction Framework, to validate the concepts.

Subsequently, another individual ideation session occurred. The most promising ideas were rated against the features of the previous chapter. The most viable among those ideas was put in the Implicit Interaction Framework to endorse the concept. Thereafter, the most auspicious idea was turned into a prototype, and usability tested.

7.1 First ideation session

The ideation session involved the use of the worst possible idea method [86]. The 'worst possible idea method' is a method to ensure that participants are not afraid of telling their ideas [86]. Not all individuals dare to disclose their ideas for fear of being judged. The worst possible idea method tries to get rid of that bias. First, the participants were informed about the goal of this ideation session. The partakers received background information about stroke patients and exercises. The participants got the following question they needed to answer: 'How might we enable unmotivated patients to do hand-stroke exercises while they brush their teeth?'

Then the actual ideation session transpired. The worst possible idea method started with creating as many bad ideas as possible. The participants got 5 minutes the time to come up with ideas. After that, everyone explained their idea and discussed it with others for 10 minutes. Then all the similar ideas were grouped. The participants ideated for another 3 minutes based on the previous ideas. The step afterward involved mixing bad ideas, which took 5 minutes. The next step involved grouping all ideas and stating the properties of all the bad ideas. Afterward, the participants stated the opposite of the bad property, which required 10 minutes. The participants ideated for 5 minutes based on the good properties to get actual ideas. At the end, the participants explained and discussed their ideas. The participants received food during the ideation session as reimbursement. In the end, the researcher thanked everyone for participating.

At the end of this ideation session, the researcher picked the most valuable ideas and adjusted them accordingly. The ideas were set against the features of the previous chapter. BCTs were added or stated for each idea. The final ideas got a visualization. After that, the feedback session occurred.

7.2 Feedback stroke patients and experts

Two (former) stroke patients and two experts gave feedback on the concepts. The feedback sessions of the stroke patients transpired at their homes, or through a video call. Each session was 45 minutes for everyone. The sessions were not recorded. The researcher took notes. For the experts, the interviews occurred through video calls, for each individually. Everyone received the ideas and visualizations in advance. The stroke patients got an explanation of a set of concepts. They were asked to answer the same set of questions per concept. In the end, the stroke patients got questions about their preferability and several additional features.

As for the experts, the nature of the questions lied in the area of expertise, rather than the user-friendliness. Especially understanding if the exercises were fitting and the target group of the exercises. Appendix E shows the semi-structured interview questions for the experts. In the end, the researcher thanked everyone for helping out. After that, the feedback was analyzed. The experts were either knowledgeable about the patient group or had experience with working with this group.

7.3 Analyzing the feedback

Of all the feedback a matrix was made with the overall opinion, plus points, and downsides from the interviewees. Every concept got a rating based on the comments. At least three people had to appreciate the concept to use it for the next step. If one group collectively disapproved of the concept, the concept was disregarded. Based on the feedback another idea might have emerged. The most promising idea based on this analysis was ready for the next step.

7.4 Implicit Interaction Framework

The next step was to see where the most preferred idea(s) lay in the Implicit Interaction Framework. This was to see how they relate to the related work. If the ideas were too close to already existing groups identified in Chapter 2, another ideation session occurred.

7.5 Second ideation session

The second ideation session was an individual ideation where the researcher tried to create as many ideas as possible. Eventually, ten of the best ideas were picked, and set against the features and BCTs. If possible, the ideas were adjusted to meet more features and BCTs. Eventually, one idea was picked that adhered to most of the features and had at least two BCTs. The exercise of the idea was compared with literature and the feedback from experts.

Chapter 8

Ideation

8.1 First Ideation session

8.1.1 Setting and equipement

The first ideation session was held with three Interaction Technology students and two BMT students. The brainstorming session occurred in the Smart XP, at the University of Twente. All participants got sticky notes and pens to write down their ideas. A whiteboard was there as well, to create an overview for everyone. The student of this project maintained an overview and directed the brainstorming session.

8.1.2 Properties

As previously mentioned, during the 'worst possible idea method' one of the goals was to understand the properties of the bad ideas, and to get the opposite of those properties. Eventually, the opposite of those properties came down to the following words: 'Focus, variety, easy, change of difficulty level, individual, small, reward, feedback, ethical, motivated, soft, ergonomic, steady, light, fitting size'. Based on these words, the group created ideas, that were fitting for the context.

8.1.3 Concepts

The researcher gathered the ideas from the 'worst possible idea method' and iterated on them. Based on that, there were five final concepts. Figures 8.1, 8.2, 8.3, 8.4, and 8.5 show the different ideation ideas.

Every concept should be combined with an application where users can perceive their feedback. All of the concepts had the BCTs *Feedback and monitoring*, *Associations*, and *Repetition and substitution*.

8.1.4 Concept 1

Concept 1 involved a toothbrush with adjustable handles. With a clicking system, users could change the handle of the toothbrush. See Figure 8.1. The upper part of the toothbrush indicated which handle the user should use for that day. The light underneath the handle indicated whether the user held the grip.

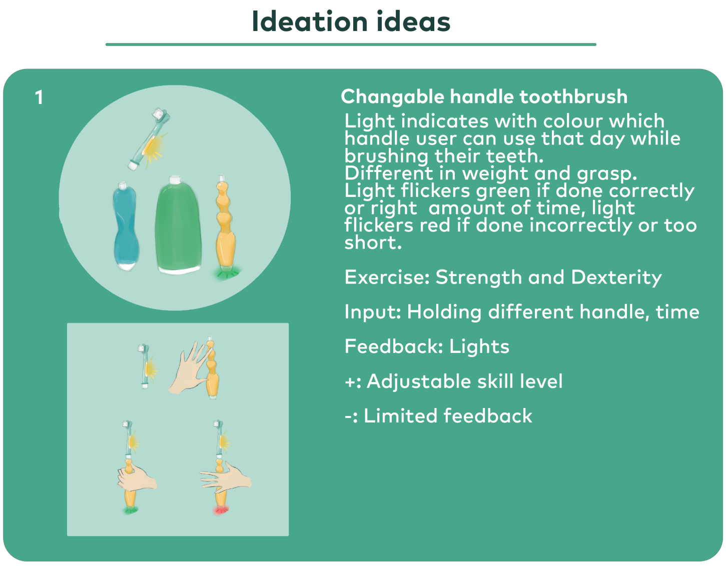

Figure 8.1: Concept 1

8.1.5 Concept 2

Concept 2 describes a toothbrush that indicates where one should place fingers. The concept had an adjustable strap that enabled users to hold the toothbrush securely. The toothbrush could indicate with lights where the user should place their finger on. All the other fingers should be stretched. If the user does that correctly, they get positive feedback with a 'positive' sound. If they are not able to achieve this, they get negative feedback with a 'negative' sound. See Figure 8.2.

8.1.6 Concept 3

Concept 3 contained exercises for the user by showing the exercise the user needs to perform in a smart mirror. The exercises involved different grasps the user should perform. Just like with the previous concept, if the user performed accurately, the toothbrush gave a 'positive' sound. If not, the user gave a 'negative' sound. See Figure 8.3.

8.1.7 Concept 4

Concept 4 concerned a toothbrush the user needed to squeeze in. An application and light indicate to the user how strongly the user should clutch. If the user did this correctly, the same light blinked. If done incorrectly, the light blinked slowly. See Figure 8.4.

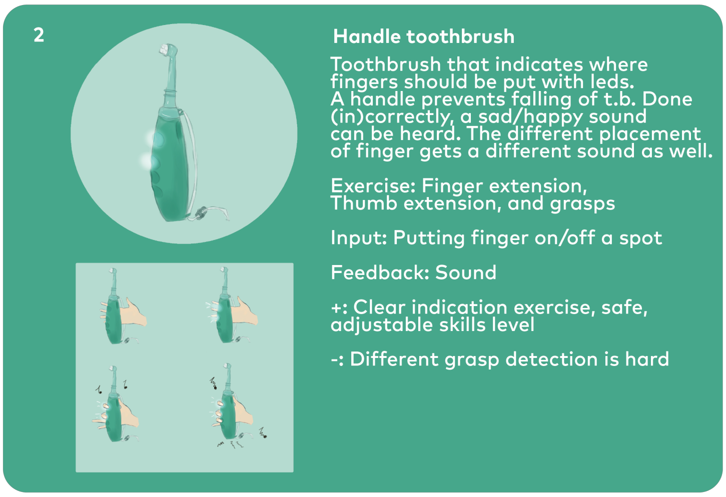

Figure 8.2: Concept 2

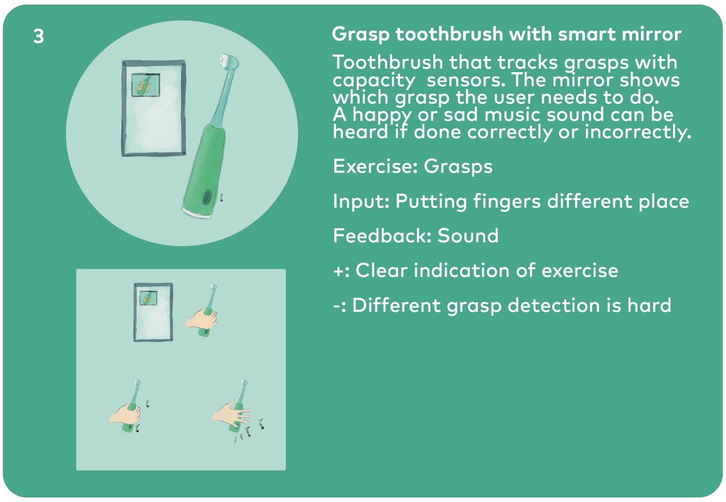

Figure 8.3: Concept 3

8.1.8 Concept 5

Concept 5 contained a toothbrush that could track the wrist movement of a person. A smart mirror indicated which way they should move their toothbrush. Once a user performed the correct movement, the toothbrush indicated the appropriate feedback to the user through sound. See Figure 8.5.

8.2 Feedback

The next step was to ask for feedback from stroke patients. The two (former) stroke patients were the same stroke patients who helped out during the observations. The two experts were both clinical experts.

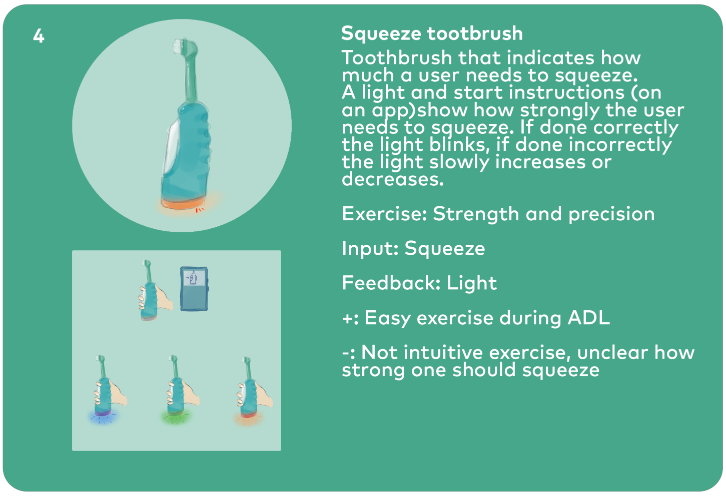

Figure 8.4: Concept 4

Figure 8.5: Concept 5

8.2.1 Findings

Based on the feedback, concepts could be chosen and discarded. See Figure 8.6 for an overview of highlights of comments the users and the experts had on the concepts.

Both the experts and the users reacted positively to Concept 1. The users mentioned that it is adaptable, and the different sizes and forms create a pleasant feature.

Concept 2 was appreciated, but not as much as the first idea. One of the users stated that hand-eye coordination is a very useful exercise. The other user was afraid of the predetermined form of the concept. The second user said it was a relevant exercise. The experts were divided on the concept. The first expert endorsed the idea and thought the exercise was appropriate. The second expert, however, disliked the idea. The concept is only for motivated people and the exercise is challenging.

Both of the users liked Concept 3 since the exercise seemed useful. The experts did not think the same way. One expert stated that users only need to open and close their hands for a similar exercise. The current exercise is too challenging for patients.

The users disliked Concept 4 and Concept 5. Concept 4 since it was not intuitive. Concept 5 was too difficult and complex. The experts on the other side liked both of these ideas. This was because the exercises were for people with limited functionality. Eventually, concepts 3, 4, and 5 were disregarded. This was because at least one whole group disliked the idea. That left Concept 1 and Concept 2. Concept 1 seemed to have the potential to become a useful idea, especially if one might be able to combine it with Concept 2.

8.3 Conclusion

Figure 8.6 shows that Concept 1 and Concept 2 adhered to the rule that at least three people approved of the concept. Concept 1 seemed fitting and adhered to most of the features addressed in Chapter 6. However, it was not near the wanted interaction. Based on the Implicit Interaction Framework the goal was to have a Reactive and Background interaction. While the concept appeared to be seamless, the concept might benefit from being reactive and in the background. See Figure 8.7 to see an estimation of where the concepts are in the Implicit Interaction Framework. Moreover, Concept 1 was especially close to the former project Gr!pp. Gr!pp aimed to change the users' movement through the design of the handle. The project could be considered as being in the background, but more on the proactive side. Concept 2 appeared to have more attentional demand, so, therefore, the concept was in the foreground. It was similar to Playcemat. Since these concepts were still not in the area of interest, so another ideation session occurred.

8.4 Second Ideation session

The second ideation session was an individual brainstorming session. During the brainstorming session, the goal was to create as many ideas as possible. Eventually, 39 ideas were written down. The top ten of these ideas were set against the wanted features from Chapter 6. Based on that, one idea was the most promising.

8.4.1 TumbleTooth

This idea involved a toothbrush that rotated its 'head' while the user was brushing their teeth. Because of that, the user needed to correct the toothbrush by rotating their wrist to brush appropriately. An additional feedback form was embedded in the charger system of the toothbrush. The stand was modified, with LEDs and a buzzer that indicated if the users rotated to the correct side. TumbleTooth involved three different difficulty levels the user could pick from. In the first level, the toothbrush only rotated from one side to the other for one time in the first minute. For the second level, it became two times in the first two minutes. For the third level, it became three times in the first three minutes. During the observations of brushing teeth with healthy people, all the users mentioned that they brushed longer than two minutes. Stroke patients tend to need more time for regular activities, therefore the

Rating of the concepts

Concepts		User #1	User #2	Expert #1	Expert #2
	1	Preferred idea, +: Adaptable -: Should not focus on punishment or reward.	Preferred idea, +: Difference in size and form -: The light should be at a different place	Liked idea, +:Great exercise for a large group. -: No comments Level: limited to high functionality	Preferred idea, +: Practical. -: Should also let users know how well they brush. Should only use cylindrical forms. Level: semi-limited to high functionality
	2	Liked idea, +: Hand-eye coordination useful exercise.	Liked idea, +: Good exercise -: Predetermined form is for one hand size. Placing fingers is difficult.	Liked idea, +: Good exercise, -: A bit smaller group than concept 1 Level: very limited functionality	Disliked idea, +: No comments -: Only for motivated people. Really difficult exercise. Level: only high functionality
	3	Preferred idea, +: Useful exercise. Liked the 'sad' and 'happy' sound. -: Smart mirror is not for him.	Preferred idea, +: Especially if the sensitivity of the placement can be different. -: Disliked smart mirror.	Disliked idea, +: No comments -: Grasps are too difficult,only need to let them open and close the hand. Level: too high	Disliked idea, +: Smart mirror -: Different grasps are too difficult. Level: high functionality
	4	Disliked idea, +: No comments -: Squeezing is not intuitive. Combination with application is not for him.	Disliked idea, +: Application is nice -: Really easy exercise so does not see the value.	Liked idea, +: Great exercise. -: Should add smart mirror Level: limited functionality.	Preferred idea, +: Squeezing is a great exercise. -: While turning their hand it is difficult Level: limited functionality
	5	Disliked idea, +: Good exercise for others. -: Smart mirror and difficult to do exercise while brushing.	Disliked idea, +: No comment -: Dislikes smart mirror. Especially 'happy'/'sad' sounds should go away.	Liked idea, +: Good exercise -: Exercise seems difficult while brushing teeth. Level: limited functionality	Liked idea, +: Wrist movement is a great exercise. -: Challenging while brushing teeth. Level: High functionality

Figure 8.6: Feedback from users and experts

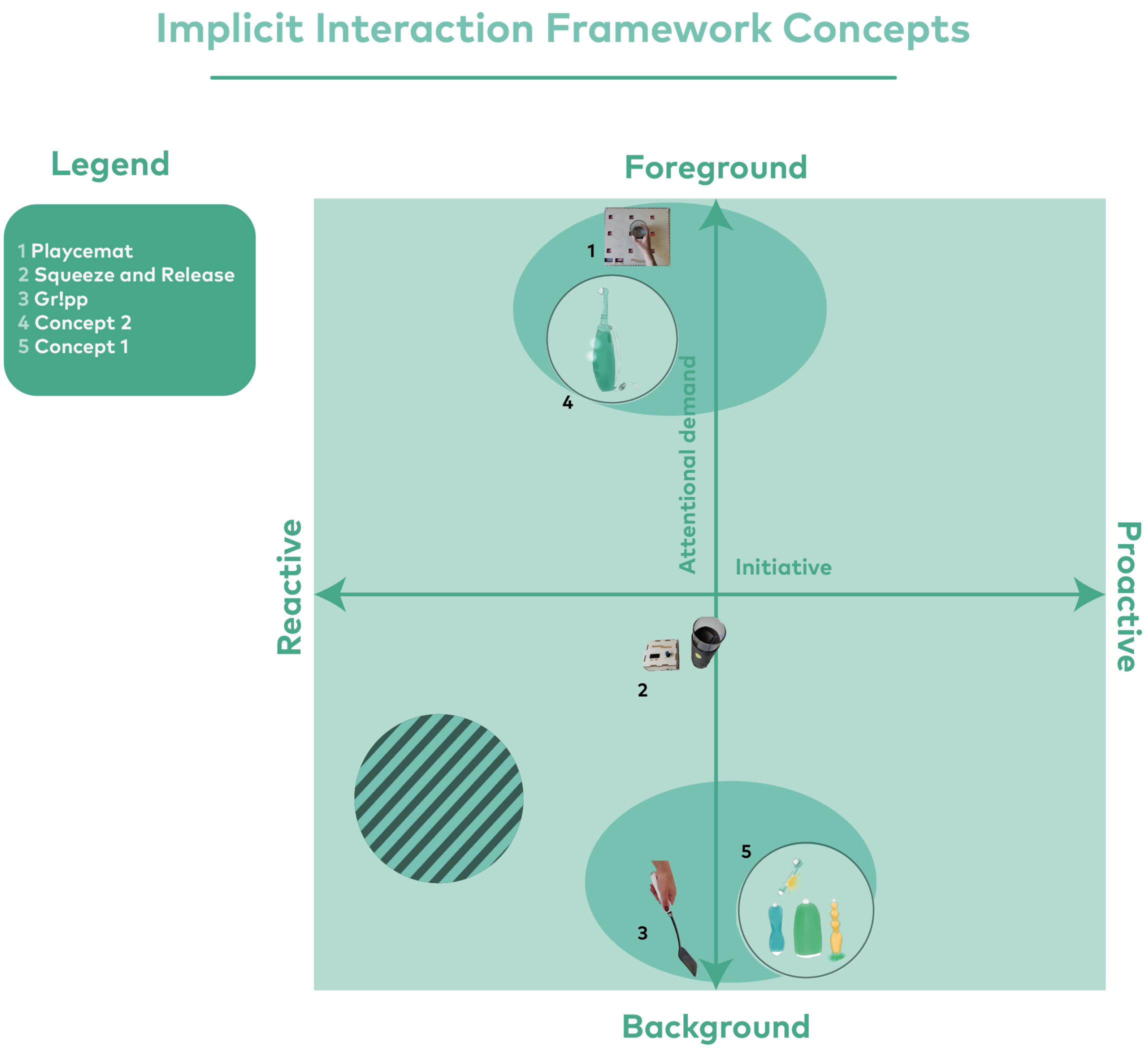

Figure 8.7: Estimation of where the concepts are in the implicit interaction framework. The green circles indicate where the concepts probably stand in this framework, and the differently shaded circle indicates the area of interest.

TumbleTooth stopped after 5 minutes. TumbleTooth had the option to indicate if the person was left-handed or right-handed. The idea was that the user could get insights into their performance. The user got an indication of the difficulty level, their performance, and their time. See Figure 8.8 for a conceptualization of TumbleTooth.

Figure 8.8: Final design of TumbleTooth

8.5 Exercise

Basteris and Amirabdollahian [84] indicated that people with a severe disability favor doing exercises based on wrist motions. Both of the experts indicated that wrist motion is a good exercise. However, they were divided on what the exact level was. Since it was a good exercise according to the experts, this concept was kept.

8.6 Seamlessness and seamfulness

When looking back at the seamlessness characterizations, some characterizations were already met because the concept was based on an ADL. Seamlessness was based on simplicity, ease of use, consistent interaction, low cognitive thinking, everyday usage, part of a set, and embedded in a specific environment/context well-known to the user. TumbleTooth adhered to: it is part of a set (brushing teeth) and it is in a specific environment (brushing teeth). As for the other characterizations, a user test had to transpire.

As for seamfulness, these characterizations were hard to measure. It was possible to state that the prototype has recognizable visible features, and the idea was to create different difficulty levels. These features were both considered seamful features. But it was not possible to tell if this design enabled design for/with uncertainty, or that it empowered individual assumptions. The user evaluation did not look into this concept. It is not possible to aim for 100% seamlessness [13]. But, perhaps if a design had seamless design features, automatically seamfulness features appeared. Moreover, it was not known how many seamful features were needed to get to the wanted mix.

8.7 Limitations

The outcome of the second ideation session did not receive feedback from the experts or the (former) stroke patients. The goal was to involve users in this process. However, there was fear that the users might not be able to understand this concept. Especially if they could not experience it. The knowledge gained during the interviews was applied to this new concept. Perhaps this omitted the problem.

Chapter 9

Prototyping

The eventual concept was developed in this phase of the project. The following sections illustrate the hardware of the concepts, and the slight changes between the concept and the actual prototype. Figure 9.1 shows the final design of TumbleTooth.

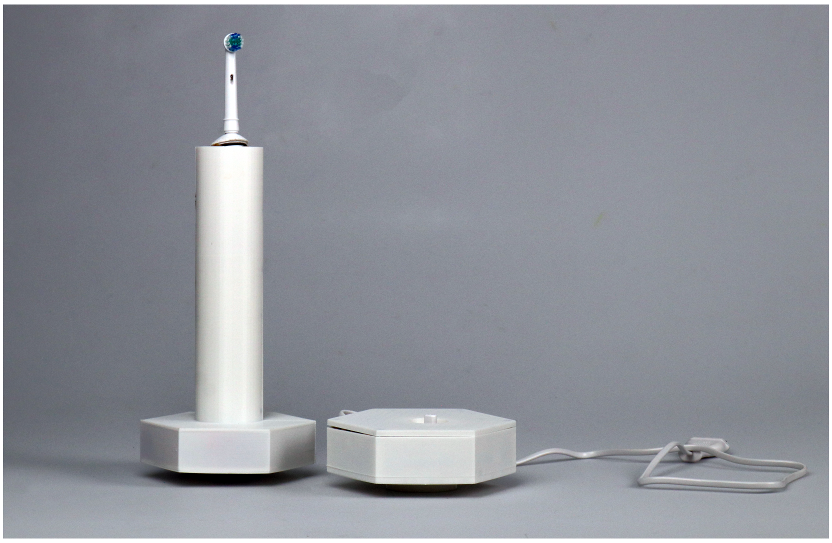

Figure 9.1: Final design of TumbleTooth

9.1 TumbleTooth

9.1.1 Differences concept and realization

Hover and colleagues [12] noticed that users were afraid to break prototypes. To omit this problem, the idea was to 3D print the cast of the toothbrush and the charging station. However, it was difficult to make sure that the electronics were not affected by water with this material. Therefore, the current prototype was not waterproof. While that was unfortunate, it did not restrict testing this concept for usability.

For safety reasons, TumbleTooth was able to detect friction when a user brushes with it. If the head of the toothbrush smacked an obstacle, the toothbrush stopped rotating. After that, it remained still for five seconds.

9.1.2 Hardware

TumbleTooth consisted of a toothbrush and a charging station for the electric toothbrush. The following sections explain each of the circuits in more depth. Both circuits were soldered.

Toothbrush

For the hardware, an actual electric toothbrush was disassembled to make room for a servo motor to rotate the head of the toothbrush. The electric toothbrush was desoldered, to rotate the head, while still being able to turn on the toothbrush.

The other part of the toothbrush had different electronic components to read, send, or sense. The circuit consisted of a Seeed Studio XIAO ESP32C3, an Motion Processing Unit (MPU) 6050, an ACS712, an ON/OFF switch, an Lithium Polymer (Li-Po) 3.7V battery, and a micro servo. Figure 9.2 shows the circuit connections.

The Seeed Studio is the microcontroller that addresses all the components of the circuit and can get information through Wi-Fi. This was crucial since the feedback system got information wirelessly.

The MPU 6050 is an accelerometer and gyroscope in one. This sensor detected if the user turned their hand accordingly. This was vital for the feedback system.

The micro servo was there to rotate the head of the toothbrush.

The ACS712 can detect the current of the circuit. If the head of the toothbrush hit something, this created friction. Because of this, the micro servo needed more power to move it, and therefore the current changed. With the ACS712 it was possible to detect this change and stop the servo from moving more.

The ON/OFF switch was added to not drain the Li-Po 3.7V battery.

Charging station

The charging station for the electric toothbrush was separated from the other parts of the circuit. The final idea was to put all of them together so that the user could look at the direct feedback.

The electric circuit for the direct feedback consisted of a Seeed Studio XIAO ESP32C3, a WS2813 LED strip, a small buzzer, an ON/OFF switch, and an Li-Po 3.7V battery. See Figure 9.3 for the circuit.

The WS2813 LED strip was in this circuit to create visual feedback. The small buzzer provided auditory feedback.

9.1.3 Software

The software of the program was written in Arduino Integrated Development Environment (IDE), which uses a variant of the C++ programming language. With an Message Queuing

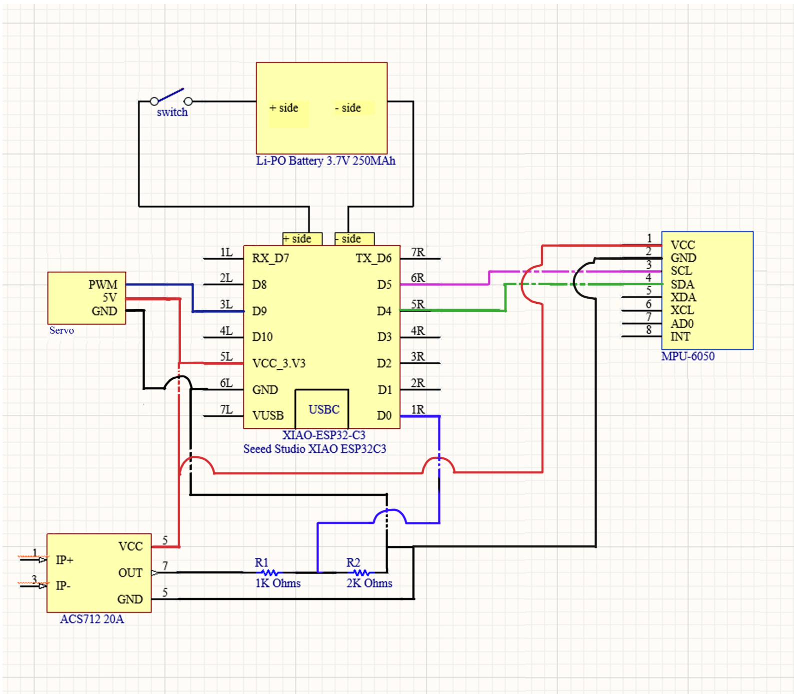

Figure 9.2: Electrical circuit of the toothbrush

Telemetry Transport (MQTT) protocol, the two Seeed Studios communicated through a WiFi hotspot. The WiFi hotspot was hosted on a laptop.

Toothbrush

In the toothbrush software, the user could indicate which difficulty level they wanted to use. The user could also state whether they were right-handed or left-handed. Moreover, the software could detect friction and send the appropriate feedback to the charging station.

The toothbrush software gave a random value to the angle of the micro servo. The angle was between the values of 40 to 80 degrees or 100 to 135 degrees. The initial position of the microservo was 90 degrees. The software could detect the motion of the user.

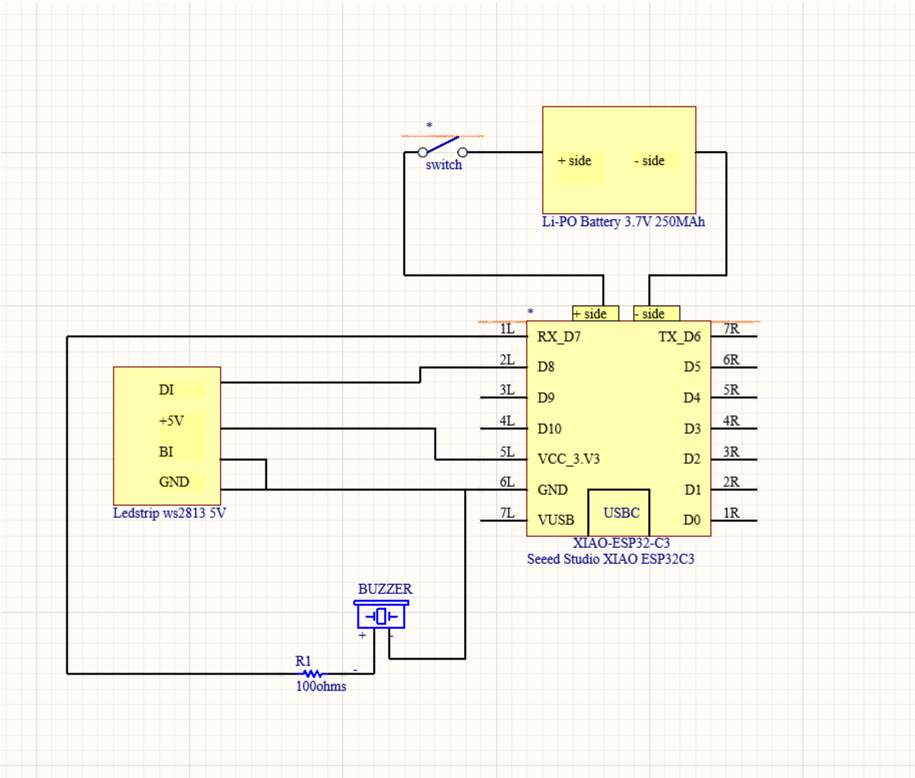

Figure 9.3: Electrical circuit of the charging station

Charging station

The software for the charging station involved changing the LED strip and buzzer accordingly and receiving information from the other Seeed Studio through WiFi.

9.1.4 Cases

For both of the 3D printing cases, some iterations were made for the design. For both 3D printing cases, there was an informal iterative design process. The following sections explain more.

Toothbrush case

The cases saw different forms. The different designs were not properly evaluated but they had their reasons.

The first three versions of the case were bulky. At first, it was tried to put the electronics next to the toothbrush inside the case. However, this created a very thick case that only felt comfortable when a person held it in two hands. The two versions after that tried to put the circuit in different places. However, the cases were still big. One of them became an ellipse form, which was different from what an expert recommended.

After that, it became clear that the printing case should either be taller or have some compartment for the circuit. Eventually, it was decided to make a compartment for the toothbrush. This would be more stable than a long toothbrush case. For this final version, several iterations were made again, to fit the electronics.

The 3D printing support was made on the inside of the case. This worked better as the outside of the cases created a texture that was difficult to remove.

Figure 9.4 shows the different cases with the final case in the middle.

Figure 9.4: Different iterations of 3D printed cases, with the final design in the middle.

Charging station

The charging station went through some different iterations. The first three bases tested different sizes and forms for the holes where the charging station would stay. Eventually, it was decided to create a hexagon form for the base to place the circuit more evenly. This was also done for proper openings for the Seeed Studio and the ON/OFF switch. At first, the idea was to put the LED strip underneath the base station, to project a glow on the surface. However, likely, some users did not have a surface the LED strip could project on. Therefore, the LED strip was inside the station. A white filament diffused the LED colors a bit.

The size of the hexagon got some iterations. See Figure 9.5 for the different iterations of the case.

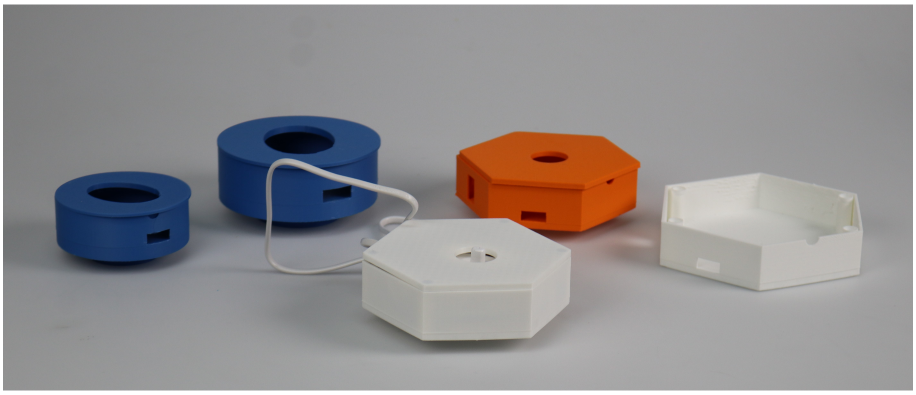

Figure 9.5: Different iterations of the charge station with the final design in the middle.

9.1.5 Limitations

The current prototype had its limitations. Currently, it was not waterproof, the electric toothbrush was not working, heavy, bulky, and visually not pleasing. The direct feedback system did not work optimally. Moreover, in the initial proposal, the current related work involved objects that require space. While the original concept was to be as small as possible, the eventual prototype was large and took up a significant area. It was less spacious than most of the related work. However, there was a possibility that it did not fit in the less spacious bathrooms. Another limitation of the prototype was that it was unable to detect when a user would use the other hand as help.

Chapter 10

User evaluation

This chapter evaluates the implementation of seamlessness and the interaction of TumbleTooth. The initial usability tests involved ten healthy people. The two (former) stroke patients provided feedback on the prototype. This chapter aims to answer the sub-research questions:

- 'What is the opinion (of stroke patients) of the final concept?
- 'Is the interaction of the prototype understandable?'
- 'What seamless and seamful features do we have in the final concept to create a meaningful experience?'

10.1 Methodology

10.1.1 Structure of the tests

This section clarifies the methodology of the experiment. The experiment consists of three evaluation tests. The first test evaluated TumbleTooth with healthy people. The second test was a control test for a part of the first test. The third test is a feedback session with stroke patients on TumbleTooth. The next sections describe in depth the procedures of the tests. Subsequently, the two known (former) stroke patients participated in a feedback session on the concept.

10.1.2 Outcome measures

Thereafter, the results of the experiment and the feedback session were analyzed. The results of the first experiment were based on the concept of seamlessness, qualitative remarks, and the dual task error rate and reaction time. The results of the second experiment were based on the error rate of the dual task and the reaction time. The outcomes of stroke patients (previously diagnosed) focus on seamlessness and qualitative commentary.

10.1.3 Procedure

Structure of the experiment - healthy people

The test was designed and evaluated by two pilot tests. After the pilot tests, the test was adjusted, such as the rotation angle of the TumbleTooth, the form of the questions, and the frequency of the dual task. The first experiment transpired with ten healthy people. The experiment started by informing the partaker about the test, the reasoning behind the experiment, and the procedures of the testing phase. It was clarified that TumbleTooth is still under development. A visualization of the concept was shown to indicate a desired design.

In the following step, the participant held TumbleTooth in their mouth to confirm if the participant used their dominant or non-dominant hand. Subsequently, the participant reported their age, gender, dominant hand, and size of the hand in a survey.

Thereafter, the participant interacted with TumbleTooth for three and a half minutes. This was without water or toothpaste to ensure the safety of the participant. Starting from this point, the user was recorded with a video camera and the audio was recorded with a phone.

Subsequently, the researcher asked the participant to interact with TumbleTooth while doing another task. This is known as a dual task. The goal of the dual task is to rate the attentional demand or cognitive load that people experience while doing an additional task [87]. This was compared to a baseline. The baseline included participants who only performed the additional task. During this specific dual task, the goal was to rate the pitch of the incoming sound as fast as possible. The pitch was high, middle, or low. This was similar to one of the dual tasks of Silsupadol et al. [88]. A video informed the participant about the dual task. This required another three and a half minutes. Similarly to the previous step, this phase was audio and film recorded.

The final part of the experiment involved a short semi-structured interview on the TumbleTooth. See Appendix F for the questions. This interview involved questions about seamlessness and thoughts about the concept. Seamlessness can be described by intuitiveness, usage in daily life, ease of use, and low cognitive thinking [13]. Low cognitive thinking was already covered with the dual task test. The other characterizations of seamlessness (simplicity, consistent interaction, being part of a set, embedded in a specific context) were not asked during the interview. It was either too complex, too familiar to one of the other characterizations, or could already be answered. The interview is recorded in audio. The participant received a cookie and/or vegetable at the end of the interview as a reward.

Structure of the experiment - healthy people dual task

Another test with ten other healthy people occurred which constitutes the baseline for the dual task. Ten other people participated in omitting the learning curve of the dual task in the data. The goal was to have a similar group in terms of gender, age, and dominant hand. These participants only needed to rate the pitch of the incoming sound rapidly and accurately. A similar video explained what was required from the participant.

Structure of the experiment - stroke patients

The third test involved receiving feedback from the two (former) stroke patients. The feedback session began with informing the (former) stroke patient of the structure and goals of the session. Again, a visualization of the desired concept was presented. After that, the participant could ask questions. Then, the stroke patient observed a demonstration of the TumbleTooth. Afterward, the stroke patient could inspect TumbleTooth themself. In the end, a similar semi-structured interview was held as the first test. Appendix F shows the questions. The participants were asked about different aspects of seamlessness, such as intuitiveness, ease of use, and usage in daily life. The stroke patients did not receive questions about simplicity. Neither about low cognitive thinking, since the patients did not operate the product.

10.1.4 Measuring the results

Dual Task

The video itself showed three ‘buttons’ that the participants could not interact with. See Figure 10.1. When the participant pointed to the button, that moment was recorded as a timestamp in the video recording. The researcher noted these points and confirmed whether the sound was properly categorized. The initial timestamps of the auditory stimuli were recorded beforehand and later subtracted from the reaction timestamp. The error rate was determined by dividing the errors by the total amount of measured data points. Subsequently, the measurements were multiplied by 100% to get the error rate in percentages. The timestamps were quantified in seconds and milliseconds.

After that, the timestamp and error rate data were determined in SPSS. Eventually, the two tests involved a Mann-Whitney U test. The null hypothesis of the Mann-Whitney U test indicated that there was no difference in the distribution of the two groups. The alternative hypothesis stated that there was a significant difference in the distribution of the two groups. For a significant outcome, the researcher inspected the effect size.

Interviews

The answers to the questions were investigated and summarised later on to make statements about the seamlessness and overall comments on the design.

10.2 Results

10.2.1 Healthy participants

6 Males and 4 Females joined the evaluation. Three left-handed people and seven right-handed people joined. One of the left-handed participants used their nondominant hand to brush their teeth. The age range ranged from 18 to 34 years. All of them thought that

Figure 10.1: One of the participants performing the dual task while brushing their teeth with TumbleTooth

the concept was a good idea. 5 participants remarked on the weight and bulkiness of the design.

There was a mixed reaction to the direct feedback system. 4 people mentioned that they would not need it, since the rotation is already more intuitive as feedback. 5 people stated that they appreciated it and used it while brushing. One of those 5 asserted that they wanted a light on the toothbrush instead of the charger. They claimed to wander around while brushing. Another one of those 5 suggested putting a light on the mirror instead. One person stated that they thought the lights were valuable, but indicated that it would probably be more intuitive to not use the direct feedback system.

3 participants brought up that the angle of the rotation should be more extreme and not random. 2 people stated that the difference in the angle change was sometimes minimal, and therefore the movement was rather slow.

Dual task - Error Rate

Regarding the baseline of the dual task session, 5 men and 5 women participated. One of the participants was left-handed. The age range ranged from 18 to 34 years old. The sample size was modest; therefore, these outcomes cannot be generalized. For the test group, the test occasionally stopped earlier due to an inaccurate timer from TumbleTooth. Therefore, the test group had 79 sounds instead of the total of 83 sounds. The baseline group consistently completed the test, therefore the error rate included 83 data points.

Appendix G shows relevant figures for statistical results. The normality of the data was investigated. The mean of the baseline group was 9.2771, and the median was 6.0241. The mean of the test group was 9.6919 and the median was 9.4937.

The baseline group had two significant outliers, namely participant 1.3 and participant 1.4. The test group has one outlier, participant 3. The significant outliers were not caused by wrong data entry. The outliers were kept in the dataset.

The p-value of the Mann-Whitney U test was 0.197 which is higher than 0.05, so it was not possible to reject the null hypothesis.

Dual task - Reaction Time

As with the previous test, the test group that used TumbleTooth had 79 points for the reaction time, and the baseline group had 83 data points for the reaction time.

To measure if there was a difference between the two groups, another statistical test should take place. The assumptions were investigated to determine the correct statistical test.

Appendix G reveals applicable statistical results. The box plots of the reaction time for both groups indicated numerous outliers. For many participants, the first sound was confusing. This is because they had not realized it already started and reacted slower than the following moments. It might also be the case the users were distracted for a moment. Therefore, all the first data points were removed.

The Mann-Whitney U test with a p-value of 0.05, revealed that the p-value was lower than 0.001. This was less than 0.05, so the researcher rejected the null hypothesis. With this, there was a significant difference in the reaction time between the two groups. The median of the baseline was 0.7660 and the median of the test group was 1.1000.

After that, it was possible to calculate the effect size. The N was 1621. The Z-value was 19.543. So;

$$r = \frac{19.543}{\sqrt{1621}} = 0.485$$

The effect size was approximately 0.5. If the effect size is 0.5 there is a large effect. This concluded that the alternative hypothesis was supported.

The null hypothesis was therefore rejected, and there was a significant difference in the reaction time. Note that the group is meager, so these outcomes cannot be generalized for a whole population.

Conclusion Dual Task

As seen in the previous two sections, the statistical analyses were completed. The outcomes of the error rate indicated that there is no statistically significant difference between the two groups. This could mean that the error rates of the groups were likely similar in their medians or distribution. This could mean that the cognitive load on rating the sound between the two groups was similar. The statistical analysis of the reaction time indicated that there was a significant difference between the two groups. This means that one group was slower than the other. In this case, the group that used TumbleTooth was slower than the baseline group. Although there was a significant difference in reaction time, the difference is not that large. The median of the baseline group was 0.7660 seconds and the median of the TumbleTooth group was 1.100 seconds. The cognitive load could be considered low for the TumbleTooth group. This was because the median differentiated in milliseconds and not in seconds.

Conclusion Seamlessness

All the participants thought TumbleTooth was intuitive and easy to use. 7 people would use it in their daily life if they needed to, 2 if their doctor would recommend it and if it was not too costly, 1 was not sure since they thought that in the morning and evening stroke patients tend to be tired. Therefore, seamlessness could occur in TumbleTooth.

10.2.2 Stroke participants

Both (former) stroke patients who previously assisted gave feedback on TumbleTooth. Figure 10.2 shows the stroke patients with TumbleTooth.

Stroke patient 1 stated that the concept seems nice. Especially if it works. He stated that it was strange that no one else had thought about this concept before. He said that he was unsure if the exercise was clear to him, he would need to use it to answer that. He indicated that he does not use an electric toothbrush, so he thought this was not suitable. The direct feedback system intrigued him, he was not sure if he would keep looking at it. He could imagine that at some point he would stop looking at it. But he indicated that it is valuable, especially to see if you are doing it correctly. He stated that the whole concept looks quite big and would make it smaller.

Stroke patient 2 indicated that she liked the concept. She stated that it looked quite bulky and big, but she understood that this concept is still in the prototype phase. She indicated that the cylindrical form is important to her. Current (electric) toothbrushes have a lot of indents and ‘ergonomic’ forms according to her. That can make it difficult to hold it. A simple cylindrical form like this is perfect.

Rotating the brush seemed like a good exercise and the exercise was clear to her. Stroke patient 2 mentioned that this is an exercise she has to do every morning and evening. She thought it was great that you need to do this exercise when you already do another activity. The fact that you do not need to take extra time to exercise and that you do not need extra motivation to do it intrigued her. She stated that she was not sure if she could properly brush her teeth with it; she would need to test it to check that.

Stroke patient 2 stated that the direct feedback system seemed interesting. She disclosed that she would not look at it, since her sight is not as it used to be, and when she brushes she needs to hold her head backward. However, she said that she would listen to the sound of the direct feedback system. She stated that she knows other stroke patients who have the opposite problem after their stroke. It is valuable to have both of these forms of feedback in the system. She remarked that price also plays a crucial role for her. If this becomes a real product, she would like to be able to try it for a while to see if it works for her.

Conclusion Seamlessness

Stroke patient 1 mentioned that he thought it would be intuitive to use and useful in his daily life. He remarked that it seems to be easy to use. Stroke patient 2 stated that it seems intuitive, she would use it in daily life, and she said it looks easy to use.

Figure 10.2: The (former) stroke patients with TumbleTooth

10.3 Limitations

The following sections discuss the limitations of the tests.

10.3.1 User evaluation

During the user evaluation, the healthy participants were all between the ages of 18 and 34. This was not the same age as the intended user group. In addition, all users were instructed to use their dominant hand for the test. In the context of stroke patients, it is possible that the dominant hand is not the affected hand.

The angle TumbleTooth rotates on was randomly determined to keep it interesting for participants. The change in angle was not consistently significant for the participant to respond to it. The random angle of the servo occasionally created awkward positions for users. Some users stated that this was difficult for them to hold.

Again, only two (former) stroke patients evaluated TumbleTooth. The two healthy groups of the dual task were also not the same regarding gender and dominant hand. Furthermore, the test group may have been tired and performed differently compared to the participants who only needed to perform the dual task for three and a half minutes. This likely influenced the dual task results.

10.3.2 Prototype

The current prototype was not waterproof. It did not restrict testing this concept for usability. But it was also not possible to know if using it while brushing becomes more difficult. For example, it might be possible that the servo rotates too fast and the toothpaste does not stay on the brush. It was not clear if it was possible to brush the teeth properly.

Unfortunately, during the user evaluation, the electric toothbrush did not work properly. The electric toothbrush would suddenly stop if the servo moved. Therefore, during the tests, the electric toothbrush circuit was not turned on. This could have influenced the users, since they do not know how the entire concept works.

Furthermore, the direct feedback did not work correctly. During the user test, it became clear that users needed to rotate their wrists frequently. The direct feedback system would work 'correctly' if a person brushed their front teeth. Moreover, the direct feedback system got stuck sporadically in one feedback type. This might have had to do with the WiFi connection or because of the speed of the rotating wrist.

10.4 Conclusion

With this chapter, it is possible to answer some of the sub-research questions. First of all:

- 'What is the opinion (of stroke patients) on the final concept?'

TumbleTooth was positively perceived by healthy participants and stroke patients. Healthy participants were divided on whether the direct feedback system had an added value. However, the overall concept seemed promising in achieving its goal. The current aesthetics of TumbleTooth were too bulky and big for the users. If that was changed, the idea would work for the users. The stroke patients were positive about this concept.

TumbleTooth seemed to be achieving this implementation of seamlessness. This can be said based on the interviews and the dual task outcomes. But to be entirely sure of this, the prototype should get a visually more pleasing look. A long-term study should be done with patients who need to perform a similar exercise.

- 'Is the interaction of the prototype understandable?'

According to all participants, the interaction was understandable. Especially after getting to know and using it for a while.

- 'What seamless and seamful features do we have in the final concept to create a meaningful experience?'

The current seamless features this concept adhered to are simplicity, ease of use, semi-low cognitive thinking, facilitating everyday usage, being part of a set, and being embedded in a specific environment. The current design did not have a consistent interaction.

The current seamful features this concept adhered to were: it is configurable (being able to change the difficulty level) and it has recognizable visible features. It was unsure if the features 'it enables design for/with uncertainty' and 'it empowers individual assumptions about the concept' were met. This should be tested in a longitudinal study.

Chapter 11

Discussion

The goal of this thesis is to address the following question:

> ***'To what extent can we design an object of daily living that seamlessly promotes hand-rehabilitation exercises in an at-home setting?'***

This chapter discusses the lessons learned from this thesis, considers the limitations, and recommends future work. The chapter shows what is learned during this thesis.

11.1 Context

Chapter 1 provided an overview of possible reasons for the health behavior of a stroke patient. I learned the motivations, goals, struggles, and mindsets stroke patients have during and after their rehabilitation phase. Through HBM [13], which describes modifying factors, perceived severity, perceived susceptibility, perceived benefits, perceived barriers, and cues to action, it can be said that stroke patients are mentally, socially, and physically severely affected [2], [6], [20], [27], [28]. They lose bodily functionality and tend to fixate on the difference in their abilities before and after they get a stroke [27]. Depending on lifestyle, environment, and hereditary status, individuals can have a higher (or lower) chance of getting a stroke [2], [25]. These factors play a role in the behavior of a stroke patient. Task-oriented training strategy and an adaptable objective can heavily impact cues to action to perform the health behavior [17], [27].

Another way to explain the behavior is through SDT [13]. According to SDT [13] autonomy, relatedness, and competence are the basic psychological needs of individuals. From the perspective of a stroke patient, autonomy can be reached if the choices of a patient are supported and if exercises are adapted to the capabilities of a patient [30], [31]. Relatedness occurs when a patient gets extrinsic confidence and when they receive understanding from others [30], [32]. Competence can be met when changing the perspective after a failure, or by giving bias-free comments [30]. Autonomy, relatedness and competence influence different motivations as well [30]. Autonomy influences intrinsic motivation, extrinsic motivation, integrated regulation and identified regulation [34]. Relatedness influences extrinsic motivation, and competence influences intrinsic motivation [34].

Solely based on the definitions of the SDT, chapter 1 states what categories of HBM influence SDT. Perceived severity, perceived benefits, perceived barriers, and cues to action all influence autonomy, relatedness, and competence differently. If one of these items is different for a patient it can be the case that relatedness, autonomy, or competence is different. For instance, if a stroke patient has a supportive partner, this can create a higher relatedness in the stroke patient. See Figure 1.2 from chapter 1 for all the relations between the two models.

HBM impacts SDT, which manipulates the motivation and behavior of the user. It is unclear if SDT shapes HBM, and currently, the connections are only based on the definitions. On the other hand, people have different motivations to attain their goals [36]. Currently, it is unclear what motivation takes place when a stroke patient rehabilitates. Patients in a health context tend to achieve their health behavior over time if they have intrinsic motivation, integrated regulation, or identified regulation [30]. Introjected regulation, external regulation, or extrinsic motivation do not seem to influence health behavior in related work [34].

As a result, this thesis uses seamlessness as a core concept in the design. Seamlessness is promising for making the hand rehabilitation tools a daily occurrence, which reduces the need for extrinsic motivation. Seamlessness is based on simplicity, ease of use, consistent interaction, everyday usage, part of a set, embedded in a specific environment, and low cognitive thinking [13]. It is not possible to get a full seamless design. Therefore, a combination of seamlessness and seamfulness is advised [13]. Seamfulness characterizations are; enabling design for/with uncertainty, empowering individual assumptions about the concept, and having configurable, recognizable features [13]. In this context, configurable features seem to be important since competence can be reached by making an adaptable plan [30]. The design should at least aim for that seamful feature.

11.2 TumbleTooth

I developed TumbleTooth based on observations, literature, related work, and feedback from users and experts. The features are based on the implications of the Research Topics [13], which states that it should be ADL-based, intuitive, task specific, easy to use, independent in use, small, seamless, can change the difficulty level, is safe, has some skill training, and direct feedback. Moreover, Lo Buono et al. [27] and Ryan and Deci [34] state that it should have an adaptable goal, and Langerak et al. [85] argue that it should supply the exercise, which are also part of the feature list. All these features are key features recommended by previous work for the design of a rehabilitation device for stroke patients [13], [27], [85].

TumbleTooth rotates randomly and indicates to the user if they correctly compensate the rotation with their wrist through light and sound. The goal is to let patients perform a wrist rotation, which is a useful rehabilitation exercise [84]. It focused on compactness, waterproofing, safety features, and visual and auditory feedback. TumbleTooth consists of small electronics, an existing electrical toothbrush, and an existing electrical toothbrush charger. The electronics were carefully chosen to make the design as small as possible. Therefore, the Seeed Studio ESP32C3 microcontroller was picked instead of other microcontrollers. Moreover, this specific microcontroller can handle WiFi, which is necessary for the wireless connection between the charging station and the toothbrush. Furthermore, the safety measures received specific attention since the brush should not move with too much force. A safety algorithm, a micro-servo, and a ACS712 took care of this. Moreover, TumbleTooth had a 3D printed case. The housing of TumbleTooth was iteratively designed to incorporate the electronics. The hope was that a 3D printed cases would appear as high fidelity to users, as well as waterproof. However, these were both unfortunately not the case.

TumbleTooth reaches seamlessness. During the user evaluation, participants answered questions about the characterizations of seamlessness. The characterizations are The participants received questions on the first four characterizations. The healthy participants and the stroke patients both agreed that it was simple, easy, and would be used on an everyday scale. However, the healthy participants stated that TumbleTooth is not consistent in use, due to the randomization of the movement. During the dual task evaluation, using TumbleTooth requires some cognitive effort, but it is rather low. As for the characterizations part of a set, and embedded in a specific environment, TumbleTooth already covers this since it is an ADL-based design [13]. All in all, it does not adhere to all the seamlessness characterizations, but as stated previously, it is not possible to reach 100% seamlessness [13]. Realistically TumbleTooth adheres to all but one characterization. It can be said that TumbleTooth has a high seamlessness indication.

TumbleTooth is configurable and has recognizable visible and computational features. These are seamful characterizations. Based on this, TumbleTooth can be considered to have a low seamfulness as far as is known. Previous work indicated that a possible aim is to have high seamlessness features and low seamfulness features [13]. TumbleTooth appears to achieve this goal.

The combination of high seamlessness and low seamfulness design might indicate that users do not need motivation to use TumbleTooth. Future work needs to evaluate if that is truly the case.

At the moment, it is not known what motivational elements TumbleTooth has. Ryan and Deci [34] urge to use a combination of extrinsic and intrinsic motivation. If we know that TumbleTooth lacks one sort of motivation, it is possible to change the object accordingly. For instance, competence influences intrinsic motivation. If a stroke patient primarily has intrinsic motivation, the design should be adaptable in difficulty level to receive high competence. See Figure 1.2 from chapter 1 for the factors that influence this. At present, TumbleTooth could be used for both intrinsically and extrinsically motivated individuals due to the nature of the design. It prompts patients to use it seamlessly every day during a regular activity. This knowledge is unfortunately missing in this thesis.

11.3 Answering the main research question

TumbleTooth enables users to seamlessly perform hand exercises for stroke patients. Based on user involving methods, literature, and evaluation, TumbleTooth appears to be a seamless concept, with a mixture of seamful characterizations. While it is not clear whether the concept works in longitudinal terms, this implementation of seamlessness seems to be successful.

11.4 Scientific contributions

A scientific contribution of this thesis is an overview of the motivations and struggles of stroke patients. It shows which elements create an intrinsically or extrinsically motivated design.

Moreover, TumbleTooth has a different approach compared to related work. Figure 11.1 shows the related work compared to TumbleTooth in the implicit interaction framework. TumbleTooth falls in the desired area which is indicated with the differently shaded circle. TumbleTooth currently breaches a gap that related work did not aim for in terms of interactions. Moreover, during the ideation phase, Figure 11.1 served as a foundational guide, offering the direction of the design.

This thesis provides a feature list for a seamless design in the stroke patient rehabilitation context. While previous work in the interaction design space focuses on features for rehabilitation design [85], they do not necessarily focus on seamless rehabilitation design.

Furthermore, TumbleTooth is the result of combining different approaches. Within the field of interaction technology, the innovation lies in its approach. This combination is unique to the best of our knowledge. TumbleTooth makes use of co-design, an ADL-based approach [13], the implicit interaction framework, and the characterizations of seamlessness.

11.5 Limitations and recommendations

Firstly, the thesis has limitations due to the number of stroke patients involved. Only two (former) stroke patients participated and were not the intended audience. The intended group for this concept was somewhere in between these two. More patients could have given better insights and other design opportunities. Therefore, future research should find more stroke patients to participate. Preferably the stroke patients differentiate in dominant and non-dominant affected hands. Future work should look into gamification and leisure activities as well, since stroke patients wanted designs for this.

Secondly, the prototype is limited. The electric toothbrush is not working, it is not waterproof, it is bulky, and visually unpleasing. The visual aspects did not affect the opinions from participants and stroke patients greatly. However, the electric toothbrush did not work properly. It is unclear if it is possible to brush the teeth correctly with this current prototype.

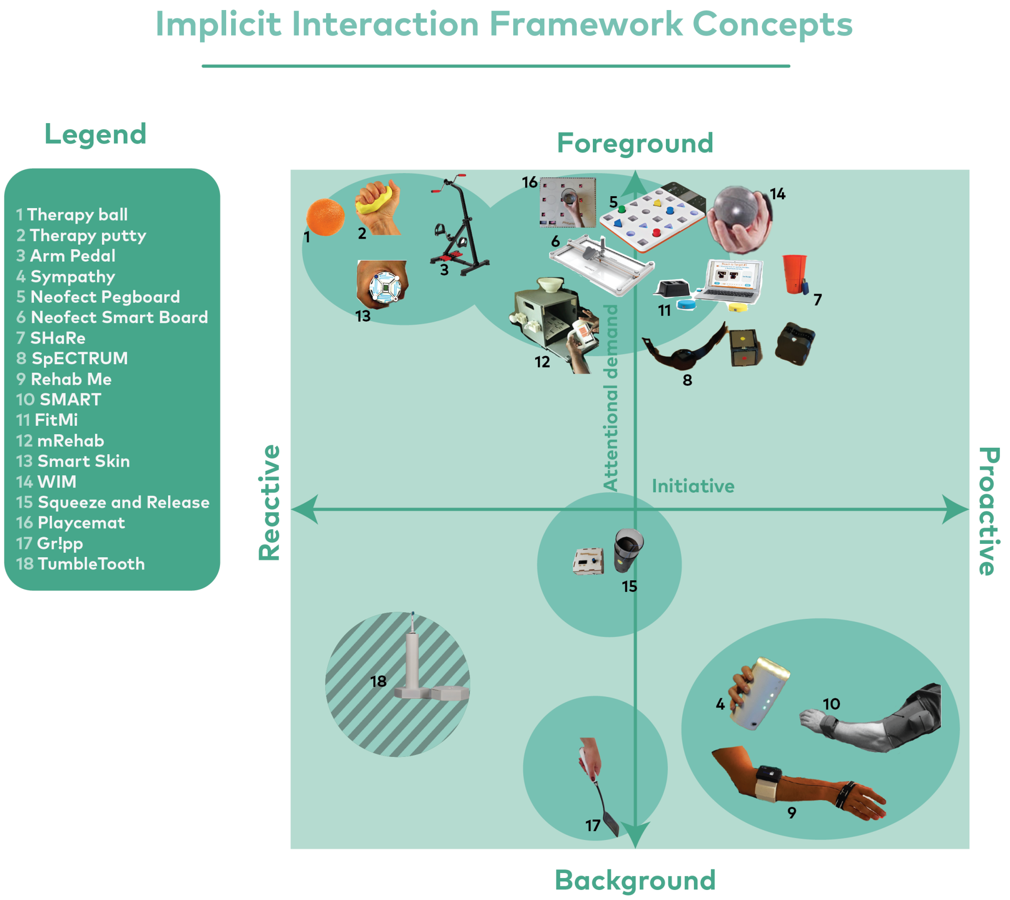

Figure 11.1: Related work in the implicit interaction framework

Therefore, future research should adjust the prototype. The goal should be to make it a high-fidelity model, by using even smaller sensors and correct materials. Materials mentioned by Bos et al. [89] might be interesting. It would be ideal if the prototype has an application, sends data to the doctor, and adjusts the exercise according to a Dynamic Difficulty Adjustment [90].

And finally, the current thesis cannot answer what kind of motivational aspects TumbleTooth has. It is also not known how to properly measure seamlessness and seamfullness. Therefore, future work should look into measuring this. Seamlessness can take place over time [13], and motivation is easier to track in different time periods [30]. Therefore, it should be a long-term study.

Chapter 12

Conclusion

TumbleTooth was an object of daily living that promoted a hand-rehabilitation exercise. Based on information gained from stroke patients, experts, related work, and literature, TumbleTooth came to be. This was a toothbrush that gave a wrist exercise to the user while they brushed their teeth and got feedback on this process. Based on the answers of the participants during the evaluation phase on the seamless characterizations, the object adhered to all but one of the seamless characterizations. Based on the design of the product, TumbleTooth also adhered to two seamful characterizations. As previously indicated, it is not possible to design a 100% seamless object [13]. Since TumbleTooth has seamful characterizations, it was possible to state that this design is a mixture of seamless and seamful features.

However, it was unknown if this is the case on a long-term basis. Seamlessness can appear over time [13], and perhaps this is the case for seamfulness too. During the interviews, it became clear that this object adheres to seamless features. It might be possible that when stroke patients use this on a long-term basis, this is not the case. Moreover, during the user evaluation, the electrical toothbrush did not function properly, and for safety reasons, users did not use toothpaste while brushing their teeth. This can influence the experience of seamlessness as well.

Still, the concept in theory and partially in practice was able to seamlessly promote a hand-rehabilitation exercise within an ADL. The question remains if this is also the case in an at-home setting and how seamless the concept is. The concept introduced an ADL-based approach that involves users and seamless exercises. Future work needs to validate the outcomes for long-term effectiveness. Moreover, future work needs to find out if stroke patients need motivation to use TumbleTooth. All in all, TumbleTooth seems to seamlessly provide a hand rehabilitation exercise on a daily basis. The researcher hopes the findings and approaches used inspire other rehabilitation designers to create seamless experiences.

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Appendix A

Ethics

This appendix shows several different ethical documents used during the user observations. This ethical process takes place to make sure the participants and researchers are not at any risk during the study and know their rights during the testing.

A.1 Consent form

This consent form displays the facts that the users understand the purpose of the research, the possible downsides, the information on how their comments are integrated into the report, and if they want to participate in a follow-up session in the future.

A.2 Information letter

The information letter provides a thoroughly informative document with everything that the user needs to know about the process. Information on what happens during the sessions, and what happens after the sessions with their data are available in the information letter.

Toestemmings formulier voor het maken van een naadloos Hand-Rehabilitatie object in dagelijkse activiteiten

U ONTVANGT EEN KOPIE VAN DIT DOCUMENT

Check het vakje na het lezen van het document	**Ja**	**Nee**
Meedoen met het onderzoek		
Ik heb gelezen over dit onderzoek dat plaats vindt op ______, of het is voorgelezen. Ik heb de kans gehad om vragen te stellen over dit onderzoek en de vragen die ik had zijn goed beantwoord.	☐	
Ik doe geheel vrijwillig mee met dit onderzoek en ik begrijp dat ik kan weigeren om antwoorden te geven en dat ik op elk moment kan stoppen zonder een reden te geven.	☐	
Ik begrijp dat als ik meedoe met dit onderzoek ik word geobserveerd tijdens dagelijkse activiteiten, en dat er vragen worden gesteld over hoe ik dat doe, of hoe ik me erbij voel. Ik snap ook dat ik later gevraagd zou kunnen worden om feedback te geven op concepten die zijn bedacht en dat ik ze mogelijk test. Ik heb begrepen dat alles wat ik tijdens de observaties zeg wordt opgenomen en sommige dingen worden opgeschreven. De audio opnames worden na de master thesis verwijdered.	☐	
Ik geef toestemming om mee te doen met latere sessies om feedback te geven op de concepten die gecreëerd zijn.	☐	☐
Informatie gebruik van deze test		
Ik begrijp dat opmerkingen die ik maak en antwoorden die ik geef op de vragen gebruikt worden voor het maken van een concept in hand-rehabilitatie. Ik begrijp dat deze informatie in de master scriptie komt en mogelijk ook nog in een andere publicatie.	☐	
Ik begrijp dat persoonlijke informatie, zoals mijn naam en mijn adres, niet gedeeld worden buiten het team dat aan dit onderzoek werkt.	☐	
Ik begrijp dat alle antwoorden die ik geef op de vragenlijst anoniem zijn. Er kunnen geen connecties worden gemaakt tussen mij en mijn antwoorden, omdat ik mezelf niet identicifeer op de vragenlijst (uw naam wordt niet vermeld op de vragenlijst.) Na het voltooien van het onderzoek kan ik niet vragen of mijn antwoorden vernietigd kunnen worden, omdat de onderzoeker niet weet welke vragenlijst van mij is.	☐	
Ik geef toestemming om opmerkingen die ik maak te laten quoten. (Dit blijft anoniem.)	☐	☐

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Figure A.1: Consent form page 1

Ik snap dat er tijdens de sessies geluids opnames worden gemaakt, en ik geef toestemming om dit te laten opnemen. ☐

Hergebruik van uw informatie
Ik geef toestemming dat de antwoorden die ik geef op de vragenlijst en ook tijdens het onderzoek worden bewaard op de Human Computer Interaction (Mens-Computer interactie) afdeling op de Universiteit Twente zodat deze gebruikt kunnen worden in de toekomst. ☐

Ik geef de onderzoekers toestemming om mijn contact informatie te bewaren en om me te contacteren voor toekomstige onderzoeks projecten. ☐ ☐

Handtekening

______________________ ______________________ _________ ☐
Naam van deelnemer Handtekening Datum

Als u moeite heeft met schrijven, vink dan het vakje aan.

Ik heb de informatie van dit onderzoek aan de mogelijke deelnemer zo accuraat mogelijk verteld/voorgelezen, en geprobeerd zo goed mogelijk duidelijk te maken waar de deelnemer vrijwillig aan mee doet.

Sterre van Arum _________________ _________
Naam onderzoeker Handtekening Datum

Contact informatie voor extra informatie:

Onderzoeker: Sterre van Arum
Email: s.r.vanarum@student.utwente.nl

Begeleider Universiteit Twente: Juliet Haarman
Email: j.a.m.haarman@utwente.nl

Contact Informatie voor vragen over uw Rechten als Onderzoeks Deelnemer.
Heeft u vragen over uw rechten als onderzoeks deelnemer, of wilt u meer informatie, andere vragen stellen, of zorgen uiten over deze studie met iemand anders dan de onderzoeker(s)? Neem dan contact op met het Secretaris van de Ethische Commissie Informatie & Computer Science: **ethicscommittee-CIS@utwente.nl**

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Figure A.2: Consent form page 2

Informatie brief:
Naadloos design van een Hand Rehabilitatie Object voor gebruik in dagelijkse activiteiten.

Doel van dit onderzoek
In dit document vindt u informatie over het doel van dit onderzoek, en wat er tijdens de sessies gaat gebeuren.

Voor een onderzoek aan de Universiteit Twente ben ik op zoek naar mensen die een herseninfarct hebben gehad en daardoor functionaliteit hebben verloren in een van hun handen. Bij voorkeur hebben deze mensen thuis oefeningen gedaan om hun hand te trainen.

Het komt vaak voor dat patiënten hun motivatie verliezen om oefeningen te blijven doen. Dit kan bijvoorbeeld komen doordat ze grote objecten moeten gebruiken voor rehabilitatie of tijd vrij moeten maken in hun dagelijkse routines. Het doel van het onderzoek is om een object te ontwikkelen dat naadloos in de leefomgeving of dagelijkse activiteiten kan worden geïntegreerd. Hierdoor hoeven deelnemers niet zelf de motivatie op te brengen en zal het gemakkelijker voor hen zijn om de oefeningen te blijven doen. We richten ons specifiek op mensen die hun hand moeten trainen, omdat het verlies van functionaliteit in een hand vaak voorkomt na een herseninfarct.

Momenteel zijn we op zoek naar de meest geschikte activiteit voor deze doelgroep en willen we graag zien hoe deelnemers bepaalde huishoudelijke activiteiten uitvoeren. We willen graag de doelgroep meer betrekken in het bepalen en maken van zo'n soort object. We zijn daarom op zoek naar mensen die binnen onze doelgroep vallen en graag willen deelnemen aan ons

De sessies
Tijdens het onderzoek zal een van onze onderzoekers meekijken terwijl u dagelijkse activiteiten uitvoert, zoals bijvoorbeeld afwassen, tv kijken of de was doen. Hierover stellen we vragen, nemen we de gesprekken op, en maken we aantekeningen. De sessies kunnen maximaal 2 uur duren, of korter aan de hand van wat de u fijn vindt. Het liefst hebben we dan meerdere sessies op verschillende dagen, maar dit gebeurt alleen als u daarmee instemt. Het is ook nog mogelijk om een sessie te doen voor een halve dag, maar dit ligt ook aan wat u liever wil. De sessies kunnen bij u thuis of in een rehabilitatiecentrum plaatsvinden.

We willen u ook vragen wat u van de concepten vindt die uit deze observaties voortkomen. U kunt aangeven of u openstaat voor later contact hierover. Tijdens die sessies leggen we mogelijke concepten uit, en vragen u om feedback hierover. Het zou kunnen dat we ook vragen of u het object wil gebruiken, en hiervan zouden we dan ook audio-opnamen en aantekeningen van maken.

Voordelen en nadelen
Als u om welke reden dan ook willen stoppen, kunt u dit aangeven en zal de sessie onmiddellijk worden beëindigd. U hoeft hier geen reden voor te geven, en hier zitten ook geen consequenties aan voor u.

U kunt ook aangeven hoe lang u wilt dat de sessie maximaal duurt. Het liefst willen we minimaal een uur wat activiteiten zien, maar als u het korter wil houden, dan kan dit. Het zou fijn zijn als u dit van tevoren kan aangeven aan het begin, of net voor, de sessie.

Een mogelijk nadeel voor u is dat er een onderzoeker in uw leefruimte komt voor een paar uur.

Figure A.3: Information letter page 1

Data
Persoonlijke informatie die wij van u vergaren zijn uw handtekening, audio-opnamen, en welke hand u minder goed kan bewegen door de herseninfarct. De handtekening wordt alleen gebruikt voor het toestemmings formulier. Alle gegevens van deelnemers zijn volledig anoniem en de audio-opnames met de aantekeningen worden na afloop van het onderzoek verwijderd. (Dit zal rond December 2023 zijn.)

Er worden ook aantekeningen gemaakt. Deze opmerkingen zullen op papier worden geschreven. Het toestemmingsformulier zal op de Universiteit Twente bewaard worden bij de HMI afdeling, volgens hun regels gedurende 10 jaar. Deze informatie wordt in een kluis gestopt.

U ontvangt een kopie van uw toestemmingsformulier.

Vragen?

Heeft u vragen over dit project? Of wilt u meer informatie? Dan kunt u deze stellen aan de master student van dit project:
Onderzoeker: Sterre van Arum
E-mail adres:

Of aan de dagelijkse begeleider van dit onderzoek:

Begeleider Universiteit Twente:
Juliet Haarman

E-mail adres:

Als u nog vragen heeft over uw rechten als onderzoeks deelnemer, of als u nog zorgen heeft over dit onderzoek, en u wilt die kwijt bij een andere onderzoeker, neem dan contact op met de Secretary of the Ethics Committee Information & Computer Science:

E-mail adres:
ethicscommittee-CIS@utwente.nl

Figure A.4: Information letter page 2

Appendix B

Rated ADL

These ADLs are taken from Costenoble et al. [91]. The researchers came up with an extended list explaining each ADL in their research. The same ADLs with the same definitions were taken except for the ADL 'Toileting'. This is because it seemed too similar to 'Continence', but just with less detail.

B.1 Criterion

The figures show the ratings and their outcome. The + shows that the ADL fits the criterion, the - implies the opposite. The 0 is used when it is unclear if the activity meets the norm, or if depending on the specific activity in the ADL differs.

In the last row, each ADL gets a score. This is based on how many +'s, 0's, and -'s an ADL has. Based on the score, it is already easier to determine which ADLs simply do not fit. Every score higher than 2 is evaluated, and everything lower than 3 is disregarded.

The score method does not immediately imply that the ADL fits this context.

B.2 Determining the ADLs

Hover [15] established an overview of which ADLs are fitting in the context of this research. She chooses the ADLs based on the work of Timmermans and colleagues [54], and places these ADLs against norms she set regarding this context. Since this thesis fixates on the exact same problem, this report takes the same benchmarks as Hover has done.

The features are adapted a bit based on new knowledge. One norm is added to the bunch Hover already made [15]. That is: 'Room for exercise'. If someone is unable to take their time during the ADL because it requires a lot of mental workload, or perhaps does not give room for a pause at all, then this ADL is not fitting in this context.

The other features are; duration, frequency, general population, applicable at home, executable by either hand, paired with an object or environment, and finally, low cognitive workload. These features are all taken from Hover [15]. Table B.1 shows the explanation of all these features.

These principles are set against the activities mentioned by Timmermans and colleagues, and the activities of Costenoble et al. [91]

Table B.1: Features for choosing ADL

Duration	Explanation
Room for exercise	ADL should have time to do an exercise.
Duration	The activity should occur in a fitting period.
Frequency	The occurrence of an activity.
General population	The action should be fitting for the general public.
Applicable at home	Activity should be done at home.
Executable by either hand	Use of either hand during the activity.
Paired with an object/ environment	To create seamlessness or a better design [13].
Low cognitive workload	To create a more seamless design [13].

B.3 Selected ADLs

Eventually, the following ADLs have a score higher than or equal to 3: Bathing, Personal grooming, Dressing, Transferring, Walking, Eating, Drinking, Telephone, Shopping, Preparing food, Doing housework, Household appliances and daily technology, Cognitive stimulating activities, and Communicate through other techniques than the phone. This appendix explains a bit why certain activities are (not) chosen. See Table B.2 as for the reasoning behind which ADL (do not) fit.

B.4 Timmermans

When comparing that outcome with the preferred behavior that Timmermans et al. [54] found, the eventual observations should at least focus on: 'Eating', 'Household appliances and daily technology', 'Personal grooming', 'Dressing', 'Doing housework', 'Preparing food', and 'Drinking'.

B.5 Conclusion

Thus for the observations, the following ADLs should be observed: 'Eating', 'Household appliances and daily technology', 'Personal grooming', 'Dressing', 'Doing housework', 'Drinking', and 'Preparing food'.

Table B.2: Selected ADL

ADL	Explanation
Bathing	**Not chosen** — Not everyone bathes daily.
Personal grooming	**Chosen** — Could fit, but not sure if either hand is used.
Dressing	**Chosen** — Could fit, not sure if there is time to do an exercise.
Transferring	**Not chosen** — No specific object or environment.
Walking	**Not chosen** — No specific object or environment.
Eating	**Chosen** — Done by everyone on daily basis
Drinking	**Chosen** — Done by everyone on daily basis
Telephone	**Chosen** — Could fit, unsure how often the general population uses their phone to call people on a daily basis.
Shopping	**Not chosen** — ADL does not take place at home.
Preparing food	**Chosen** — Could fit, might take a high cognitive workload.
Doing housework	**Chosen** — Could fit, might take a high cognitive workload.
Household appliances and daily technology	**Chosen** — Done by everyone on daily basis
Cognitive stimulating activities	**Not chosen** — ADL is not for the general public.
Communication through other techniques	**Not chosen** — ADL could create awkward situations while having conversations.

b-ADL	Duration	Frequency	General population	Home	Either hand	Specific object/environment	Low workload	Room for exercise	Score
Bathing	+	-	+	+	+	+	0	+	5
Personal grooming	+	+	+	+	-	+	0	+	5
Dressing	+	0	+	+	+	+	-	-	3
Transferring	+	+	+	+	-	-	+	+	4
Walking	+	+	+	+	-	-	+	+	4
Continence	0	+	+	+	0	+	-	-	2
Eating	+	+	+	+	+	+	0	+	7
Drinking	0	+	+	+	+	+	+	+	7
i-ADL	**Duration**	**Frequency**	**General population**	**Home**	**Either hand**	**Specific object/environment**	**Low workload**	**Room for exercise**	**Score**
Telephone	0	0	+	+	+	+	0	0	4
Using transportation	0	0	0	-	+	+	0	+	2
Shopping	+	0	+	-	+	+	0	0	3
Preparing food	+	+	+	+	+	+	-	0	5
Doing housework	+	+	+	+	+	+	-	0	5
Doing laundry	+	-	+	+	+	-	-	0	1
Caring for household objects	0	+	0	+	-	+	+	-	2
Taking medications	-	-	0	+	-	+	+	-	-1
Handling finance	+	-	+	0	0	+	+	-	2
Lifting and reaching	+	-	+	0	+	-	0	0	1

Figure B.1: basic activities of daily living (b-ADL) and instrumental activities of daily living (i-ADL)

a-ADL	Duration	Frequency	General population	Home	Either hand	Specific object/environment	Low workload	Room for exercise	Score
Sophisticated kitchen activities	+	-	0	+	+	+	-	+	**3**
Household appliances and daily technology	-	+	+	+	+	+	+	+	**6**
Go on a holiday	0	-	+	-	0	-	-	+	**-2**
Caring for household objects	0	0	0	+	+	+	-	-	**1**
Semi-professional work	0	0	-	-	+	-	0	-	**-3**
High level gardening	+	-	-	+	+	+	-	0	**1**
Cognitive stimulating activities	+	0	-	+	+	0	+	+	**4**
Craftwork and arts	+	-	-	+	-	+	-	0	**-1**
Complex economic activities	0	-	-	-	-	+	+	-	**-3**
Communicate through other techniques than the phone	+	0	+	+	0	+	-	-	**3**
Sports	+	-	+	0	+	0	-	+	**2**
Transportation by vehicles	+	-	0	-	+	+	-	-	**1**
Self-Development	+	-	0	-	-	-	+	+	**-1**

Figure B.2: advanced activities of daily living (a-ADL)

Appendix C

User Observations

This appendix shows the questions stated during the user observations.

C.1 During observations

I state the following questions during the observations:

- Can you comment on why you gave these answers to the previous question?
- What are particular issues you struggle with during this activity?
- Do you need to concentrate a lot while doing this activity?
- Why (not)?

C.2 After the observations

At the end of the user observations, I ask the following questions:

- What would the ideal rehabilitation object be for you? (Show or state examples if this is unclear to the participant.)
- Would you like to do an exercise while you have to wait for something?
- What daily tasks would be fun to do with exercises?
- What are the current exercises you already do?
- What daily objects do you use at home? (Cutlery, remote controller, phone, laptop, cups..)
- Do you think that any of these objects might be fitting for doing exercises with?
- What do you like or dislike about that object?

Appendix D

Exercises

D.1 Exercises for hand stroke patients

This appendix shows the exercises for hand stroke patients, ranked in difficulty. Blue exercises are for patients that have lost all functionality, pink exercises are for patients with some functionality, and orange exercises are for patients with quite some functionality. The exercises are taken from different sources [80]–[83].

Category	Affected body part	Name	Level (blue,pink,c	Duration	Grasp	Either hand	Specific object/environment	Opportunity of transferability
Strength	arm	Weigthed bicep curl [80]	Pink	Yes	Medium wrap	Yes	No, but it is possible	yes
Range of motion	arm	Open arm movement [80]	Pink	Yes	Medium wrap	Yes	No, but it is possible	yes
Range of motion	arm	Side arm raise [80]	Pink	Yes	Medium wrap	Yes	No, but it is possible	yes
Control	Hand and wrist	Lift hand [81]	Pink	Yes	-	Yes	No	yes
Control	Hand	Getting a cup [81]	Pink	Yes	Medium wrap	Yes	Yes	yes
Fine motor skills	Hand	Crumple a paper [81]	Pink	Yes	Precision Disk	Yes	Yes	yes
Fine motor skills	hand and arm	Butter a sandwich [81]	Pink	Yes	Thumb-2 Finger	Yes	Yes	yes
Fine motor skills	hand and arm	Folding a cloth [81]	Pink	Yes	Precision Disk	Yes	Yes	yes
fine motor skills	hand and arm	using the phone [81]	Pink	No	Medium wrap	Yes	Yes	yes
Fine motor skills	hand and arm	opening a toiletry bag [81]	Pink	No	Lateral pinch	Yes	Yes	yes
Fine motor skills	hand and arm	reading a magazine [81]	Pink	Yes	Lateral pinch	Yes	Yes	yes
coordination	hand and arm	touching nose, ear, shoulder [82]	pink	Yes	-	Yes	No	No
Coordination + Streng	hand	put fingers on a door handle. [81]	pink	No	Medium wrap	Yes	Yes	yes
Strength	hand and arm	hold plastic shopping bag [81]	pink	Yes	Medium wrap	Yes	Yes	yes
coordination	hand and fingers	o form with thumb and fingers [81]	pink	Yes	-	Yes	No, but it is possible	perhaps
Strength	hand and arm	carry light objects next to your body [83]	pink	Yes	Medium wrap	Yes	No, but it is possible	yes
range of motion	hand	rolling a bottle [83]	pink	Yes	Medium wrap	Yes	Yes	yes
range of motion	hand	wrist curl [83]	pink	Yes	Medium wrap	Yes	No, but it is possible	yes
Fine motor skills	hand	grip and release pen [83]	pink	Yes	Index Finger Extens	Yes	Yes	yes
Strength	hand	power grip ball [83]	pink	Yes	Power Sphere	Yes	Yes	yes
Strength	hand	Pinch ball [83]	pink	Yes	Thumb-3 Finger	Yes	Yes	yes
Strength and Fine mo	hand	Thumb extension ball [83]	pink	Yes	Tripod	Yes	Yes	yes
Strength	hand	Table roll ball [83]	pink	Yes	-	Yes	Yes	yes
Strength	hand	Finger flexion ball [83]	pink	Yes	Power Sphere	Yes	Yes	yes
Strength	hand	Thumb roll ball [83]	pink	Yes	-	Yes	Yes	yes
Strength	hand	Thumb opposition ball [83]	pink	Yes	-	Yes	Yes	yes
Strength	hand	Finger squeeze ball [83]	pink	Yes	Tripod	Yes	Yes	yes
Strength	fingers	Finger extension putty [83]	pink	Yes	-	Yes	Yes	yes
Strength	hand and fingers	Finger spread putty [83]	pink	Yes	-	Yes	Yes	yes
Range of motion	hand and arm	Elbow stretch [83]	pink	Yes	-	Yes	No	perhaps
Dexterity	arm	Crawling stretch [83]	pink	Yes	-	Yes	No	No
Range of motion	hand and arm	Wrist Motion [83]	pink	Yes	-	Yes	No	perhaps
Fine motor skills	hand and fingers	stacking coins [83]	orange	No	Lateral pinch	Yes	Yes	yes
Fine motor skills	hand and fingers	playing board games (like chess) [83]	orange	Yes	Index Finger Extens	Yes	Yes	yes
Fine motor skills	hand and fingers	playing piano [83]	orange	Yes	-	Yes	Yes	yes
Fine motor skills	hand and fingers	playing piano app [83]	orange	Yes	-	Yes	Yes	yes
Fine motor skills	hand and fingers	putting together a puzzle [83]	orange	Yes	Index Finger Extens	Yes	Yes	yes
Fine motor skills	arm and hands	brushing hair [81]	orange	Yes	Medium wrap	Yes	Yes	yes
strength	arm and hands	taking care of plants [81]	orange	Yes	Medium wrap	Yes	Yes	yes
strength + range of m	arm and hands	cleaning the bed [81]	orange	Yes	Precision Disk	Yes	Yes	yes
fine motor skills	hands	using the phone [81]	orange	No	Medium wrap	Yes	Yes	yes
fine motor skills	hands	placing sugar sticks to another bowl [81]	orange	Yes	Index Finger Extens	Yes	Yes	perhaps
Fine motor skills	Hand	Squeeze out a washing cloth [81]	orange	No	Precision Disk	Yes	Yes	perhaps
Fine motor skills	Hand	Cards [81]	orange	Yes	Index Finger Extens	Yes	Yes	perhaps

Figure D.1: Exercises for hand stroke patients

Fine motor skills	Hand	Writing [81]	orange	Yes	Thumb-2 Finger	No	Yes	No
Fine motor skills	Hand	Using computer [81]	orange	Yes	Lateral tripod	Yes	Yes	yes
Strength	Arm	Using weights [82]	orange	Yes	Medium wrap	Yes	No, but it is possible	yes
Fine motor skills	hand	Pen spin [83]	orange	No	Thumb-2 Finger	Yes	Yes	yes
Fine motor skills	hand	coin drop [83]	orange	Yes	Lateral pinch	Yes	Yes	perhaps
Fine motor skills	hand and fingers	Finger walk [83]	orange	Yes	-	Yes	No	No
Strength	arm and hand	Seated push up [83]	orange	Yes	-	Yes	No	No
Strength	arm	Sitting elbow flexion [80]	orange	Yes	Medium wrap	Yes	No, but it is possible	yes
Strength	arm	Overhead press [80]	orange	Yes	Medium wrap	Yes	No, but it is possible	yes
Strength	arm	Shoulder adbuction [80]	orange	Yes	Medium wrap	Yes	No, but it is possible	yes

Figure D.2: Continuation of exercises for hand stroke patients

Appendix E

Questions feedback sessions

This appendix shows the questions asked during the feedback sessions.

E.1 Questions for each concept-users

The following questions are asked for each concept:

- What are the strong characteristics of this concept according to you?
- What are the weak characteristics of this concept according to you?
- What would you like to change about this idea?
- What would you keep?

E.2 General questions-users

The following questions/instructions are asked after all the concepts have been discussed:

- Number the ideas from most liked to least liked.
- Why do you like idea X the most?
- Why do you like idea X the least?
- Is there a feature from one of the ideas you really like?
- Are there (part of) ideas you would like to merge?
- What do you think of a smart mirror?
- What do you think of an application together with the ideas?
- What do you think of being able to change the lights and the audio?

E.3 Questions for each concept-experts

The following questions are asked for each concept:

- Is this a correct exercise for rehabilitating stroke patients in an at-home setting who need to recover or keep up to stay at the same functionality?
- How can the exercise become better?
- For which level is this exercise?
- How can the exercise cover more levels? How would we need to change it to achieve this?

E.4 General questions-experts

The following questions/instructions are asked after all the concepts have been discussed:

- Which concept has your preference while keeping the exercise in mind?
- What do you think of combining concept 1 and concept 2?
- Is that too much for the user or would that help them out?

Appendix F

Participant questions

This appendix shows the questions stated during the evaluation.

F.1 Healthy participants

I stated the following questions after the dual task:

- What were your thoughts on TumbleTooth?
- Was the exercise clear to you?
- Was the use intuitive to you?
- Would you use this in your daily life?
- Was it easy for you in use?
- Do you think you can brush your teeth with this?
- What did you think of the feedback system?
- Did you look at it while brushing for feedback?
- What would you change on the interaction/feedback system?
- What would you keep on the interaction/feedback system?

F.2 Stroke patients

I asked the following questions after showing TumbleTooth:

- Was the exercise clear to you?
- Do you think it is intuitive to use?

- Would you use this in your daily life?
- Do you think it is easy to use for you?
- Do you think you can brush your teeth with this?
- Do you think it is valuable for other stroke patients?
- What did you think of the feedback system?
- Would you look towards the feedback system while brushing?
- What would you change on the interaction/feedback system?
- What would you keep on the interaction/feedback system?

Appendix G

Statistical outcomes

This appendix shows additional statistical outcomes from the tests for the dual task.

G.1 Error rate

This involves the statistical analyses for the error rate.

G.2 Reaction Time

This section involves the statistical analyses for the reaction time.

Descriptives

	group#			Statistic	Std. Error
errorrate	baseline group	Mean		9.2771	3.13690
		95% Confidence Interval for Mean	Lower Bound	2.1809	
			Upper Bound	16.3733	
		5% Trimmed Mean		8.4337	
		Median		6.0241	
		Variance		98.402	
		Std. Deviation		9.91976	
		Minimum		1.20	
		Maximum		32.53	
		Range		31.33	
		Interquartile Range		7.53	
		Skewness		1.893	.687
		Kurtosis		2.965	1.334
	test group	Mean		9.6919	1.91108
		95% Confidence Interval for Mean	Lower Bound	5.3688	
			Upper Bound	14.0151	
		5% Trimmed Mean		9.4327	
		Median		9.4937	
		Variance		36.522	
		Std. Deviation		6.04336	
		Minimum		1.27	
		Maximum		22.78	
		Range		21.52	
		Interquartile Range		7.28	
		Skewness		.924	.687
		Kurtosis		1.599	1.334

Figure G.1: Mean, median, and skewness of the error rate from the baseline group and the test group

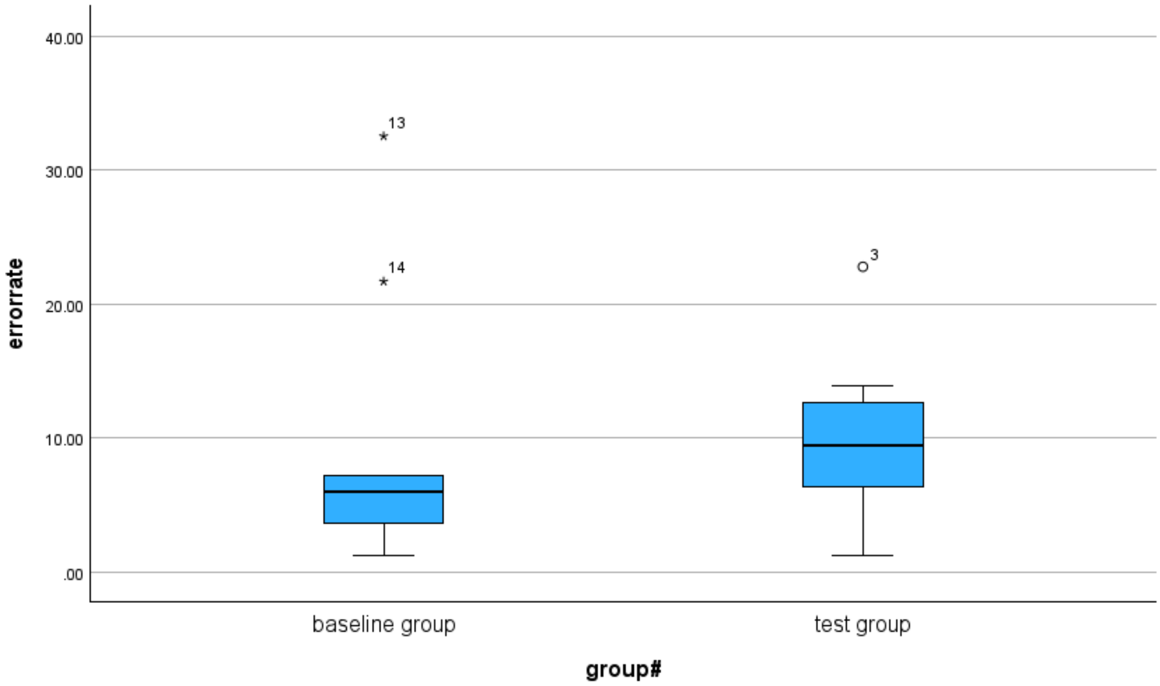

Figure G.2: Boxplots of the error rate for both of the groups

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	group#	Statistic	df	Sig.	Statistic	df	Sig.
errorrate	baseline group	.382	10	<,001	.711	10	.001
	test group	.142	10	.200*	.947	10	.628

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Figure G.3: Test of normality for the error rate of both the groups

Normal Q-Q Plots

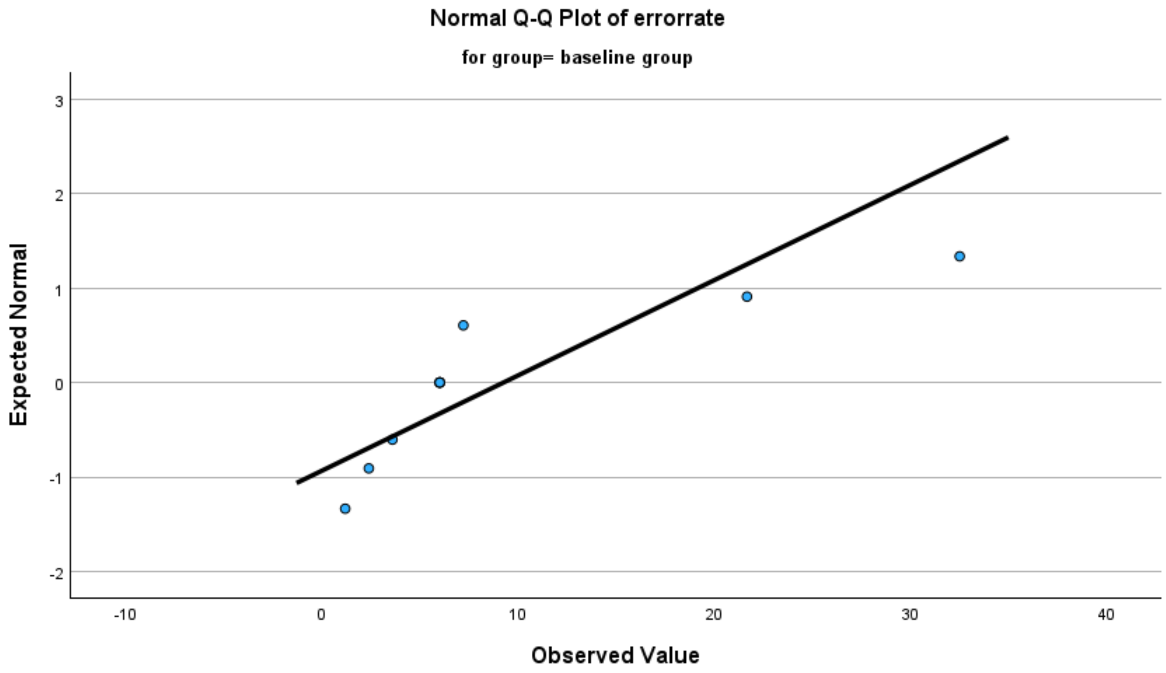

Figure G.4: Normal QQ test for the baseline group with error rates

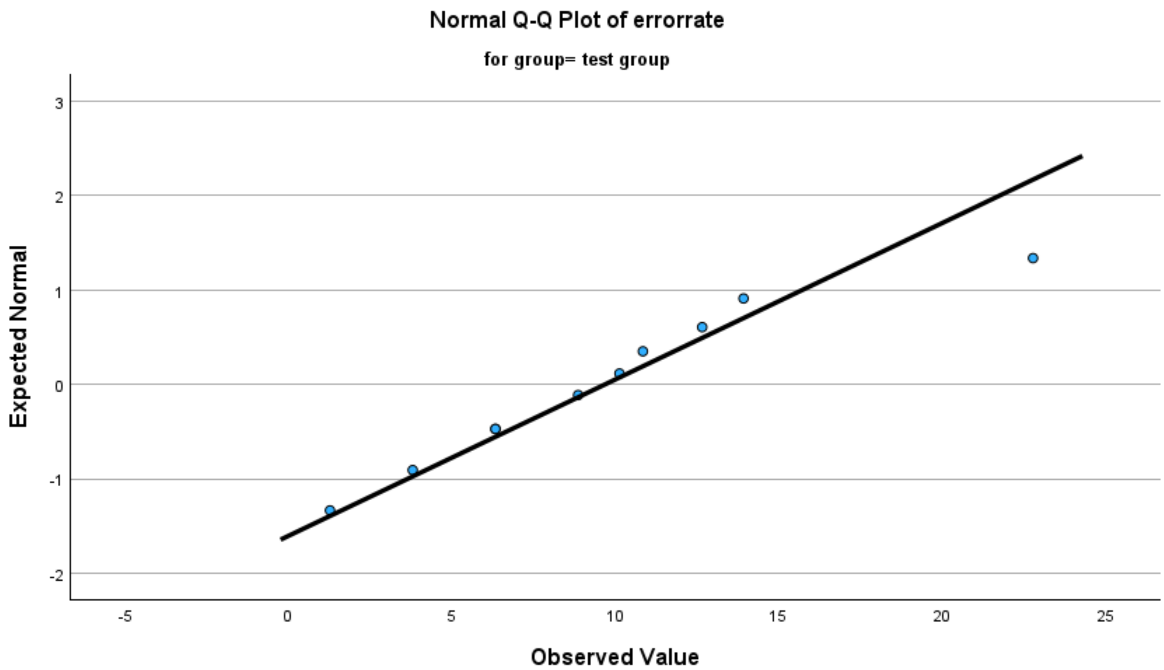

Figure G.5: Normal QQ test for the test group with error rates

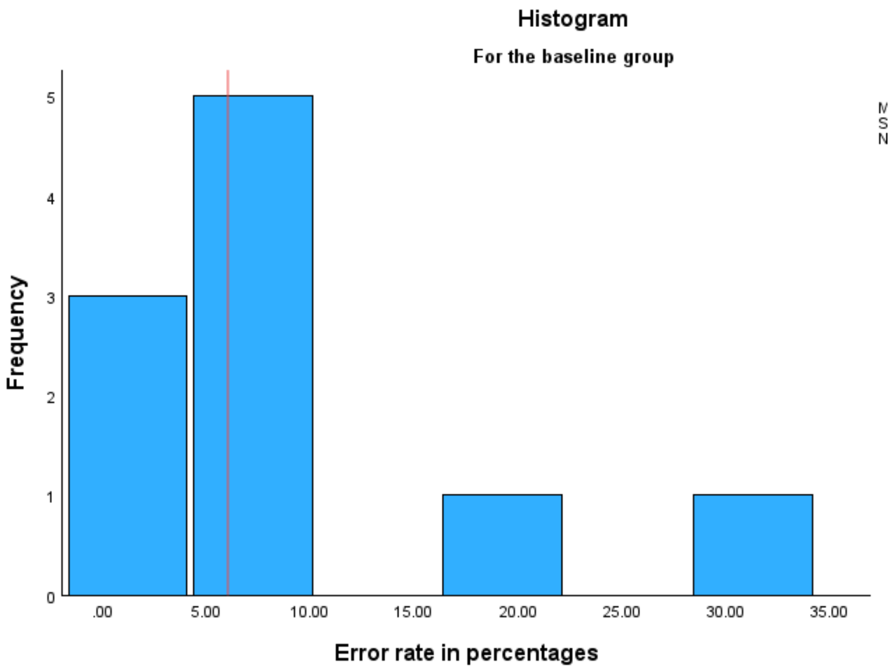

Figure G.6: Histogram of the error rate of the baseline group

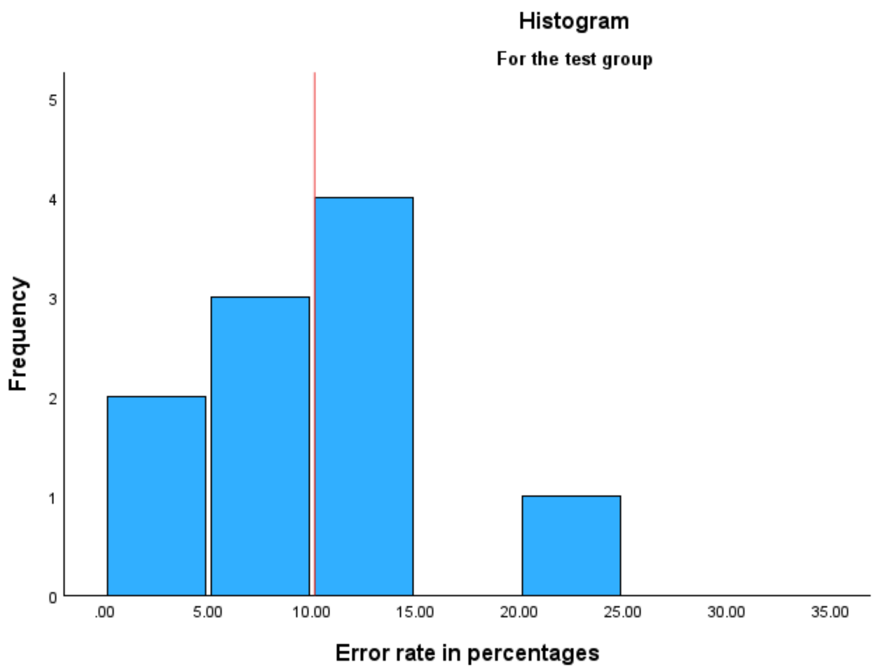

Figure G.7: Histogram of the error rate of the test group

Descriptives

	group			Statistic	Std. Error
reactiontime_insec_millisec	baseline_group	Mean		.8562	.01280
		95% Confidence Interval for Mean	Lower Bound	.8310	
			Upper Bound	.8813	
		5% Trimmed Mean		.8226	
		Median		.7660	
		Variance		.135	
		Std. Deviation		.36712	
		Minimum		.27	
		Maximum		5.27	
		Range		5.00	
		Interquartile Range		.30	
		Skewness		3.303	.085
		Kurtosis		26.924	.170
	test_group	Mean		1.1900	.01602
		95% Confidence Interval for Mean	Lower Bound	1.1586	
			Upper Bound	1.2215	
		5% Trimmed Mean		1.1480	
		Median		1.1000	
		Variance		.199	
		Std. Deviation		.44559	
		Minimum		.33	
		Maximum		5.33	
		Range		5.00	
		Interquartile Range		.43	
		Skewness		2.894	.088
		Kurtosis		17.206	.176

Figure G.8: Mean, median, and skewness of the reaction time from the baseline group and the test group

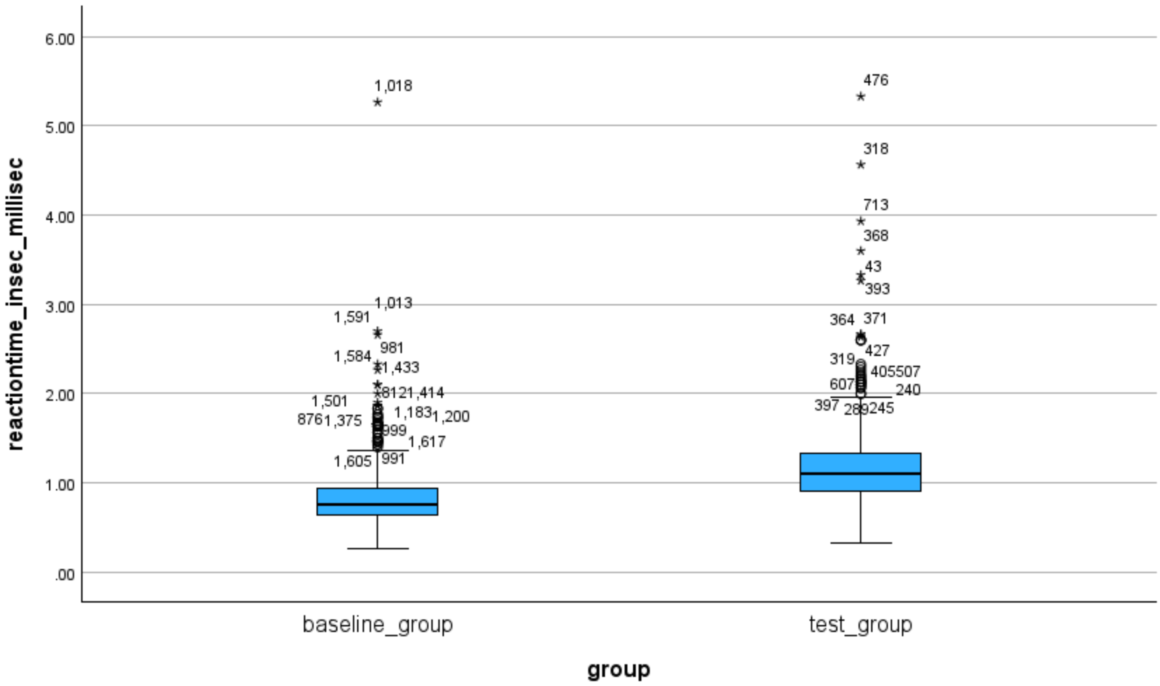

Figure G.9: Boxplots of the reaction time for both of the groups

Tests of Normality

	group	Kolmogorov-Smirnov[a] Statistic	df	Sig.	Shapiro-Wilk Statistic	df	Sig.
reactiontime_insec_millisec	baseline_group	.169	822	<,001	.780	822	<,001
	test_group	.131	774	<,001	.798	774	<,001

a. Lilliefors Significance Correction

Figure G.10: Test of normality for the reaction time of both the groups

Normal Q-Q Plots

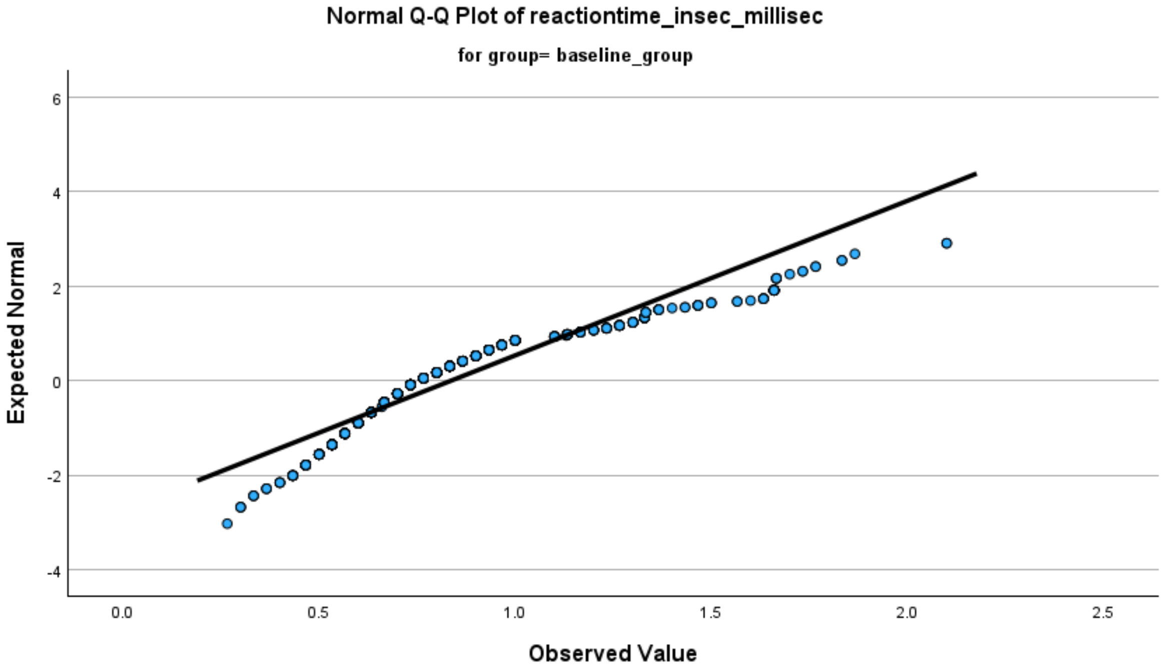

Figure G.11: Normal QQ test for the baseline group with reaction time

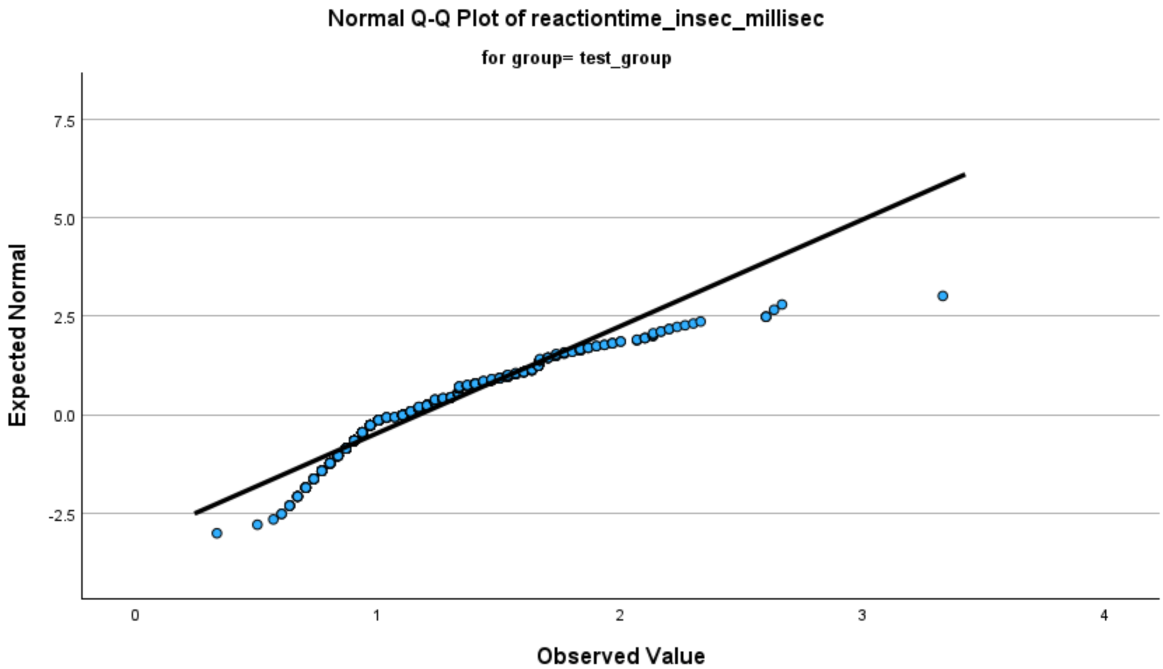

Figure G.12: Normal QQ test for the test group with reaction time

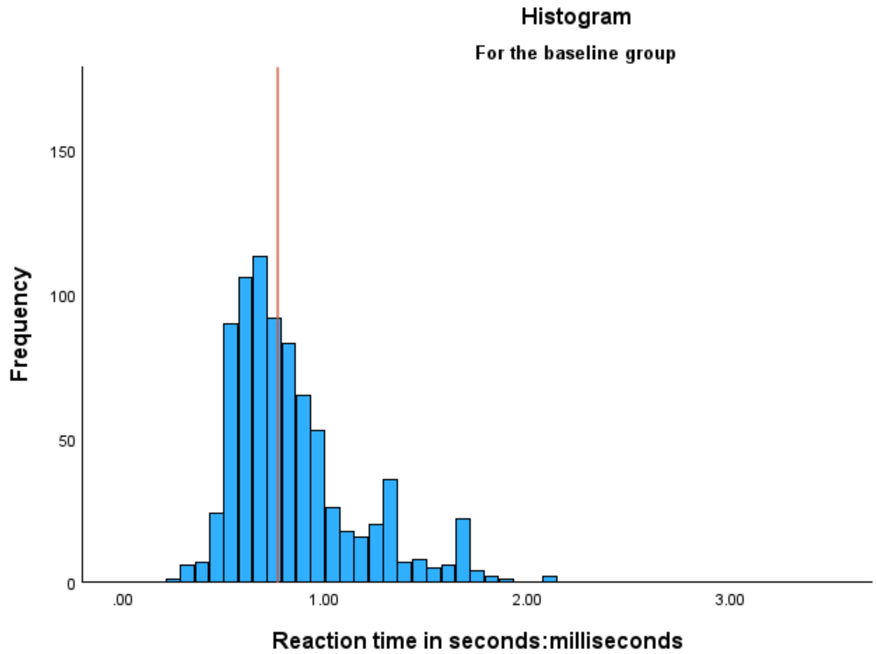

Figure G.13: Histogram of the reaction time of the baseline group

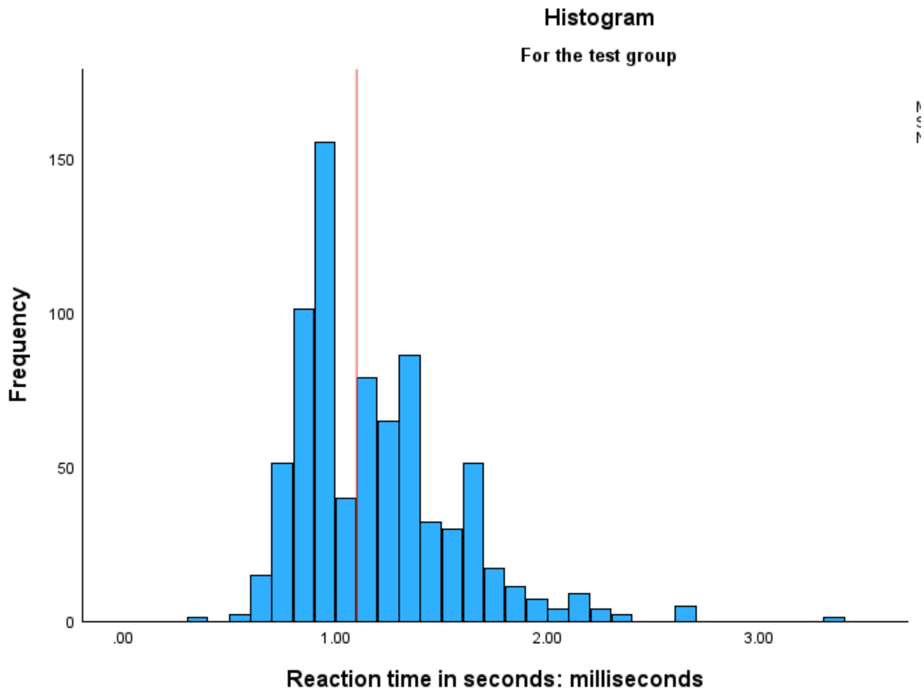

Figure G.14: Histogram of the reaction time of the test group