DESIGN IMPLICATIONS FOR THE DESIGN OF ASSISTIVE DEVICES FOR PEOPLE WITH PHYSICAL DISABILITIES

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ABSTRACT

This study focuses on finding design implications for the design of assistive devices for people with physical disabilities. It has three parts. In the first part, a literature review has been performed, to find existing design implications that could be used for the design of assistive devices for people with physical disabilities. In the second part, experts on designing assistive devices are interviewed on their experience with designing for people with physical disabilities. In the third part, the analyzed and synthesized design implications are evaluated through the Research through Design method, where a design process is performed with the use of the found design implications. This study provides a list of design implications divided into several topics, that could be used for the design of assistive devices for people with physical disabilities.

KEYWORDS

Design implications, Physical disabilities, Assistive devices, User-centered design, Disability studies, HCI, Technology abandonment, Research-through Design,

1. INTRODUCTION

Becoming physically impaired can have a big impact on someone's life. People who recently became physically disabled have to adapt to their impairments, by learning how to do their daily tasks in a different way. This new situation brings along new challenges and frustrations that people have to deal with, which might cause them to feel helpless or dependent on others. Assistive devices can guide people with physical disabilities in their process of adaptation and rehabilitation. In order to design assistive devices that fit the user, it is important to understand what the needs of the users are.

In disability studies, there are two ways of approaching the needs of users with physical disabilities. The first is through the medical model, which states that the experience of disability is caused by physical limitations [13], and the second is through the social model, which states that the experience of disability is caused by societal and cultural factors, such as acceptance by society. [14]. Currently, the medical model is commonly used for understanding disabilities, as opposed to the social model [49]. With the medical model, mostly the medical needs of the people with physical disabilities are considered, while the social needs, such as personal acceptance, are often forgotten. This can lead to situations where assistive devices are abandoned and never used [44]. To prevent this from happening, it needs to be clear for developers of assistive devices how to approach the design process, which design guidelines to use, and which other aspects need to be taken into account.

One way of conveying such design guidelines and approaches to the developers is through design implications, which are ideas and knowledge that are retrieved from empirical research

and findings [1]. These design implications can be used to guide designers during the design process. A list of design implications would help to bridge the gap between fieldwork and design and could make it easier for designers and engineers that are new to this field to develop effective assistive devices that accommodate the need of the user.
Therefore this paper focuses on finding design implications for designing non-medical assistive devices, which are devices that do not cure, treat, diagnose or prevent a condition, but can assist in making the condition more bearable [54]. The aim of this paper is to answer the following question: "What are the design implications for a non-medical device that can assist people who are permanently physically impaired?". To answer this research question, design implications will be analyzed and synthesized through the use of literature research. Besides, this paper provides the insights of three experts on designing assistive devices. Furthermore, the design implications will be evaluated through the Research through Design method and will then be discussed. In the end, this paper will provide a list of design implications that can be used when designing a non-medical assistive device for people who are permanently physically impaired.

2. ABOUT DESIGN IMPLICATIONS

Before finding design implications, it is necessary to understand how they can be generated, and what types of implications there are.

2.1 Design implication sources

There are three different sources for generating design implications [1]. According to Sas et al. [1], these sources are fieldwork-, practice-, and human science-informed design knowledge.
In fieldwork-informed design knowledge, methods for gathering design implications include using requirements, using ethnographic research, creating personas and scenarios, sensitizing concepts, and using conceptual models [1, 31-33]. It is important to note that all of these methods have their own limitations and it can be difficult to translate them into specific design implications. Requirements, for example, can be too specific and are not always applicable to new designs. Ethnographic research can also be hard to evaluate and use for design implications [35]. Furthermore, sensitizing concepts can lack clarity or cannot be implemented easily into technology.
In practice-informed design knowledge, the focus lies not on gathering new data but on basing research on existing successful systems [34]. An approach such as Höök's strong concepts [2] can be used, that exists of properties that can be found in multiple systems. Gaver [3] has a different approach that is deliberately not specified because he suggests that designs should be ambiguous. In both approaches, there are no criteria mentioned for evaluating new designs and therefore it is hard to use them for design implications [1]. For instance, research-through-design (RtD) is known as a practice-informed design knowledge method [4]. In RtD, the sequence of planning, acting, observing and reflecting, makes it a useful method to find design implications through practice.

In human science-informed design, design principles are derived from social science knowledge and human behavior [1]. The design principles that are found using this method are more people-oriented than technology-oriented, but still abstract and general and therefore still applicable to many design concepts.
All these knowledge sources have their advantages and disadvantages (see table 1) but are nevertheless useful for gathering design implications. Therefore, to gather design implications for non-medical devices that can assist people who have recently become permanently physically impaired, multiple sources will be combined.

Table 1. Advantages and disadvantages of several design implication sources

Type of source	**Method**	**Advantages**	**Disadvantages**
Fieldwork-informed design knowledge	Requirements	Capable of capturing the richness of social settings	Difficult to generalize
	Ethnographic research	Capable of capturing the richness of social settings	Hard to evaluate or to express into design knowledge
	Personas and scenarios	Versatile, makes it possible to engage with fictional characters	None
	Sensitizing concepts	Promotes generalizability	Lack of clarity
	Conceptual models	Tend to be generalizable	None
Practice-informed design knowledge	Strong concepts	Lead to new instances of a design concept	No criteria for evaluating design concepts
	Design Heuristics	Can be used to improve on existing designs	Are less useful for generating new designs
Human science-informed design knowledge	Social science knowledge	Widely applicable	Need to be interpreted before they can be used

2.2 Design implication types

With the sources described in section 2.1, five different types of design implications can be described (see table 2). In practice, most design implications consist of short descriptions, but also prescriptions, abstractions and meta-abstractions, sensitizing concepts, and instantiations are used [1][50]. In this section, the different types of design implications will be explained. Descriptions are commonly linked to design problems for which the design implications are used. The prescriptions are most commonly linked to the design solution. There can for example be a description for approaching wheelchair inaccessibility (design problem), and a prescription for wheelchair entrances (design solution). Abstractions, meta-abstractions, sensitizing concepts, and instantiations are specifically meant for making it easier to use research outcomes and information when designing new products [1].

Abstractions in technology can be used to visualize general functionalities of existing technologies, while meta-abstractions focus on new technologies. Abstractions and meta-abstractions are meant to give guiding principles [50].
A different type of design implication is an instantiation. Instantiations are not general ideas like abstractions, but concrete examples that can be an inspiration for new designs and systems [1][51]. These types of design implications are based on fieldwork.
Sensitizing concepts, like abstractions, exist of generalized design knowledge. They are useful for finding guidelines that are less specific than requirements, but are still abstract [52]. Sensitizing concepts are mostly based on human behavior and are often more open than the abstraction and instantiation design implications. This however means that these design implications are not immediately usable, but need interpretation from the designer in a specific context [1].
Descriptions are also design implications found by fieldwork data. They describe and characterize the specifics of the problem that can be used to find a solution for that problem. In these descriptions, it is also important to mention why the description is important. This type of design implication is however not very generalizable and cannot always be implemented technologically [1].
The final type of design implication is prescriptions. Prescriptions are very specific and can be used as requirements and can be implemented immediately [53]. They are linked to a design solution. This means, however, that it is difficult to write prescriptions that can be used in a different setting than the one that was used to make the prescription [1].

A thorough understanding of what design implications are, and what types are common, makes the search for new design implications more focussed and efficient. A wide variety of design implications is beneficial for answering the research question of this paper as thoroughly as possible. To create design implications that are usable for designing assistive devices for people with physical disabilities, abstractions, sensitizing concepts, and instantiations are best suited to use. These types of design implications are generalizable and actionable, because they can be

used in multiple settings and are very concrete. They will be used further in this paper to describe the analyzed design implications.

Type of design implication	**Function of design implication**	**Example**
Abstractions and Meta-abstractions	Visualizing general functionalities of existing technologies (abstractions) or new technologies (meta-abstractions).	There are two important technical approaches in improving accessibility for disabled people in games. The first is the use of external devices, such as screen readers or mouse emulators. The second is the design of fully accessible games, specifically designed for one type of disability [21] When designing for long-term disabilities, the assistive devices should be durable and reliable, because the user will need them for a long period of time (P1).
Instantiations	Giving concrete examples that can be used as inspiration for new designs and systems.	PrEmo is a method that can be used to measure the emotions that a product evokes [5][7]
Sensitizing concepts	Finding guidelines that are less specific than requirements, but still abstract.	Self-expression and social contexts determine the long-term adoption of assistive devices, together with usability, cultural factors, and aesthetics [9][10][11]
Descriptions	Describing and characterizing the specifics of the problem that can be used to find a solution for that problem.	Involving multiple stakeholders, both with and without disabilities, helps with understanding the experience of disability, and can lead to developing effective solutions [47].
Prescriptions	Can be used as requirements and can be implemented immediately in similar situations.	When designing assistive devices for children, it is an important requirement that the device can grow with them (P1, P3)

Table 2. Types of design implications with examples retrieved from the results of this paper.

3. METHOD

To find design implications that are usable for designing assistive devices for people with physical disabilities, both literature research and interviews have been used as a source. In this literature review, research has been done in existing design implications, either stated as design implications or analyzed from the content of these papers. Research has been done about different topics, such as designing with emotion in mind, or designing for Human Computer Interaction.

To gain insights into what happens during the design process of assistive devices in practice, I conducted three interviews with people who have experience with designing assistive devices for people with physical disabilities. Two of these experts are developers of prosthetic devices, and are working at a University. One of them also works at the Research and Development department of a rehabilitation facility. The third expert is a Master's graduate who developed a new medicine strip for people with rheumatism. I will refer to the experts as P1, P2, and P3.

The questions that I asked the experts during the interview were related to the approach of a design process, the challenges that they encountered, the involvement of the user, and their found design implications. The interviews were semi-structured and were based on several core questions. They lasted between 30 and 45 minutes.

The interviews were then transcribed and thematically analyzed through the use of coding. After the interviews were coded, similarities, differences, and interesting findings were written down and compared with the literature findings from section 4. The analyzed design implications can be found under each section.

To investigate if the identified design implications can be used in the design of assistive devices for people with physical disabilities, a Research through Design approach will be followed. Together with a participant, a design process will be started that focuses on solving a simple problem in the daily life of the participant, using the identified design implications. These implications will then be used in the design process and evaluated. Then, the results of their use will be discussed.

4. LITERATURE FINDINGS

In this section, design implications have been analyzed and synthesized on four different topics. These design implications will be explained and then listed per topic. An overview of all design implications can be found in the appendix.

4.1 Designing with emotion in mind

4.1.1 Methods and tools

Emotions play an important role in experiencing a product as pleasant. As a designer, it could be beneficial to design a product that has the intention to be experienced as pleasant, because users prefer to use products that they experience as pleasant [5]. To design a product with the intention to evict a certain emotion is called "emotion-driven design" [6].There are different methods and

tools that can be used to design products that take the emotional aspect of the user experience into account.
The emotion-driven design method can for example be used when the intention is to design a product that needs to be experienced as pleasant. It can however be difficult to predict what the evoked emotions of a design will be, because emotions are personal and not all users will have the same feelings about a product. There does exist a tool that can be used to measure emotions that are evoked by a certain design. This tool is called the Product Emotion Measurement Instrument (PrEmo), developed by Pieter Desmet [5][7]. It is mostly used for evaluating designs, but can also be used when designing a new product. An example of this is the design of wheelchairs for children, by Eva Dijkhuis in 2003, where she measured the emotions of six existing wheelchairs to see what emotions they evoked [5]. Each emotion was caused by a different concern, so by knowing the concerns she could design a new wheelchair that matched those concerns.

- It is important to design products that are experienced as pleasant products [5]. A method that can be used to achieve this is called emotion-driven design [6].
- PrEmo can be used to measure the emotions that a product evokes [5][7]

4.1.2 User involvement

Another method for designing with emotion in mind is participatory design. In a recent study participatory design was used to create hearing aids that are less stigmatizing and more appropriate for their users [8]. Many deaf people, or people who are hard of hearing, refuse to use assistive devices because of cost, discomfort, foreignness, stigmatization, social rejection, poor aesthetics, and shame [9]. Functionality is important, but self-expression and social contexts determine the long-term adoption of assistive devices, together with usability, cultural factors, and aesthetics [9][10][11]. In different settings, such as formal or informal, the social context changes, which means that there are different needs from the assistive device in different situations [8]. It can be, for example, that in some settings the user wants others to see the assistive device, so they know that the user is capable of doing the same things. But in other settings, the user needs to have a non-visible assistive device, because they could mark the user as being disabled [10]. In the study, smart jewels were created that matched the interest and emotional wellbeing of its users [8]. The final product matched the needs and wishes of the users very well. According to the researchers, this was a result of good interaction with the user during the design process. Participatory design is therefore a good method to involve the user during the design process. A different conclusion of this study, is that the generalization of user preferences can result in bad design. Therefore, user research is necessary to find the specific needs of the user, so that a product can be designed that fits to their needs [8]. To gain insight into the user experience, discussions and evaluations of prototypes can be used. However, when working together with users, for example during “participatory design” or “co-design”, suggestions given by the users can limit the creativity of the designer in the design process [8].

- Self-expression and social contexts determine the long-term adoption of assistive devices, together with usability, cultural factors, and aesthetics [9][10][11]
- In different settings the social context changes, which means that there are different needs from the assistive device in different situations [8]
- Generalization of user preferences can result in bad design [8]
- User research is necessary to find the specific needs of the user [8]
- Discussions and evaluations of prototypes can be used to gain insight into the user experience, [8]
- When working together with users, suggestions given by the users can limit the creativity of the designer in the design process [8]

4.1.3 User-Centered Design

The methods mentioned in this paragraph are all a type of User-Centered Design (UCD). In general, it can be said that UCD can lead to the development of products that are more likely to be accessible, applicable, and adopted [40].

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4.2 Designing with disability studies in mind

4.2.1 Social and medical model

Disability studies focus on academic work related to the experiences of people with disabilities [12]. Knowledge of disability studies might prevent the making of wrong assumptions, such as that a disability is always a problem that needs to be solved. Instead, a disability is sometimes created by designers that (indeliberately) exclude people from using their product, while otherwise there would not be a problem [13]. This way of looking at disabilities can be put under a “social” model [14]. In social models, cultural and societal factors determine when a person experiences disability, as opposed to medical models, where disability is defined by the physical conditions and limitations of a person [13]. However, both models have limitations, since medical treatment should not be neglected and social constructions do play a role.

- It is preferable to look at disabilities through the social model, as opposed to the medical model, to create designs that are experienced as more positive by the user.

4.2.2 Inclusion by personalization

The role that disability studies have when designing assistive devices is important when solving accessibility problems [13]. There can, for example, be smart solutions for understanding web pages for people who are visually impaired. An example for such smart solutions are screen readers. These screen readers however only work when those web pages have been designed

with screen readers in mind [13]. By not making a web page accessible for screen readers, the designer has excluded a group of users that can only access the web page through a screen reader. In these instances, it is likely that the designer only had limited training about universal design [38] and inclusive design [13]. However, if these methods are used, people with physical disabilities will feel less dependent and less excluded [39]. Universal design, for example, is a process, where products are not adapted or specifically designed for people with disabilities, but are designed with accessibility in mind, so that everyone can use the product [38]. In this way, all people, regardless of age, size, and abilities can use and understand the product. When people with disabilities can use products without the necessity to make adaptations or use external devices, they feel more independent and less prompted with their disabilities [39]. It could however be possible that adaptions have to be made, for example when there are different end-users. When there are different end-users, and therefore different needs, it should be an option to personalize the way information is conveyed [20], but when there are few or no contradictory needs, design for all [22] is a good method for including as much of the population as possible. It involves taking into account factors such as gender, age, skills, and disability so that as few as possible people get excluded [21].

- When there are different end-users, and therefore different needs, it should be an option to personalize the way information is conveyed [20]
- When there are few or no contradictory needs, design for all [22] is a good method for including as much of the population as possible.

4.2.3 Discrimination towards people with physical disabilities

Disability studies also show that discrimination towards people with a disability is not uncommon [29]. Assistive devices can play a role in this discrimination. For example, when a person does not look like they have a disability, but then are seen with an assistive device, such as a white cane or a wheelchair, they can be treated very badly. It is therefore important to take the context and experiences of people with disabilities into account, but also people without disabilities, when designing assistive devices to prevent discrimination [30].

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4.2.4 Permanent disabilities

Another thing disability studies can tell us is that there are some differences between the emotional state of people with temporary disabilities and permanent disabilities. One difference is that on average, people with permanent disabilities indicate to have a higher quality of life and higher life satisfaction than those who have a temporary disability [15]. However, being permanently physically disabled can still lead to a variety of emotional responses. For each

person, this response is different, but common reactions to permanent physical disabilities are depression and putting more focus on physical symptoms and feelings [55]. When designing assistive devices for people who are permanently physically disabled, it is therefore important to know that their emotional response will affect the impact of an assistive device [55]. Besides, when designing for long-term disabilities, the assistive devices should also be durable and reliable, because the user will need them for a long period of time.

- The emotional response of people with permanent physical disabilities will affect the impact of an assistive device [55].
- When designing for long-term disabilities, the assistive devices should be durable and reliable, because the user will need them for a long period of time.

4.3 Designing for Human-Computer Interaction

4.3.1 User interface design

Accessibility of Human-Computer Interaction (HCI), such as online games and websites, plays an important role in including people with physical disabilities online. One aspect of accessibility is the user interface. The user interface has to be understandable and usable by the target audience and intended end-users. To design a suitable user interface, the capabilities and incapabilities of the end-user need to be mapped out well, so that information and features can be conveyed to the user [21]. Existing guidelines can be used, but some guidelines have to be adapted to the user [28]. There are many disability-access guidelines and standards available [36]. These guidelines are intended for product developers, such as industrial designers, or software programmers. However, even when the guidelines are used by industrial designers, a programmer-centric approach should be used for the design of accessible websites [37]. In this way, the programmers can use the help of industrial designers or other accessibility experts to make a user interface accessible from the beginning, instead of having to put additional time and effort into the accessibility afterward [36]. This also supports the principle of universal design, because this way of approaching HCI includes accessibility for everyone.

- To design an appropriate user interface, the capabilities and incapabilities of the end-user need to be mapped out well, so that information and features can be conveyed to the user [21]
- Existing design guidelines can be used for designing HCI, but some guidelines have to be adapted to the user [28]
- A programmer-centric approach should be used for the design of accessible websites [37].

4.3.2 Web design

For including people with physical disabilities on websites, guidelines exist for designers. Direct guidelines for web accessibility can for example be found on the World Wide Web Consortium’s

Web Accessibility Guidelines [16]. Most of the guidelines provided are however directed to people with blindness. To evaluate if a web page is accessible, simulation can be used to get initial feedback about the accessibility [17]. After the evaluation with simulations, user testing should still be performed to test if it is truly accessible enough. An alternative to this evaluation method is to include one or a few users during the design process. Often people with disabilities are only asked questions during interviews or are only involved in the design process for a short period. However, more and more accessibility researchers view people with disabilities as an expert on their field and could be an asset in the design process. Participatory design is a good method for including those experts [30].

- Guidelines for web accessibility can be found on the World Wide Web Consortium's Web Accessibility Guidelines [16]
- To evaluate if a web page is accessible, simulations can be used to get initial feedback about the accessibility [17]. After the evaluation with simulations, user testing should still be performed to test if it is truly accessible enough
- Participatory design is a good method for including people with disabilities in the design process, who can be seen as experts on their disability [30]

4.3.3 Improving accessibility and usability in games

Rehabilitation processes, of repeating the same activities over and over again, can become boring over time. To prevent boredom, and to distract from pain [19], games can be used in the rehabilitation process of people with a disability. When designing these games, or other types of Human-Computer Interaction (HCI), it is necessary to take accessibility into account [20].
To achieve good accessibility, there must be different options for conveying and receiving information and feedback that are appropriate for the characteristics, capabilities, and skills of the end-user, taking into account the accessibility [21]. Besides that, usability has to be taken into account. While accessibility is about who can use a system, usability is about how well someone can use a system. There are two important technical approaches in improving accessibility for disabled people in games. The first is the use of external devices, such as screen readers or mouse emulators. The second is the design of fully accessible games, specifically designed for one type of disability

- Usability and accessibility have to be taken into account when designing games for people with disabilities [21]
- There are two important technical approaches in improving accessibility for disabled people in games. The first is the use of external devices, such as screen readers or mouse emulators. The second is the design of fully accessible games, specifically designed for one type of disability [21]

4.3.4 HCI design for children

There are different users for every product, and different users have different needs. HCI directed to children should therefore be approached in a different way than HCI directed to adults [23]. There are already different studies that have written guidelines for the design of interactive experiences for children [23][24][25][26]. These studies are focused on children without a disability, but for children with a disability, there are different needs. Adapted guidelines are required for people with a disability [28]. For children with a hearing impairment, the APRehab methodology can be used for designing serious games [27]. This methodology provides a list of design guidelines for psychomotor rehabilitation activities.

- There are already different studies that have written guidelines for the design of interactive experiences for children [23][24][25][26]
- For children with a hearing impairment, the APRehab methodology can be used for designing serious games [27]. This methodology provides a list of design guidelines for psychomotor rehabilitation activities.

4.4 Designing for the prevention of abandonment of assistive devices

4.4.1 Unwanted attention

One aspect often missing in disability studies, is how the design and aesthetics of an assistive device have an influence on the view on disability [41]. It can shape the identities and actions of a person [42][43]. Some influences of assistive devices are unwanted, and that can in some cases lead to the abandonment of an assistive device. According to Prior [44], reasons for the abandonment of assistive devices can be a lack of access to devices, lack of information about devices, repair, or maintenance, changes in the capabilities of the user, inflexibility or ineffective performance of the device, lack of motivation, support, or need for the device, or negative family attitudes. One example of assistive device abandonment is the abandonment of orthopedic shoes for people with diabetes. People who have diabetes do not look like they have a disability. However, the design of most orthopedic shoes is so recognizable, that it immediately puts the label of “disabled” on a person. This can lead to people with diabetes not wearing those shoes (P1). Unwanted attention can lead to abandonment, which can lead to inaccessibility in social situations [46]. Improving the social accessibility of assistive devices could lead to less unwanted attention [47].

- Unwanted attention can lead to abandonment, which can lead to inaccessibility in social situations [46]. Improving the social accessibility of assistive devices could lead to less unwanted attention [47]

4.4.2 How to reduce abandonment

Design implications for improving social accessibility are drawn up by Shinohara [47], and are part of a User-Centered Design method, called “Design for Social Accessibility”. Firstly,

accessibility should be the most important requirement. The final product should meet the user's needs and preferences. The second implication for improving social accessibility is to involve multiple stakeholders, both with and without disabilities. This helps with understanding the experience of disability and can lead to developing effective solutions. The final design implication is that disabled and nondisabled views about social consideration should be balanced. Knowing the opinions and experiences of both people with and without disabilities can lead to more understanding about social situations and help to quickly address issues about accessibility. The improvement of social accessibility can in the long term improve the adoption of assistive devices and play a role in the reduced abandonment of assistive devices [45].

- Accessibility should be the most important requirement when improving social accessibility to reduce the abandonment of an assistive device [47].
- Involving multiple stakeholders, both with and without disabilities, helps with understanding the experience of disability, and can lead to developing effective solutions [47].
- Disabled and nondisabled views about social consideration should be balanced. Knowing the opinions and experiences of both people with and without disabilities can lead to more understanding about social situations and help to quickly address issues about accessibility [47].

4.5 Conclusion

In this section, design implications have been analyzed and synthesized through literature findings. These design implications are divided into four different sections, and listed under each subsection. They can be used in the design process of an assistive device for people with physical disabilities, but they are mostly based on theory. To find what design implications are used in practice, further research has been done in section five.

5. INTERVIEW FINDINGS

5.1 Interaction with the user

Important findings from the interviews include a list of design implications related to the design of assistive devices for people with physical disabilities. All three experts included the user in the design process. However, this involvement was limited. During the start of the design process, users were interviewed to find out what their needs were. All three experts mentioned that it is very important to do these interviews in person. In this way, you will not only be aware of the stated answers of the user, but also of the context which has an influence on the answer of the user (P2). After the start of the design process, the user often did not get involved until the testing of the first prototypes (P1, P2, P3). The experts found out that during testing of the prototype, the user preferred to have a physical mock-up. The user will then have a better understanding of what the product will look like (P2).

- Interactions with the user should happen in person as much as possible (P1, P2, P3)
- Physical prototypes are preferred when doing evaluations with the user (P1, P2, P3)

5.2 Importance of target group and stakeholders

Not only the needs of the end-user are important, but also the ones of the stakeholders (P1, P2, P3). These stakeholders could be people like medical doctors, who have to assist for example people who need a prosthesis, or orthopedic instrument makers, who have to make adaptations to those prostheses (P1). The stakeholders, however, could have different interests in an assistive device. A method for finding and combining all interests is the Analytic Hierarchy Process (AHP) (P3) [48]. With this method, math and psychology are used to organize and analyze complex decisions. According to two of the experts (P1, P2), there is also a danger in involving the users and stakeholders in the design process. For example, when the user gives too much input and suggestions, it could limit the creativity of the designer, and the solutions could be less out-of-the-box:

> "*[To closely involve the user during the design process] is difficult, because there are a number of people who can think along very well, but a lot of other people think 'this is a prosthesis and that is it' and if you then ask what could be done better, they can or do not dare to think outside the box*" (P1).

Besides that, stakeholders or end-users can identify a problem, which is not always the actual problem:

> "*As a designer, you have to search for the actual underlying problem*" (P1, P3).

It is also important to take into account that although a specific target group has certain needs, inside the target group, the needs may differ (P1, P2, P3). The option of adaptation or personalization of an assistive device is therefore also important. With children, for example, it can be convenient to design an assistive device that can grow with the child. Then it is not necessary to replace the device when the child grows (P1, P3). Children can also have different needs from the same product than adults. With a prosthesis, for example, children need the device to be simple and robust, while adults often want more functionality (P1).

- Both the interests of the users and other stakeholders, such as specialists or doctors, should be mapped (P1, P2, P3)
- A method for finding and combining the interests of all stakeholders is AHP (P3)
- By involving users in the design process, there are fewer possibilities for out of the box solutions (P1, P3)

- Sometimes the problem that you are trying to solve is not the actual problem, but the problem that the user believes is the problem. You have to see through that and find the actual problem (P1, P3)
- Different target groups have different needs, but in the target group itself, there can be different needs (P1, P2, P3)
- No person is the same, especially with physical impairments, so personalization is very important (P1, P2, P3)
- For children, it is important that the device can grow with them (P1, P3)
- Children often do not need a lot of functionality, because they are very maneuverable. It should be simpler and more robust (P1)

5.3 Defining list of requirements

After defining the problem and identifying the needs of all the users and stakeholders, a list of requirements can be created. Not only are the functional requirements important, but the user requirements also play an important role in the design process. In some situations, where the designers already have a lot of experience in designing a specific product, or designing for a specific target group, it can be that the designers already can construct a list of user requirements from the experience of previous projects (P1). However, to find the most accurate requirements, you need to do user research (P1, P2, P3). Some common design principles should be taken into account in every design process, such as that providing feedback is important. However, when designing for people with physical impairments, user research is necessary to find which types of feedback are interpretable (P1, P2). There are situations where it is impossible to predict a certain need of the user without user research:

> "*Sometimes there are things that users come up with that make you think "oh I never thought of that" For example, with club feet. The parents find it annoying to have to walk around with a child who has plaster on his feet. They can feel the looks of people in the supermarket, who might think they were abusing their child. We never thought that something like that would play a role. Sometimes unexpected things come out.*" (P3).

This example also indicates that social experiences and acceptance play an important role in the success of an assistive device. During the interviews, the experts gave in total seven examples of the failure of assistive devices, all due to the lack of acceptance by its user, without being asked about social influences. The three experts indicated that they were aware of the importance of acceptance and social factors:

> "*Something can be designed that works well technically, but if it remains in the closet, it is of no use.*" (P3).

In general, it can be said that the user does not like it when the device draws unwanted attention to them (P1, P2, P3). However, none of the experts usually evaluated or researched the social aspects and effects of their designs.

- User research is necessary to find requirements that you would not think of yourself (P1, P2, P3)
- Providing feedback to your user is important. You have to take into account what the user is capable of in understanding the feedback (P1, P2)
- Functionality is important, but if the user does not accept the solution, the product is of no use (P1, P3)
- People do not like it when the device draws attention to them (P1, P2, P3)

6. EVALUATING FOUND IMPLICATIONS

6.1 Research-through-Design

To discover if the identified design implications in this paper can be used in the design process of a non-medical assistive device for people with physical disabilities, a simple design process is set up where the Research through Design approach [4] will be used.

6.1.1 Used design implications

Before the first contact with the participant started, I came up with an approach for involving the participant in the design process, based on the design implications in this paper. A list was made of design implications that could be used, should be used, or were not applicable such as the HCI guidelines. Not all design implications could be used, because some of them are about designing for children, or about designing for HCI. All design implications that could be used have been used, and are described in table 3. The results of the used design implications are also described.

Table 3. Used design implications with their results.

Design implication	Sub-section	Use	Result
User research is necessary to find requirements that you would not think of yourself (P1, P2, P3)	Defining list of requirements	User research was done by involving the user closely during the design process.	Interesting requirements were found, such as that the product should provide grip on the bottle, instead of the bottle cap.
User research is necessary to find the specific needs of the user [8]	Designing with emotion in mind	User research was done by involving the user closely during the design process.	The needs of the user were found, such as that they needed to use the product at home, or that they needed to use

			the product with just one hand.
Participatory design is a good method for including people with disabilities in the design process, who can be seen as experts on their disability [30]	Designing with disability studies in mind	The user was involved in the making of design choices and during the evaluation process. The opinion and feedback of the user was taken into consideration in the next design steps.	Important design choices were well underpinned and resulted in a design that was functional for the user.
When working together with users, suggestions given by the users can limit the creativity of the designer in the design process [8]	Designing with emotion in mind	The user was only involved when making decisions between options, and had no influence on the ideation phase.	The creativity of the designer was not limited.
Interactions with the user should happen in person as much as possible (P1, P2, P3)	Interaction with the user	Unfortunately due to corona and other personal circumstances of the participant, interactions could not happen in person. Instead, interactions happened through online chatting and videos.	Communication was slow and sometimes confusing, both for the designer and participant.
Sometimes the problem that you are trying to solve is not the actual problem, but the problem that the user believes is the problem. You have to see through that and find the actual problem (P1, P3)	Importance of target group and stakeholders	Together with the user the problem was found. This was done through a conversation that focussed on the daily activities of the user and their main struggles.	Opening bottles was not seen as a big problem for the user because they could still open the bottle by asking for help, or by using their teeth. However, this did cause the user to feel dependent on others, which actually was a problem.
Different target groups have different needs, but in the target group itself, there can be different needs. (P1, P2, P3)	Importance of target group and stakeholders	In the target group of people who can only use one hand, different needs exist for the product, such as opening different kinds of bottles, or using the product in a different context. Those needs were mapped out.	The product makes it possible to open different kinds of bottles. Next to that, it allows the user to bring it with them or store it away, because of the small size and flat shape.

Discussions and evaluations of prototypes can be used to gain insight into the user experience, [8]	Designing with emotion in mind	Seven prototypes were made that could be used for the evaluation process. Different aspects were evaluated, such as functionality and experience.	Insight was gained about the user experience, such as which prototype had the best functionality, which design they liked the best, or whether they would display the product at their home.
Physical prototypes are preferred when doing evaluations with the user (P1, P2, P3,)	Interaction with the user	All prototypes were sent to the home of the participant to be evaluated. In this way the participant could interact with the prototypes.	The prototypes could be tested on functionality by the end user, which provided valuable feedback.
Disabled and nondisabled views about social consideration should be balanced. Knowing the opinions and experiences of both people with and without disabilities can lead to more understanding about social situations and help to quickly address issues about accessibility [47].	Designing for the prevention of abandonment of assistive devices	Both people with disabilities as people without disabilities were asked to evaluate the prototypes. They were also asked about social aspects, such as if they would display the prototype at home and how they would feel about that.	Some prototypes were marked as stigmatising by non-disabled people, while other prototypes were marked as subtle and fitting with some interiors. These results were taken into consideration with the final product.
Involving multiple stakeholders, both with and without disabilities, helps with understanding the experience of disability, and can lead to developing effective solutions [47].	Designing for the prevention of abandonment of assistive devices	Both people with disabilities as people without disabilities were asked to evaluate the prototypes. The differences between the experience of people with and without disabilities have been noted.	The participant with the disability appeared to be less critical of the functionality of the prototypes, whereas the people without disabilities gave more constructive feedback, which could be used in the further development of the product.
Functionality is important, but if the user does not accept the solution, the product is of no use (P1, P3)	Defining list of requirements	Both the functionality as the user experience were evaluated with the use of prototypes.	Prototypes that had more functionality, but looked less appealing, were evaluated as less desirable than prototypes that looked more appealing.
People do not like it when	Defining list of	The product was made	The final product does

the device draws attention to them (P1, P2, P3)	requirements	small and storable to avoid drawing attention. Furthermore, feedback from the evaluation was used to make the design of the product more subtle.	not draw attention to the user, but is subtle and not stigmatising.
It is important to design products that are experienced as pleasant products [5]. A method that can be used to achieve this is called emotion-driven design [6].	Designing with emotion in mind	The end user was closely involved during the design process to make sure that the product was experienced as pleasant.	The participant evaluated the final product as something they would like to use every day and they would display it in their house.
Self-expression and social contexts determine the long-term adoption of assistive devices, together with usability, cultural factors, and aesthetics [9][10][11]	Designing with emotion in mind	Social experience, usability, and aesthetics were evaluated with the prototypes. Besides that, the end user was involved with making decisions about usability and aesthetics.	The final product has been accepted by the end user. However, the long-term adoption of the assistive device is not yet confirmed.

6.1.2 Design process

The design problem that was to be solved with the design process was found together with a participant that took a role in the design process. The participant lost functionality in their dominant hand and arm due to a stroke, and as a result, has lost a lot of independence and confidence in their life. During a series of online conversations, one particular problem was found: to open bottles, such as medicine or beverage bottles, is experienced as very difficult by the participant. They showed how they could still open a bottle, using both their functional hand and teeth, but the process took long and could cause frustration. Thus I started the ideation process of finding many different solutions. Two solution directions were found.

The first design solution focuses on providing more grip on the base of the bottle, rather than on the bottle cap (figure 1), while the second design solution focuses on improving grip on the bottle cap, which makes it possible to open the bottle with one hand (figure 2). Together with the participant, the best solution was identified. I expected the second solution to be the best, because it allowed the user to bring the tool with them and it would not attract a lot of attention. However, the participant could not see themselves in using the second solution, because it would only allow them to open a selection of bottles, and they would mostly open their bottles at home so there was no need to bring it with them. The participant preferred a solution that could be used at home, and that could be used for many different types of bottles.

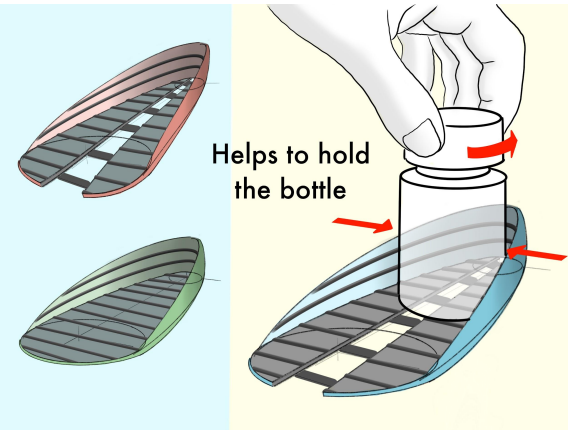


Figure 1. Solution direction one

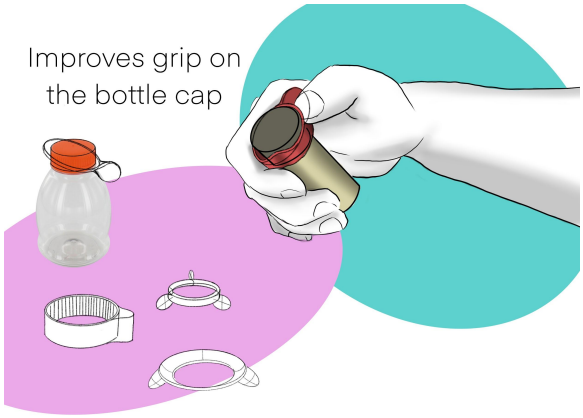


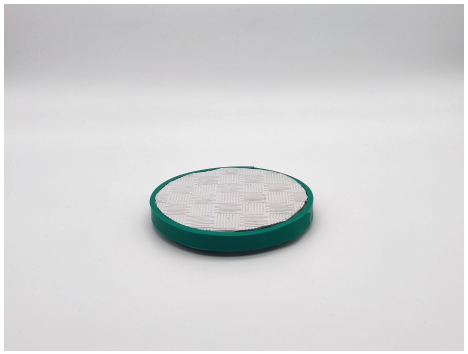
Figure 2. Solution direction two

After getting a clear understanding of the needs and wishes of the participant, the first prototypes could be made. Four prototypes were produced that experimented with shape, materials, and design. Six people, including the participant, were then asked to evaluate the prototype. This led to a clear result, in which prototype number four was identified as the most preferred solution. People mentioned that this prototype was more beautiful and was more likely to be displayed at home. It also was seen as less stigmatizing and the easiest to use.

Prototype 1

Prototype 2

Prototype 3



Prototype 4

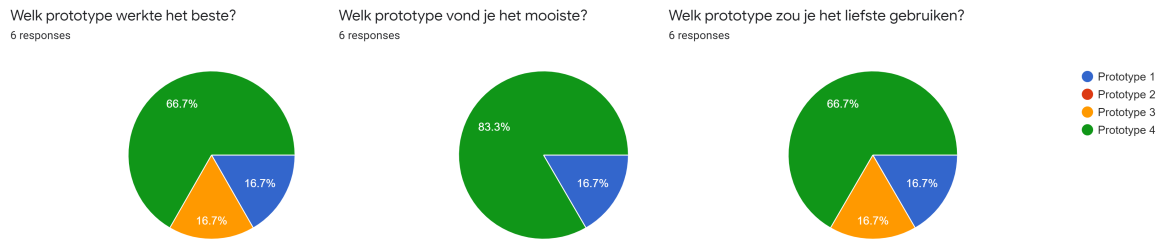


Figure 3. Results evaluation

Still, prototypes one to three had some advantages over prototype four, such as the supporting sides which keeps the bottles in place. Therefore three new prototypes were made that took the feedback and results of the evaluation of the first round of prototypes into account.

Prototype 5

Prototype 6

Prototype 7

These prototypes were sent to the participant for evaluation. The prototypes were experienced as more aesthetically pleasing and overall a better functionality. The participant was able to open all their bottles with prototype four and five. They however liked the design of prototype four the most.

The final product will be a more developed version of prototype four. This product will be produced for the participant for daily use.

6.1.3 Conclusion

The use of the design implications in this paper resulted in a product that fit to the needs of the user. The design implications could be used as guidance in the design process, as well as a method to use for the evaluation of the product.

7. DISCUSSION

7.1 Discussion of results

In this paper the answer was found on the following research question: “What are the design implications for a non-medical device that can assist people who are permanently physically impaired?”. A list of design implications for designing assistive devices for people who are

physically disabled can be found throughout this paper. In the appendix, an overview of all design implications can be found.

The analyzed and synthesized design implications from the literature findings are consistent with the existing research they are based on. The design implications gathered from the interview findings are also consistent with the literature review. For example, “By involving users in the design process, there are fewer possibilities for out of the box solutions (P1, P3)” is very similar to “When working together with users, suggestions given by the users can limit the creativity of the designer in the design process [8]”. There is however an interesting difference between the literature and interview findings. In the literature findings, there is a lot of emphasis on different methods and principles to use when involving the user in the design process, while in practice, these methods and principles are not explicitly used, but are just called “user research”. This might mean that the methods and principles described in the literature findings can be used in practice, but that it is also possible to combine methods and principles, or to find a new way to do user research.

Most of the design implications are in favor of involving the user very closely in the design process. This can lead to products that are more likely to be accepted and valued by the user. In practice, we see however that the user is often not closely involved in the design process, which can lead to the abandonment of assistive devices. Interestingly, P1, P2, and P3 were all aware of the importance of involving the user during the design process but still did only include the user during user research and testing of prototypes. For P1 and P3, this led to the abandonment of assistive devices, but there was no intention to involve the user more in the design process to prevent this from happening. It is therefore likely that the design implications in this paper could be familiar to experienced designers, but their importance is underestimated.

During the Research through Design process in this research, design implications were used, which led to a product that was acknowledged and valued by the user. The use of design implications had a positive result on the design process. It provided structure on the design process, and suggested guidelines and requirements for the final product. There were also design implications that could not be used due to circumstances, such as the following design implication: “Interactions with the user should happen in person as much as possible (P1, P2, P3)”. The consequence of this was that the communication between the participant and I was slow and difficult. If the design implication could be met, the communication would probably be more smooth and easier. This also is an indication that the design implications are beneficial to the design process.

The design outcome of the Research through Design process meets the needs of the users well. It is functional, but most importantly, subtle and not stigmatizing. To improve on the design of this bottle-opener, I would suggest to make the product look even more like a coaster. In this way, the

user can own multiple products on different locations, and the product would very well blend into their environment, because coasters are not an uncommon product in a house. A lesson that can be learned from this design process, is that a product does not always have to be very complicated for it to be a good product. If the final product is a simple but efficient product, then that is not a waste of the design process, but a good design outcome if it fits to the needs of the user.

7.2 Limitations

This paper has been written during the COVID-19 pandemic, which has led to some limitations during the research process. It was first of all difficult to get in contact with care homes or health institutions for participants in this research. They were so occupied and careful with their patients that they preferred not to cooperate with this research. This has led to the decision that only experts on designing assistive devices for people with physical disabilities have been interviewed, instead of also interviewing people with physical disabilities who use assistive devices. Interviewing people with physical disabilities who use assistive devices could have led to more interesting findings about the experience of assistive devices.

The difficulty in finding participants to cooperate in this research has also led to a small user group during the Research and Design process. The design implications in this paper are not only meant for designing assistive devices for just one person, but also for large user groups and for mass production. Due to the small user group it could not be tested if the design implications are indeed suitable for mass production.

To further evaluate the effectiveness of the design implications in this paper, a larger group of users with physical disabilities have to be involved during an evaluation. Besides that, the designed and produced products that have been designed with the use of the design implications in this paper have to be tested over a longer period of time, to make sure that the assistive devices will be adopted on a long-term basis.

7.3 How to use the design implications

This paper gives an overview of various design implications in different topics, meant for designing assistive devices for people with physical disabilities. The implications are divided in the following sections:

- *Interaction with the user*
- *Importance of target group and stakeholders*
- *Defining list of requirements*
- *Designing with emotion in mind*
- *Designing with disability studies in mind*
- *Designing for Human-Computer Interaction*
- *Designing for the prevention of abandonment of assistive devices*

Each section can be consulted before, during, or after the design process. I would advise to read all design implications before starting to design assistive devices for people with physical disabilities. The design implications can be used as guidelines for the approach of a design process, such as how to involve the user during this process. Other applications of the implications could be to use them as a check during the evaluation process, such as that the product should not draw attention to the user.
Not all design implications are applicable to every design process, because some of them are specifically intended for HCI, or for the design of products for children. For each design process, a list can therefore be made of which of the design implications to use. This can help to consult the design implications more effectively. When, for example, a digital game for children with hearing loss has to be created, it would be useful to consult the section “Designing for Human-Computer Interaction”. When designing assistive devices that are intended to be used for a longer period of time, it would be wise to consult the section “Designing for the prevention of abandonment”. It is however always useful to consult the first three sections “Interaction with the user”, “Importance of target group and stakeholders”, and “Defining list of requirements”. The design implications mentioned in those sections are general and applicable to most design processes for designing assistive devices for people with physical disabilities.

7.4 Conclusion

In this paper, design implications have been provided for the design of non-medical assistive devices for people who are physically impaired. The results in this paper contribute to the design of more accepted and valued assistive devices for people with physical disabilities. The design implications in this paper can have a positive impact on the user experience of assistive devices when implemented in the design process. Use of the implications can therefore lead to less abandonment of assistive devices, and can make a design process more guided and structured. It is advisable to take the use of these design implications strongly into consideration when designing assistive devices for people with physical disabilities. It is important to note that the design implications in this paper are not complete, and further research has to be done to find more design implications for the design of assistive devices for people with physical disabilities. However, the design implications in this study are a good asset for both inexperienced and experienced designers who want to design accepted and valued assistive devices for people with physical disabilities.

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APPENDIX

List of all design implications

DESIGNING WITH EMOTION IN MIND

- It is important to design products that are experienced as pleasant products [5]. A method that can be used to achieve this is called emotion-driven design [6].
- PrEmo can be used to measure the emotions that a product evokes [5][7]
- Self-expression and social contexts determine the long-term adoption of assistive devices, together with usability, cultural factors, and aesthetics [9][10][11]
- In different settings the social context changes, which means that there are different needs from the assistive device in different situations [8]
- Generalization of user preferences can result in bad design [8]
- User research is necessary to find the specific needs of the user [8]
- Discussions and evaluations of prototypes can be used to gain insight into the user experience, [8]
- When working together with users, suggestions given by the users can limit the creativity of the designer in the design process [8]
- User-Centered Design can lead to the development of products that are more likely to be accessible, applicable, and adopted [40].

DESIGNING WITH DISABILITY STUDIES IN MIND

- It is preferable to look at disabilities through the social model, as opposed to the medical model, to create designs that are experienced as more positive by the user.
- When there are different end-users, and therefore different needs, it should be an option to personalize the way information is conveyed [20]
- When there are few or no contradictory needs, design for all [22] is a good method for including as much of the population as possible.
- It is important to take the context and experiences of people with disabilities into account, but also people without disabilities, when designing assistive devices to prevent discrimination[30]
- The emotional response of people with permanent physical disabilities will affect the impact of an assistive device [55].
- When designing for long-term disabilities, the assistive devices should be durable and reliable, because the user will need them for a long period of time.

DESIGNING FOR HUMAN-COMPUTER INTERACTION

- To design an appropriate user interface, the capabilities and incapabilities of the end-user need to be mapped out well, so that information and features can be conveyed to the user [21]
- Existing design guidelines can be used for designing HCI, but some guidelines have to be adapted to the user [28]
- A programmer-centric approach should be used for the design of accessible websites [37].
- Guidelines for web accessibility can be found on the World Wide Web Consortium's Web Accessibility Guidelines [16]
- To evaluate if a web page is accessible, simulations can be used to get initial feedback about the accessibility [17]. After the evaluation with simulations, user testing should still be performed to test if it is truly accessible enough
- Participatory design is a good method for including people with disabilities in the design process, who can be seen as experts on their disability [30]
- Usability and accessibility have to be taken into account when designing games for people with disabilities [21]
- There are two important technical approaches in improving accessibility for disabled people in games. The first is the use of external devices, such as screen readers or mouse emulators. The second is the design of fully accessible games, specifically designed for one type of disability [21]
- There are already different studies that have written guidelines for the design of interactive experiences for children [23][24][25][26]
- For children with a hearing impairment, the APRehab methodology can be used for designing serious games [27]. This methodology provides a list of design guidelines for psychomotor rehabilitation activities.

DESIGNING FOR THE PREVENTION OF ABANDONMENT OF ASSISTIVE DEVICES

- Unwanted attention can lead to abandonment, which can lead to inaccessibility in social situations [46]. Improving the social accessibility of assistive devices could lead to less unwanted attention [47]
- Accessibility should be the most important requirement when improving social accessibility to reduce the abandonment of an assistive device [47].
- Involving multiple stakeholders, both with and without disabilities, helps with understanding the experience of disability, and can lead to developing effective solutions [47].
- Disabled and nondisabled views about social consideration should be balanced. Knowing the opinions and experiences of both people with and without disabilities can lead to

more understanding about social situations and help to quickly address issues about accessibility [47].

INTERACTION WITH THE USER

- Interactions with the user should happen in person as much as possible (P1, P2, P3)
- Physical prototypes are preferred when doing evaluations with the user (P1, P2, P3)

IMPORTANCE OF TARGET GROUP AND STAKEHOLDERS

- Both the interests of the users and other stakeholders, such as specialists or doctors, should be mapped (P1, P2, P3)
- A method for finding and combining the interests of all stakeholders is AHP (P3)
- By involving users in the design process, there are fewer possibilities for out of the box solutions (P1, P3)
- Sometimes the problem that you are trying to solve is not the actual problem, but the problem that the user believes is the problem. You have to see through that and find the actual problem (P1, P3)
- Different target groups have different needs, but in the target group itself, there can be different needs (P1, P2, P3)
- No person is the same, especially with physical impairments, so personalization is very important (P1, P2, P3)
- For children, it is important that the device can grow with them (P1, P3)
- Children often do not need a lot of functionality, because they are very maneuverable. It should be simpler and more robust (P1)

DEFINING LIST OF REQUIREMENTS

- User research is necessary to find requirements that you would not think of yourself (P1, P2, P3)
- Providing feedback to your user is important. You have to take into account what the user is capable of in understanding the feedback (P1, P2)
- Functionality is important, but if the user does not accept the solution, the product is of no use (P1, P3)
- People do not like it when the device draws attention to them (P1, P2, P3)