MASTER

Designing a wheelchair with people's intuition in mind
a new method

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Designing a wheelchair with people’s intuition in mind, a new method

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Abstract

When designing a product, it is desirable to take into account applicable intuitive knowledge of the users so that the product is perceived to be intuitive during use. However, current methods do not evoke all applicable intuitive knowledge accurately or pose unacceptable preconditions. In this study, our novel method analyses Skeleton Joint Tracking data of participants who act out interactions with an imagined wheelchair in order to find intuitive knowledge about mounting locations of a charging port. After adjusting the analysis, the novel method was able to rival an existing method (interview method) and preliminary support was found for the claim that intuitive knowledge is being found. Further research that improves on the current study is needed to validate this novel method.

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1. Introduction

Life&Mobility, a company which develops wheelchairs, is designing a new wheelchair that should be as intuitive as possible during use. However, the question is what makes a product to be perceived as intuitive. Intuition has a lot of different definitions and possible viewpoints. First, we will look at what intuition use actually entails and why it actually is beneficial to design a intuitive product. Subsequently we will look at the requirements of a method that could assist a company like Life&Mobility in designing a wheelchair that is as intuitive as possible.

Intuitive use:

Blackler and her team define intuitive use in the following way (Blackler, Popovic, Mahar, 2009):

> Intuitive use of products involves utilising knowledge gained through other experience(s). Therefore, products that people use intuitively are those with features they have encountered before. Intuitive interaction is fast and generally non-conscious, so people may be unable to explain how they made decisions during intuitive interaction.

Research shows that having previous experience with products made for quicker and more intuitive use experiences (Blackler et al., 2002). So, designing a product which is very innovative and which is not comparable to anything a user has used before requires more careful designing in order to make it intuitive to use. Intuitive interactions can be subdivided hierarchically from Body Reflectors (almost innate knowledge, where the product mirrors the shape of the human body), Population Stereotypes (a screw fastens clockwise), Familiar Features from same or other domains (learned knowledge about conventions) to Metaphors (use analogies with other things people already know, for example the desktop metaphor on a computer) (Blackler & Hurtienne, 2007).

This is not the only way to define intuitive use, however. Mohs et al. (2006a) define intuitive use as:

> A technical system is intuitively usable if the users' unconscious application of prior knowledge leads to effective interaction.

Compared to the previous definition, effective interaction is added as a characteristic of intuitive use. Effective interaction is a desirable trait for a lot of products, also for wheelchairs of Life&Mobility. Mohs et al. (2006a) also argue that prior knowledge can be seen as a continuum, from innate knowledge, knowledge gained through interactions during early childhood (sensorimotor), culture specific knowledge to expertise knowledge acquired in profession. Regardless of the type of information, it is used without awareness of the user. The lower levels of information (closer to innate knowledge) are present in a larger group of humans than the higher levels of information. For example, almost everybody 'knows' to pull back his finger when a flame comes close, but not everybody knows how to cycle without actively thinking about it. Higher level information (closer to expertise knowledge) differs more per person as it depends on a person's specific experience.

A similar field of research is that of intuitive theories, which usually focusses more on forming webs of concepts: *'…intuitive theories are comprised of an ontology of concepts, and a system of (causal) laws that govern how the different concepts interrelate.'*. (Gerstenberg & Tenenbaum, 2017). This web of theories helps a person interpret things in the world, where higher abstract information is associated with less abstract incoming information. Unlike the previous viewpoints on intuition, the field of intuitive theories has more focussed on modelling knowledge, for example people's understanding of physics.

Intuitive knowledge, or at least parts of it, is learned through interactions and also used during interaction. A general principle about knowledge is that the way it has been learned and used is related to the way this information can be retrieved (Swaak & de Jong, 1996). The way information is retrieved actually depends on the way information is learned (Shute and Glaser, 1990) This means that it would make sense to use interactions to extract intuitive knowledge. This is not the only requirement a method for evoking intuitive knowledge should meet, as will be seen in the following section.

Problem statement

As stated, the company Life&Mobility would like to design a wheelchair which is perceived as intuitive during use. That means that there is a need for insight into the intuitive knowledge that users possess. The to be designed wheelchair should integrate this knowledge in order to be perceived as intuitive during use. Therefore, a method is needed which should meet the following requirements:

- The method should be able to retrieve intuitive information. E.g., this information should have characteristics of intuitive information as specified in the previous section. Designing a product which allows users to apply their intuitive knowledge should lead to effective interaction (Mohs *et al,* 2006a).
- The method should not only rely on a product that already exists. A person who is in the process of designing a product will want to know how to shape his product at the moment he is shaping the product. The goal is to prevent having to make a physical product, testing it and changing it because it is not intuitive during use. The later in the process changes are implemented, the higher the costs (Tan *et al,* 2017). The intuitive knowledge of the user determines what the form of the product is.
- The method should not be confined by the subjective assessment of the designer. People do not only use knowledge that is directly applicable to the product, but they also use knowledge from other domains (Blackler, Alethea, Hurtienne & Joern, 2007). A designer might have ideas about the intuitive knowledge that the users have, but all intuitive knowledge that is applicable to the product should be taken into account. This also mean that the full range of intuitive knowledge should be taken into account, from innate knowledge to expertise knowledge acquired in profession.

- Intuitive knowledge is learned and later on used during interactions. As described in the previous section, this determines the way intuitive knowledge should be retrieved. Therefore, the method should take advantage of interactions in order to find intuitive knowledge.

In the following sections multiple ways of designing intuitive products and direct ways to evoke intuitive knowledge are looked into. These methods will be evaluated in order to see whether they meet the set requirements.

Possible methods for evoking intuitive knowledge and designing intuitive products

Design principles are developed in order to develop products that are intuitive during use. These are very general, encouraging the designer to use aspects that are already familiar to the user (functions that are already known for example). Designers are motivated to make us of peoples' capability of using intuitive knowledge from other domains. For example, when no products exist yet that are comparable to a new product, the designer can incorporate familiar characteristics of other products that the target group has used before. Also, providing consistency within the design and redundancy when needed is stressed. Some research methods exist that give insight into the intuitive knowledge that people possess (Blackler, 2018). For example, observations of interaction, verbal protocols such as Think Aloud, questionnaires, technology familiarity questionnaire, Technology Acceptance Model, interviews, diaries and Image Schemas.

Mohs et al (2006a) also mentions principles which are: suitability for the task, compatibility, consistency, gestalt laws, feedback, self-descriptiveness and affordances. Explaining these principles is outside the scope of this report, but they all are general principles that serve as inspiration to the designer, but puts the responsibility of incorporating the intuitive knowledge with the designer. To assist in the mentioned principles, a questionnaire and an Image Schema catalogue are made by the same research group. The Evalint questionnaire is used for evaluating intuitive interaction with a product and gives insight into four scales; perceived effortlessness of use, perceived error rate, perceived achievement of goals, and perceived effort of learning. Image schemas 'are abstract representations of recurring dynamic patterns of bodily interactions that structure the way we understand the world' (Johnson, 1987). For example, pressing the up-arrow on a keyboard will make the selection go up one row; the up-down schema. ISCAT is a database with examples and explanation about image schemas that is updated as new schemas are being found (Hurtienne & Blessing, 2007).

Some design methods and processes exist that include the user in the design process while not being explicitly focussed on evoking intuitive knowledge. Some of these will be discussed briefly in the following sections in order to see whether these meet the requirements.

Value co-creation methods put emphasis on the user as source of value. The perception and experience of the customer determine the value that is attributed to a product (Mukhtar *et al*, 2012). There is real interaction and cooperation with the customer. Only when there is a use for a product it gains value: value in use. A company has to get knowledge about the customer and for example their goals. An example of a value co-creation model is the DART model (Prahalad & Ramaswamy, 2004). Its key strategies are dialogue with the customer, giving them access to company insights, shouldering the risks together and being transparent with the customer. Other value co-creation models such as Payne's model (Payne *et al,* 2008) and Gronroos's model (Svensson & Grönroos, 2008) have a more process focus and a focus on the way of value fulfilment respectively.

Customer co-creation methods on the other hand see the customers as co-creator, buyers, end-users, co-producers, co-designers and/or sources of ideas. One of these customer co-creation methods, the participatory method (Wilkinson & De Angeli, 2014), brings the user and designer together to create a solution, where the researcher/designer facilitates the expression of people's creativity. The user is seen as the expert. Emphatic design (Postma *et al,* 2012) is more focussed on studying the users in their own environment. one of the goals of emphatic design is to discover latent user needs. Some methods make use of artefacts or prototypes, which represent not yet existing products (Edvardsson, Enquist, Johnston, 2005). Users are asked to express their experiences (Matthing, Sandén

& Edvardsson, 2004). Other customer co-creation techniques are the use of personas and avatars, laddering techniques of interviews and co-designing (Mukhtar *et al*, 2012).

However, none of the mentioned methods completely meet all the requirements that were set. Some of these methods depend (directly or indirectly) on an existing product, such as observations of interactions and emphatic design, which relies on observations in the real world where shortcomings of existing products can be identified. As stated, a physical product or prototype might not always exist yet when designing a new product, especially not when designing an innovative product without similar predecessors. Therefore, these methods do not meet our needs. Other methods, like the technology familiarity questionnaire, take into account only a subset of all the intuitive information that could be useful when using a new product. The mentioned questionnaire is composed by the researcher. The researcher decides which technologies are taken into account, which limits the amount of intuitive knowledge that can be found. Methods and principles such as image schemas and the general principles mentioned before suffer from a similar drawback, where the designer is expected to design a product based on very general and limited information. They therefore do not meet the requirement of taking into account all applicable intuitive knowledge. Some methods are questionable in their output of intuitive knowledge. Intuitive knowledge is defined as unconscious knowledge. However, methods like interviews and Think Aloud expect users to verbally explain themselves, which necessitates becoming conscious of ones' knowledge. This is also the case for a lot of value co-creation and customer co-creation methods. On top of this, these co-creation methods do not give insight in the extent to which intuitive knowledge is taken into account.

Since none of the mentioned techniques meet all the requirements that were set for this study we shift our attention to the development of a new method which should meet all the requirements.

Description of the intuitive method

We have seen in the previous sections that no method exists that meets all the set requirements. To meet the set requirements, a new method is devised.

The existing method of observations of interactions is taken as a starting point. In this method, participants are observed while they use a real product (Blackler, Popovic & Mahar, 2004). This means that at some point, the product is presented to the participant. At that moment the participant gets his or her first clues about the product, for example by looking at it. Based on these clues he or she will form a hypothesis about the product via the automatic cognitive process of intuition, i.e. based on the intuitive knowledge present in the participant (Bowers et al, 1990). People interpret information they acquire and are able to describe the situation on a higher level of abstractness (Gerstenberg & Tenenbaum, 2017). For example, a wheelchair is interpreted as having the higher-level function of providing people with mobility. This is crucial when the participant actually interacts with the product. The more the hypothesis of the product matches the actual product (and its function, meanings etc), the more intuitive the interactions will be (Hurtienne, Klöckner, Diefenbach, Nass & Maier, 2015).

Observing the interactions of the participants gives information about what intuitive knowledge the participants possess. The method of observations of interactions has the benefit that it uses interaction to evoke intuitive knowledge, which is one of the requirements. However, it uses interaction with an existing product to do so, which violates the requirement about not needing a physical product. In order to mitigate this drawback, the new method will use an imaginary product instead of a real product. This however means that the clues that are present when encountering a real product are not present here anymore. The substitute of these clues will be a description of the product that will be used. This means that the participant is verbally explained what functions, aesthetics or other characteristics the product has. Based on this description the participant forms a hypothesis about the product, guided by the intuitive knowledge he or she has (Bowers et al, 1990).

As described earlier, intuitive knowledge is learned through interactions and therefore should also be retrieved using interactions. The participant of the new method will be asked to interact with the product. These interactions are based on the envisioned use that the designer has of the product. Since no physical product is present, the participant is asked to act out the interactions with the imagined product, akin to a mime-player. For this method to work, participants have to be able to imagine a product and interact with this imagined product. Research shows that people are able to interact with an imaginary device based on spatial memory (Gustafson, Holz & Baudisch, 2011). Also, people are able to interact with an imaginary interface by making gestures in pre-defined areas (Gustafson, Bierwirth & Baudisch, 2010).

Just like the method of observations of interactions, the interactions of the participants with the imagined product are observed. Out of many possible ways, this study will use Skeleton Joint Tracking and video recordings to extract the intuitive knowledge.

The target group of the to be designed product will determine the participant population. These are the people who benefit from having intuitive interactions with the product, so the product should match the intuitive knowledge of this group of people.

The description of the product is crucial for the formation of the imagined product in the participant's mind. The description of the product should allow for some interpretational freedom on the part of the participant. For example, when a designer wants to get insight into what people intuitively assume about the height of a fridge door handle, he should not explicitly explain how high a handle is usually located but leave that up to the imagination of the participant.

The aforementioned method is however not yet validated nor compared to any existing methods. Therefore, we will use interviews for comparison. The following section will present the questions that should be answered in this study. This all leads to the research question which is formulated as:

Research Question: How can acted out interactions with an imagined device be used in order to retrieve intuitive knowledge about characteristics of that device?

Hypotheses

The first hypothesis will test whether the new method actually meets the requirement of being able to evoke intuitive knowledge. If that is the case, the evoked knowledge should have characteristics of intuitive knowledge, such as the characteristic defined by Still *et al* (2015). According to their research, when a higher percentage of people agree on the execution of a certain interaction this interaction can be seen as more intuitive. For example, Still and Dark (2008) classified interactions where a larger percentage of participants executed a task in the same way as more intuitive than an interaction which was executed less consistent. When using our new method, we therefore expect that when a larger portion of participants act out interactions in the same way (i.e. very consistent data) this interaction is perceived as more intuitive. When a product is modified in order to implement this interaction it therefore should be perceived as more intuitive than a modification which is based on less consistent interactions.

Hypothesis 1: More consistent data from the proposed method leads to modifications that are perceived to be more intuitive during use.

When this hypothesis is supported it is a first suggestion that the proposed method indeed leads to intuitive knowledge.

As elaborated on earlier, some methods exist already that give insight into intuitive knowledge that people possess. However, all of those methods have some shortcomings, which leads to the expectation that the proposed method should outperform an existing method:

Hypothesis 2: The proposed method leads to modifications that are perceived to be more intuitive during use than an existing method.

1. Method

Design

A new method for acquiring intuitive knowledge has been proposed as described in the introduction. The hypotheses can be written as the following goals:

- to find support for the claim that the new method indeed results in intuitive knowledge
- to find out whether the new method is able to outperform an existing method for acquiring intuitive knowledge

As this study is executed for the company Life&Mobility which designs wheelchairs, all phases of this study will evolve around the design of a wheelchair. In order to keep the research manageable, the focus will be on the location of the charging port on a wheelchair with electric push assist for the attendant.

This study consists of three phases. The first phase provides us with the needed information to be able to execute both methods. In the second phase both methods are executed in order to acquire intuitive knowledge about charging ports. The intuitive knowledge from both methods is implemented in real life wheelchairs. In the third phase these wheelchairs are rated on their intuitiveness by participants. The results of these are used to answer the hypotheses of this study.

Phase 1, preparation

The goal of this phase is to be able to accurately describe a wheelchair, as this is needed for execution of both method in phase 2. Another goal is to get more understanding of the viewpoint of people who use wheelchairs. Semi-structured interviews are conducted with people who have experience with attending or knowledge about wheelchairs. The results are analysed qualitatively, with a focus on (requirements for) everyday use of wheelchairs, what a wheelchair actually is and (charging of) electrically assisted wheelchairs.

A between-subjects design is used, where every participant is interviewed once.

This phase was also to contain an observation phase, where the researcher would spend a day with a caregiver and collect as much real-life experience and knowledge about wheelchairs as possible. However, due to restrictions in connection with the Covid-19-pandemic, especially in areas with vulnerable people such as nursing homes, multiple appointments had to be cancelled.

Phase 2, data acquisition

In this phase, our method as well as an existing method are used in order to collect intuitive knowledge.

Our proposed method is used to collect intuitive knowledge about the location of the charging port on a wheelchair. Therefore, this method will be called 'the intuitive method' throughout the rest of this report.

In this method, participants are given the description (which is based on the results of phase 1) of a wheelchair and asked to interact with this imaginary wheelchair (i.e. they act out interactions). Since the participants imagine this wheelchair based on the description, it is important that this description be accurate but also allows for interpretational freedom in areas that are of interest to the designer. In the case of this study, the charging port of a wheelchair. As such, one of the interactions that the participants are asked to act out is plugging the charger into the charging port. The description and the interactions can be found in appendix C.

Acted-out interactions are recorded resulting in colour video data and Skeleton Joint Tracking. This tracking data contains the locations in three-dimensional space of the main joints of the body. For each participant one datapoint is extracted from the data, which is the location of the charging port on the imaginary wheelchair. Within these datapoints, clusters of locations are searched for using a clustering algorithm. The largest cluster is seen as the location which is most consistently regarded by the participant as

the expected location for a charging port. One wheelchair is fitted with a charging port on the location suggested by the largest cluster: the 'first choice intuitive wheelchair'.
The second largest cluster is seen as the location which is less consistently regarded by the participant as the expected location for a charging port. Another wheelchair is fitted with a charging port on the location suggested by the largest cluster: the 'second choice intuitive wheelchair'.

The two wheelchairs will be compared in phase 3 in terms of intuitiveness. If the first choice intuitive wheelchair outperforms the second choice intuitive wheelchair it supports the claim that the intuitive method indeed results in intuitive knowledge: the first hypothesis of this study.
Processing of the Skeleton Joint Tracking is explained in further detail in the section 'Processing of Skeleton Joint Tracking-data'. The video data and Skeleton Joint Tracking data are used for exploratory research as well.

For the existing method, interviews are used to collect intuitive knowledge about the location of charging port on a wheelchair. Therefore, this method will be called 'the interview method' throughout the rest of this report.
In this method, people are asked to describe the location of the charging port on the described and imaginary wheelchair in a semi-structured interview. In a thematic analysis, a charging port location is extracted which fits the results best. A third wheelchair is fitted with a charging port on the location suggested by the interview method: the 'interview wheelchair'.

In phase 3, the interview wheelchair will be compared to the first choice intuitive wheelchair in terms of intuitiveness. If the first choice intuitive wheelchair outperforms the interview wheelchair it means the intuitive method can outperform the interview method: the second hypothesis of this study.

A between-subjects design is used. The two factors are the intuitive method and the interview method. Both methods result in information that should represent the intuitive knowledge people have of the charging port of a wheelchair. Participants are pseudo-randomly assigned to both conditions. Every third participant is assigned to the interview method with the remaining participants being assigned to the intuitive method, as specified in the following section about the participants.

Phase 3, validation

This phase tests the multiple outcomes of the intuitive method and compares the intuitive method with the interview method. This is done by using the knowledge that both methods delivered in phase 2 to make modifications on wheelchairs. Charging ports are added to three wheelchairs to contain the different sets of intuitive knowledge in the following way:

- 2 wheelchairs are modified based on the intuitive method. The modified charging point locations represent the most chosen and second most chosen location from the proposed method. Therefore, these two wheelchairs will be called 'first choice intuitive wheelchair' and 'second choice intuitive wheelchair' respectively.
- 1 wheelchair is modified based on the interview method. This wheelchair will be called 'interview wheelchair' from now on.

The participants in this phase use the wheelchairs with a focus on charging the wheelchairs using the modified charging ports. The perceived intuitive use of each wheelchair is measured using the Quesi-questionnaire (Naumann & Hurtienne, 2010), as well as the perceived handiness and logicality. The participants are also asked to write down their opinions of the different charging port locations.

The results of the Quesi-questionnaire will be used to find out whether both of the hypotheses of this study are supported.

A within-subjects design with 3 repeated measurements (the three wheelchairs) is used. The order of measurements is pseudo-randomized, where the goal is that all possible combinations of wheelchair-order are measured equally as often.

An addition to phase 3 is added for exploratory reasons. This consisted of a fourth wheelchair, wheelchair D, which is based on the first choice intuitive wheelchair. Participants were asked to give their thoughts on this wheelchair. This addition will be explained more thoroughly in the procedure-section.

Participants

Participants of phase 1 consisted of 2 caregivers and 3 occupational therapists from multiple different care facilities and treatment practices. All of them were women (average age: 43 years).

All participants in phase 2 and 3 were employees of the company Life&Mobility, from all departments (sales, development, production, logistics among others). These participants were volunteers, and informed and acquired either through a message on the internal information system of the company or by inviting them directly during work hours. Appointments made by asking employees directly were spread out over the two different phases, so as to keep the samples the same as much as possible.

Participants were not compensated financially, but they were given a small gift (chocolate bar) for their participation. When inviting and scheduling people for participation, an effort was made to divide people from specific departments evenly over phase 2 and 3.

Phase 2 uses k-means clustering. For k-means clustering algorithms a sample of at least 20 participants per subgroup is advised in order to have the power to detect clusters (Dalmaijer et al, 2020). Since two clusters are searched for, the sample size goal for the intuitive method is set at 40 participants. A similar approach is taken for the interview method where one subgroup had to be found, which gives a sample size goal of 20 participants.

42 participants were recruited for phase 2. Of these, 28 participants were assigned to the intuitive method (average age: 38,5 years, 21,4% women, 10,7% left-handed). The other

14 participants were assigned to the interview method (average age: 33,1 years, 14,3% women, 7,1% left handed).

A power analysis is done for phase 3. A benchmark of the Quesi-questionnaire (Naumann & Hurtienne, 2010) is used to guide the power analysis. The scores of two samples of participants who rate an Apple iPod Touch are taken as the maximum and minimal value for the calculation of Cohen's d (Cohen, 1988). With an estimated intermediate variability, this yields an f-value of 0.495 and a required sample size of 29 participants. See appendix E for a printout of this calculation.

29 participants were recruited for phase 3 (average age: 39,8 years, 37,9% women, 10,3% left-handed)). Out of these participant, 12 were asked to participate in the additional research with the wheelchair D.

Apparatus and Materials

The interviews of phase 1 were conducted using video calling services and voice-recorded using a smartphone.

In the intuitive method of phase 2, a Microsoft KINECT for Xbox One (model 1520) is used, mounted on a tripod at a height of 117cm. A Kinect adapter for Windows (model 1637) is used to connect the sensor to an Apple MacBook Pro 15" computer running Microsoft Windows. Additionally, a vertically positioned plexiglass plate (55cm x 55cm) is used, with a stand on the bottom and a female wall outlet mounted at a height of 30 cm. To clarify, this 'wall-outlet' is not mounted on a wall in this study, but on a plexiglass plate, as can be seen in figure 1. Lines on the floor are used to indicate to the participant the corners and edges of the usable area and the start position.

For the analysis of the data, the programs Matlab (Matlab, 2019) and program Xefextract (Wang, 2017) are used.

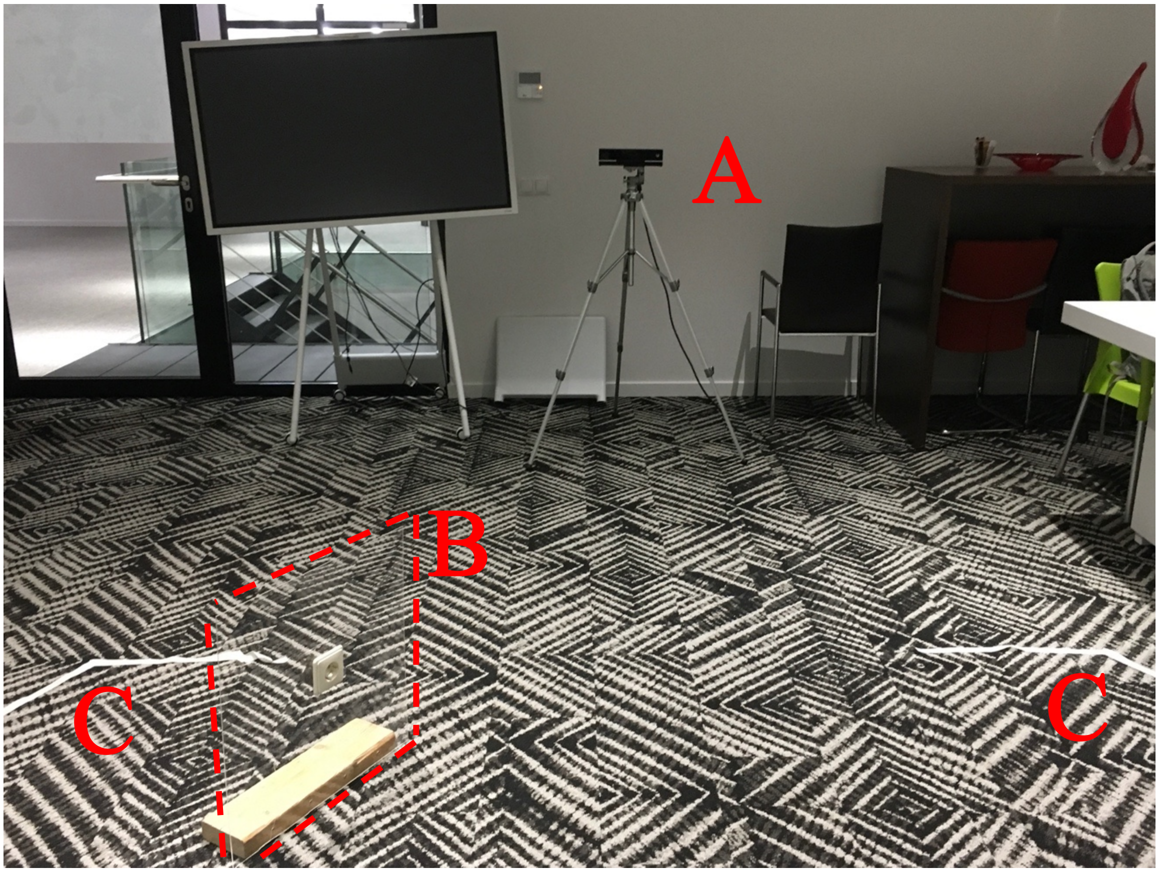


Figure 1 - The research environment for the intuitive method of Phase 2. A: the Kinect-camera. B: the wall outlet mounted on in the centre of a plexiglass plate. A dashed red line is added around the plexiglass plate on the photo (not to the real-life plexiglass) for clarity. C: the lines which denote the usable area for the participants.

In the interview method of phase 2, a smartphone is used to make voice recordings.

In phase 3, three wheelchairs of make Life&Mobility and model Roxx are used, each of which has been fitted with a R-Net charging port made by Penny & Giles in a unique location. A prototype charger is made from a power cord (length: 1.4m), a small box and a Penny & Giles cord (length: 1m) with an R-Net connector that fits into the charging port on the wheelchairs, see figure 2.

Figure 2 - Left: R-net female charging port that was fitted on the wheelchairs. The yellow logo was taped off in the experiment. Right: prototype charger.

In order to measure intuitive use the Quesi-questionnaire is used with 5-point Likert-scale answers (Naumann & Hurtienne, 2010), conducted on a laptop-computer using Google Forms. This questionnaire measures intuitive use by averaging scores of 5 subscales. Each Quesi-questionnaire is accompanied by two 5-point Likert-scale questions on how the charging point is rated on handiness and logicality.

Due to the design of this experiment (repeated measurements with only a few minutes between filling in each of three questionnaires) the Quesi-questionnaire is shortened from 14 to 5 items, where 1 question from each subscale is selected. Two items of each subscale were identified as being most equal (Blue and Green items, see Table 1). One item of each pair was chosen for use during Phase 3 (Green items, numbers 11,7,3,9 and 5). This way an attempt is made to preserve most of the questionnaire, see table 1.

Another questionnaire, the general questionnaire, contained demographic questions as well as questions about the participants preferred wheelchair, remarks about the three wheelchairs, whether they are left- or right-handed and how often they are the attendant of a wheelchair. All questionnaires are added to the appendices, see appendix F and G.

Both phase 2 and phase 3 are conducted at the company location of Life&Mobility.

Table 1 – Quesi-questionnaire, divided into its 5 subscales. Green = item that was used during Phase 3. Blue = item that was seen as similar to the green item but not used during Phase 3. Black = item that was not seen as similar to other items and not used during Phase 3.

Subscale	*Item*
Subjective mental workload	1. I could use the system without thinking about it.
	6. The system was not complicated to use.
	11. I barely had to concentrate on using the system.
Perceived achievement of goals	2. I achieved what I wanted to achieve with the system.
	7. I was able to achieve my goals in the way I had imagined to.
	12. The system helped me to completely achieve my goals.
Perceived effort of learning	3. The way the system worked was immediately clear to me.
	8. The system was easy to use from the start.
	13. How the system is used was clear to me straight away.
Familiarity	4. I could interact with the system in a way that seemed familiar to me.
	9. It was always clear to me what I had to do to use the system.
	14. I automatically did the right thing to achieve my goals.
Perceived error rate	5. No problems occurred when I used the system.
	10. The process of using the system went smoothly.

Processing of Skeleton Joint Tracking-data

The Kinect-camera provides Skeleton Joint Tracking-data; the location of 24 joints of the human body during the span of the experiment. Before importing this data into Matlab, the .XEF files are converted with the program Xefextract. The data consists of points (joints) in three-dimensional space. Two moments in time are important:

Moment A: the participant holds both grips of the wheelchair (left hand: location A_{left}, right hand: location A_{right}, midpoint between hands: location $A_{midpoint}$).

Moment B: the participant plugs in the charger with one of his hands (location B).

We want to be able to say how far in front, to the right and above Location B is compared to the midpoint between the hands A3. The origin of the coordinate system of the data is translated to location $A_{midpoint}$ and rotated so that one of the horizontal axes of the new coordinate system is parallel with a line through A_{left} and A_{right}. In the new coordinate system, which will be used to report the results, a positive value on the x-axis means that B is more to the right of the midpoint between the hands of the participant. A positive value on the y-axis means that B is in front of the hands of the participant. A positive value on the z-axis means that B is above the hands the participant.

Procedure

Phase 1

Participants were asked to answer a predetermined set of questions, in the form of a semi-structured interview. Interviews took between 17 minutes and 52 minutes and were conducted over a videocall. The interview questions can be found in appendix A and B.

Phase 2

Intuitive method

After signing the informed consent, the participants are explained that they are expected to act out some scenarios. In order to show what is expected and to take away some possible awkwardness, an example of using a kettle to make tea is acted out by the researcher. It is emphasized that there are no wrong answers, and the participants can do whatever they feel is right. A wheelchair is described using information from phase 1, and the participant is given the role of attendant of this wheelchair. The description and further script of this method can be found in appendix C.

The participant is asked to hold the wheelchair that stands in front of him or her. Subsequently, the participant is asked to push the wheelchair to a table at the edge of the usable area and back, so that the imagined passenger can grab something from the table. The participant is explained that the wheelchair also has an electric push assistance, so it also contains a battery and motor. They are made aware that it might be required to turn the wheelchair on and there might be an option to change the amount of push assist. The next task is to use this electric assisted wheelchair in order to walk in a circle around the usable area.

The plexiglass plate with wall outlet is positioned between the start position and camera. The participant is told that the wheelchair has to be charged and that there is a charging port somewhere on the wheelchair. The charger consists of small box with one cord that goes into the wall outlet and another cord that goes into the wheelchair (but no physical charger is present). The participant is asked to park the wheelchair with its left side next to the wall outlet, hold the wheelchair for a second and plug the charger in the wheelchair first, followed by plugging the charger into the wall outlet.

The last task consists of unplugging the wheelchair, pushing it to a corner and making sure that the wheelchair cannot be moved (could be some kind of brake). Each session took 10-15 minutes.

Interview method

In the interview method, participants are given the same description of a wheelchair (including its electric push assist system and charger), they are explained their role as attendant and are told that there is no correct or wrong answer. They are asked to explain how they envision charging a wheelchair, and specifically to describe the location of the charging port on the wheelchair.
Each session took roughly 5 minutes.

In the interview method as well as in the intuitive method participants were asked about their demographics and how often they are the attendant of a wheelchair and whether they are lefthanded or righthanded. Both methods also contained a limited number of extra tasks in order to collect some more information on expected wheelchair design for Life&Mobility, for example on brake location. All of these tasks were executed after all measurements for this study were made, as to not influence this study.

Phase 3

After signing the informed consent, participants were asked to carry out a set of interactions with a wheelchair. This interaction consisted of pushing the wheelchair for a few meters, plugging in the charger into the socket on the wheelchair, disconnecting the charger and pushing the wheelchair back. After completing this interaction, they were asked to rate the intuitiveness of the location charging point using the questions of the Quesi-questionnaire and the questions about handiness and logicality. This process was repeated for the two other wheelchairs, with the same interactions and the same questionnaire. Therefore, every participant used all three wheelchairs: the first choice intuitive wheelchair, the second choice intuitive wheelchair and the interview wheelchair. The order of these wheelchairs was randomized. After using all wheelchairs, participants were asked to fill in the general questionnaire with open ended questions about the wheelchairs and demographic questions. Each session took roughly 15 minutes.

Post hoc addition to phase 3, wheelchair D

After completing the mentioned procedure, a fourth wheelchair was presented to the participant, wheelchair D. The participant was asked to compare this wheelchair with the three wheelchairs they had used before and whether they would prefer the wheelchair D over the other three wheelchairs or not. Their responses were written down by the researcher.

The wheelchair D has a charging port location that is based on the first choice intuitive wheelchair. But instead of directly implementing the charging port on the location of the cluster, the data is interpreted with the guiding question of what the participants actually meant to do. This addition was added when the experiment was already being executed, so only a portion of the participants was able to participate in this addition.

2. Results

Phase 1

The goal of this phase is to find out how a wheelchair can be described and to get more understanding of the viewpoint of people who use wheelchairs. The ability to describe a wheelchair will be used in phase 2. The 5 transcribed interviews are coded for things that are said about wheelchairs. These codes are translated into themes. Each theme is classified under one of three overarching question. See figure 3 for the results. Some themes are discussed in detail.

Within the first overarching question, most codes were found in connection with the mobility of the occupant (9 times), followed by comfort being important (5 times). Remarks about charging wheelchairs with an electrical system resulted in 7 codes, of which 5 mentioned wheelchairs being charged in a dedicated space. The remaining codes mentioned that wheelchairs were being charged wherever there is room. Out of the total of 7 codes about the tilt function, 3 mentioned that this function is useful when the occupant wants to rest. Of the 9 codes which stressed the significant differences between wheelchairs, 6 were about the fact that transport wheelchairs usually offer less ease of use, although the majority of these codes come from the same participant. Half of the codes about larger dimensions of a wheelchair having negative implications talked about electric wheelchairs.

The information from this phase is used in order to develop the scripts for phase 2. The information from the first overarching question contributed to the description of a wheelchair that was given to the participants of phase 2. Since there was no unambiguous information about the wheelchairs either being charged in a specific location or just wherever there is place, it was decided that it would be left up to the participant of phase 2 to imagine the surroundings while charging. As the researcher of this study had limited experience with wheelchairs before executing this study, phase 1 also contributed by providing a better understanding of wheelchairs and their users.

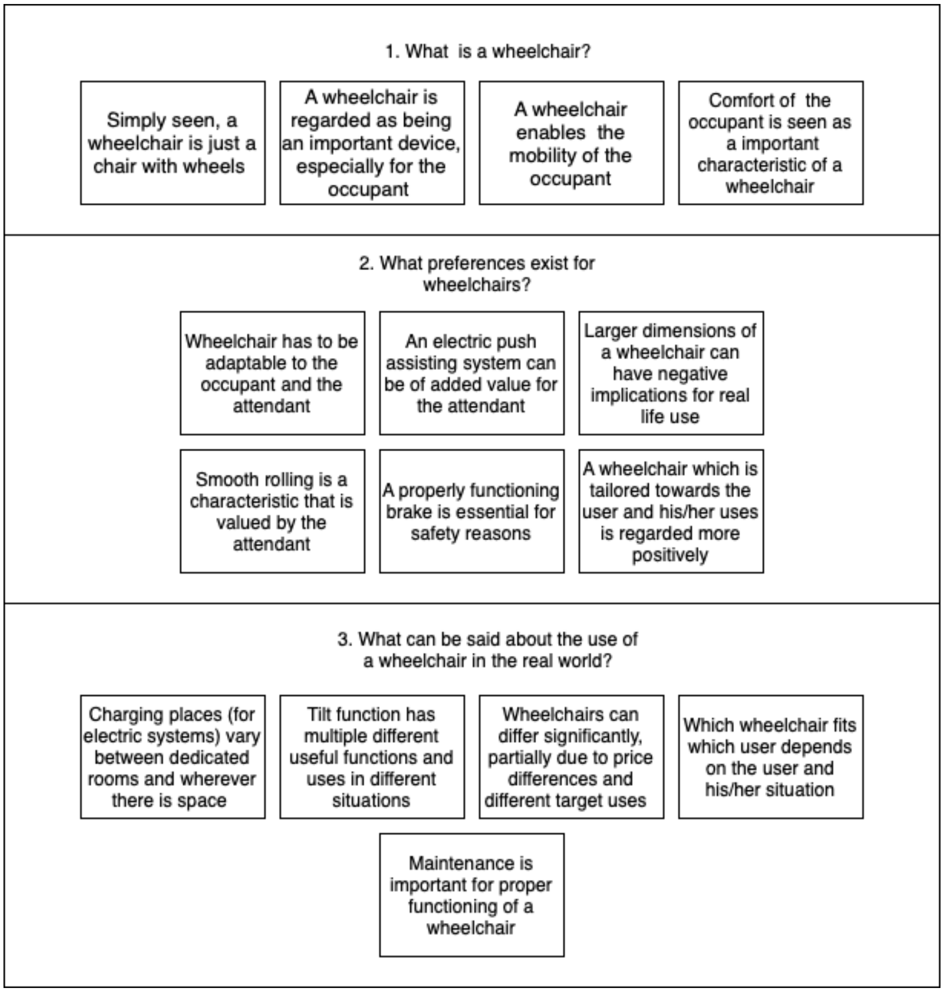


Figure 3 - Results of the thematic analysis of the interviews of phase 1.

Phase 2

In this phase, the intuitive method as well as the interview method are executed and intuitive knowledge should be evoked. The results of this phase will be used in phase 3 to find answers to the hypotheses.

Intuitive method

Participant are given a description of a wheelchair, based on phase 2, and act out interactions with this imagined wheelchair. The location at which the participant plugged in the charger into the wheelchair is extracted from the Skeleton Joint Tracking data. All participants made a forth-and-back movement with one of their hands, where the moment of direction change is taken as the data-capture moment. All datapoints can be seen in figure 4 and 5. It can be seen that almost none of the datapoints in the lower region coincide with the frame of an actual wheelchair.

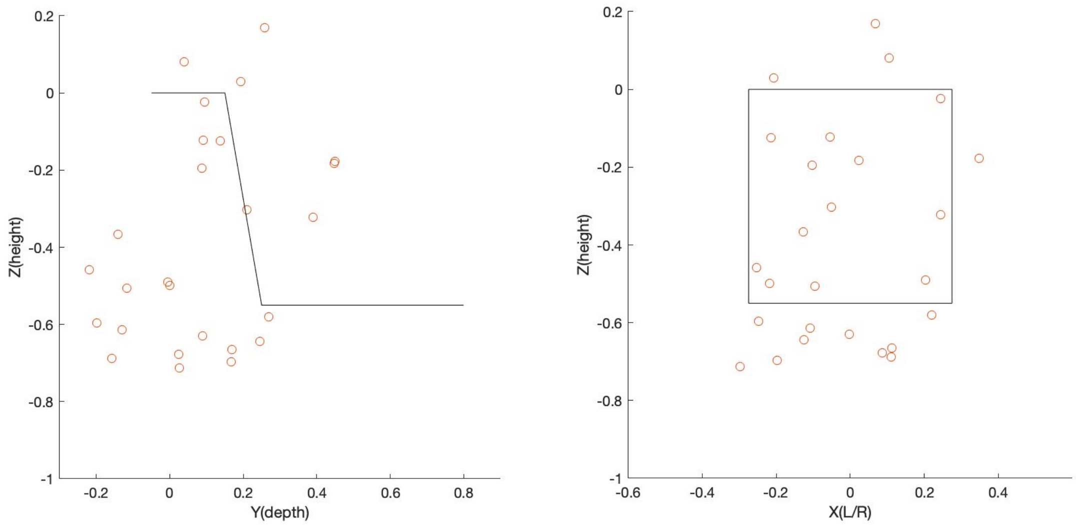


Figure 4 - Datapoints from Intuitive Method. Left: sideview. Right: rear view. A frame of a wheelchair is drawn in the graph for clarity, with grips, back tubes and seat (with a width of 55cm), based on a Life&Mobility Roxx wheelchair. Dimensions in meters and the origin is the midpoint between the grips.

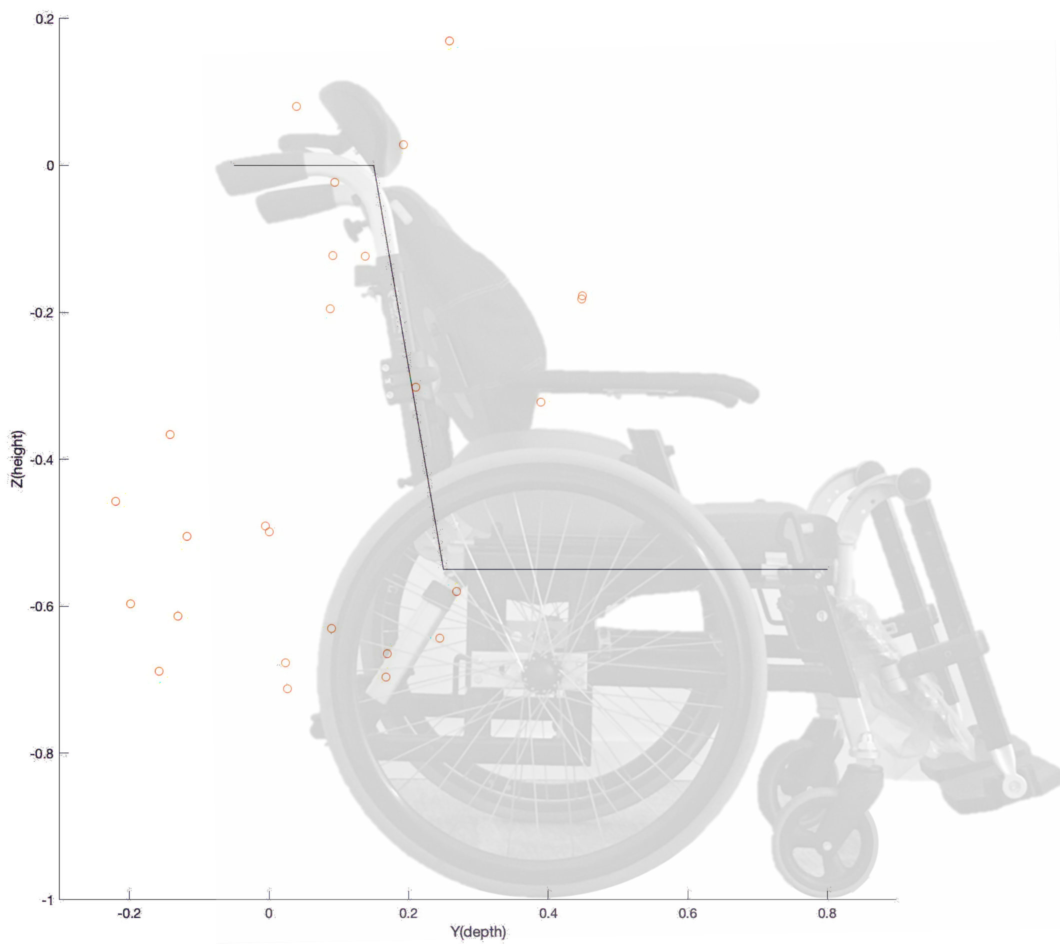
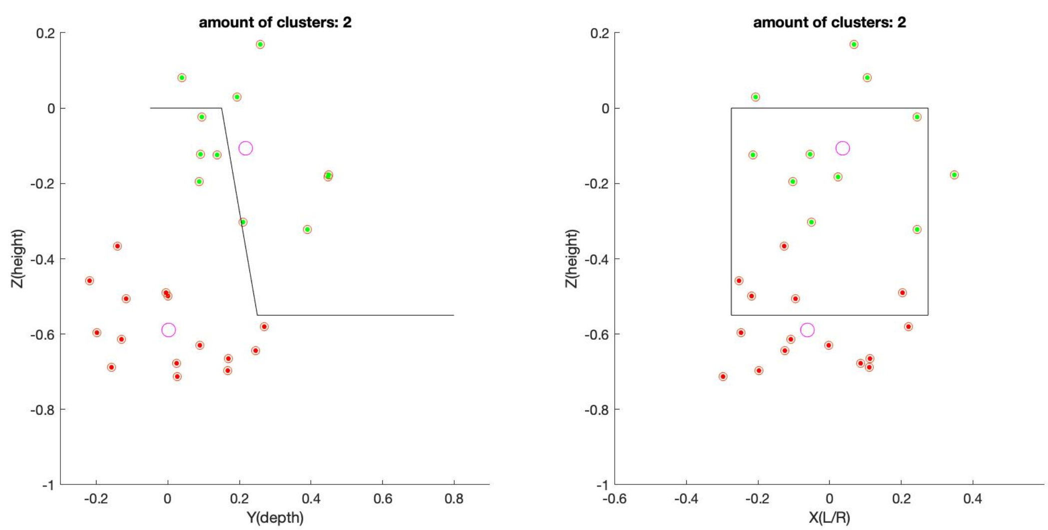
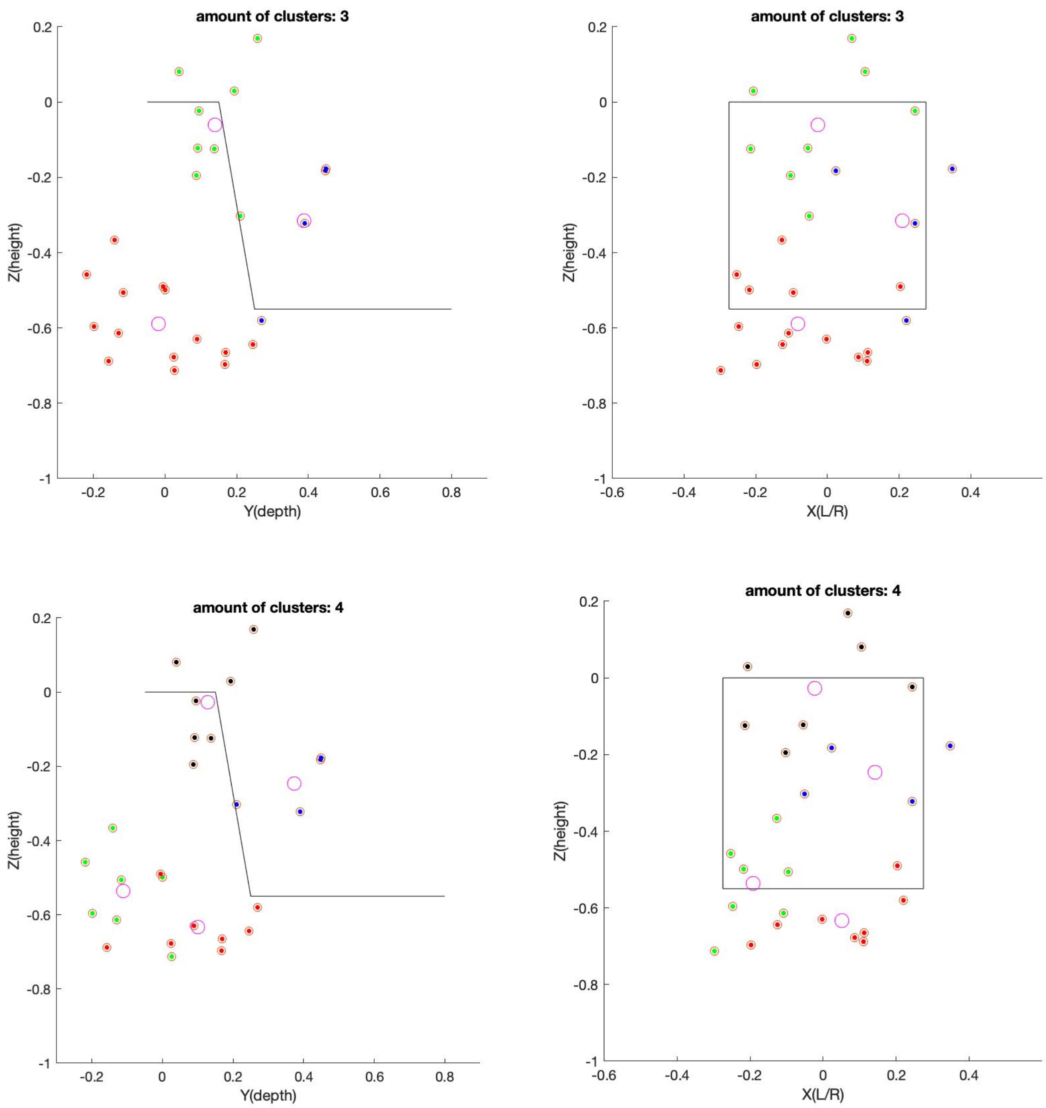


Figure 5 - Side view of the datapoints of the Intuitive Method with overlay of a Life&Mobility Roxx wheelchair for reference. Dimensions in meters and the origin is the midpoint between the grips.

Clusters within this data are being searched for. The largest cluster is seen as the most consistent data (first choice), while the second largest cluster is seen as the less consistent data (second choice). These results will be implemented in two different wheelchairs in order to be tested in phase 3.

K-means is chosen as clustering algorithm. This algorithm is widely used and results in as many clusters as the user specifies. Each cluster has a centre, which is the mean of all the datapoints in that cluster. Therefore, an appropriate number of clusters (K) has to be selected. See figure 6 for the resulting clusters for K is 2,3,4 and 5.




amount of clusters: 3
Z(height)
Y(depth)
amount of clusters: 3
Z(height)
X(L/R)
amount of clusters: 4
Z(height)
Y(depth)
amount of clusters: 4
Z(height)
X(L/R)

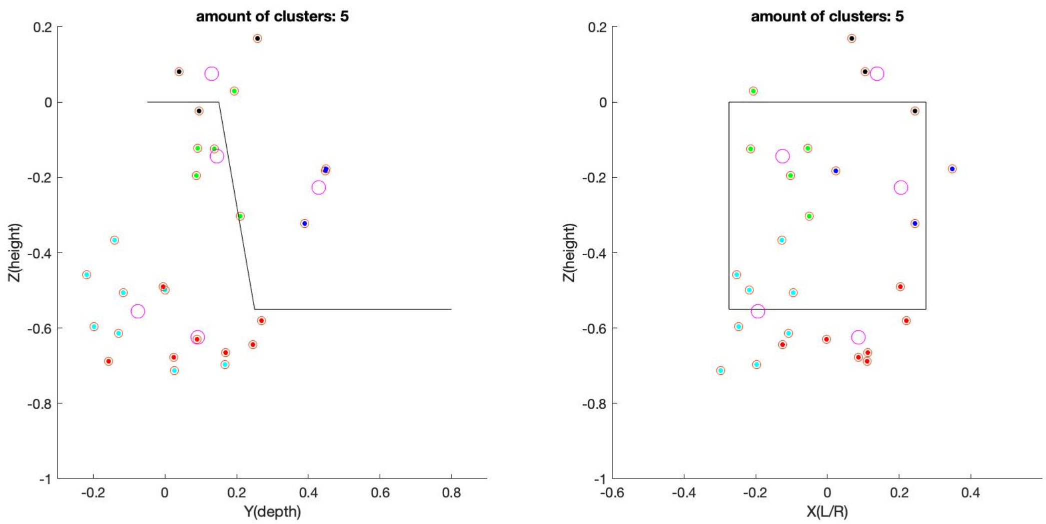


Figure 6 - K-means clustering with differing numbers of clusters (row one: 2 clusters. Row two: 3 clusters. Row three: 4 clusters. Row four: 5 clusters). Each figure on the left is a sideview, where each image on the right is a rear view. Dimensions in meters and the origin is the midpoint between the grips.

With two clusters, a clear distinction is seen between the upper data points and the lower datapoints.

With three clusters the same distinction is seen, with the added cluster of datapoints which are more forward (in front of the back tubes of the wheelchair).

With four clusters, the lower cluster is split into two clusters. One of these is positioned more forward and to the right (as seen from the rear of the wheelchair) and the other one is further from the wheelchair and is positioned more to the left.

When five clusters are extracted, the upper cluster is split into a higher and lower cluster again, where the higher cluster is more to the right.

During the experiment and afterwards during review of the video footage the observation was made that participants either preserved their upright position while plugging in the charger or they bend or kneeled down. A third kind of interaction involved walking around the imaginary wheelchair before plugging the charger into the front of the wheelchair. This observation coincides with the three clusters found with k=3 and is therefore selected as the final result. The coordinates of the two largest clusters are given in table 2, relative to the middle point between the grips. The Within-Cluster-Sum of Squared Errors (WSS) is added for use in the discussion section of this report.

Table 2 – Locations of the two largest clusters of the intuitive method as found by the K-means algorithm. The origin (0,0,0) is the middle point between the two hands of the participant, on the moment he was holding the grips of the imaginary wheelchair. $WSS/n_{cluster}$: Within-Cluster-Sum of Squared Errors, divided by the n of that cluster.

	X-coordinate (L/R)	Y-coordinate (depth)	Z-coordinate (height)	$WSS/n_{cluster}$
Largest cluster (14 datapoints)	-0.083m	-0.018m	-0.589m	0.055
Second largest cluster (8 datapoints)	-0.027m	0.139m	-0.061m	0.048

Two wheelchairs are modified to contain a charging port on each of the two cluster-means of the two biggest cluster. These modifications can be seen in Figure 7.

Figure 7 – Left: modification based on largest cluster from intuitive method (first choice intuitive wheelchair). Right: modification based on smaller cluster from intuitive method (second choice intuitive wheelchair).

Intuitive method - explorative

In order to check whether the datapoints are indeed captured at the moment at which the direction of the movement changed from forth to back, additional data is extracted. The gesture of the hand of each participant, while he or she is plugging the charger into the imaginary wheelchair, is extracted from the data. The trajectories of these gestures can be seen in appendix H where the squares are the datapoints as used for clustering in the previous section. The spatial characteristics and time needed for completion differed per participant.

Most trajectories seem to show a forth-and-back movement, where the captured datapoint for clustering is at the sharpest turn in direction. Some trajectories however contain multiple forth-and-back movements.

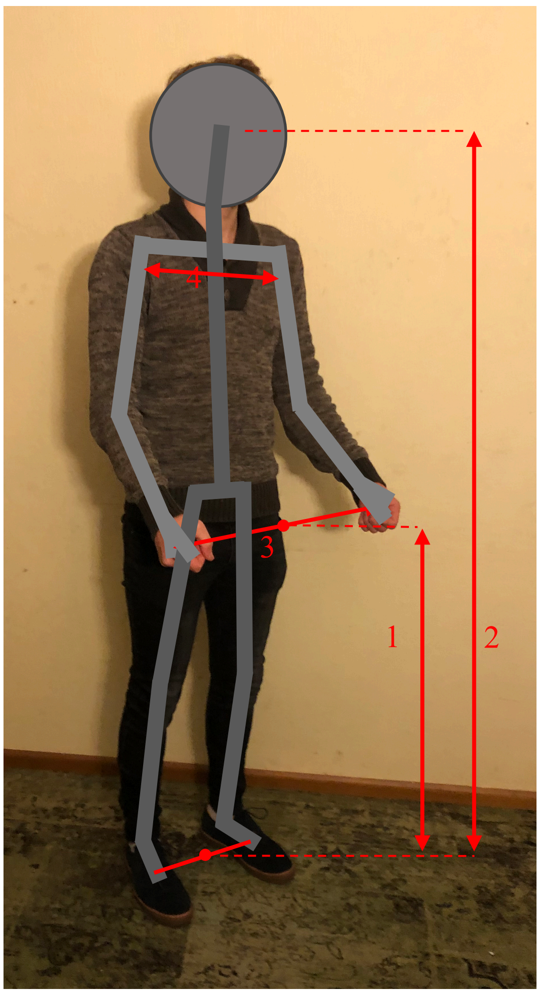


Figure 8 - Example stick figure obtained from the Skeleton Joint tracking software of the Kinect (Microsoft, USA). Number 1 shows how the height of the grips was measured, number 2 shows person length, number 3 the width of the grips and 4 the width of the shoulders of the participant.

Additional data is extracted in order to explore whether size-aspects of the wheelchair can be estimated based on body part measurements, which could guide designers in the design of wheelchairs. The height of the person, the width of their shoulders, the distance between their hands (while holding the imaginary grips of the wheelchair) and the height of their hands at that moment are extracted from the data (see figure 8 and table 3). Correlations are calculated, see table 4. The correlation between person length and grip height is significant and moderate. The correlation between shoulder width and grip width is not significant.

Table 3 – Means of the height (1) and width (3) of the hands of the participants while holding the grips of the imaginary wheelchair and the mean length (2) and shoulder width (4) of the participants.

	Mean (m)	SD (m)
1. Grip height	0.944	0.091
2. Person length	1.515	0.078
3. Grip width	0.463	0.088
4. Shoulder width	0.351	0.020

Table 4 – Correlations between the different measurements of table 3.

Correlation items	Pearson's *r*	p-value
Person length – Grip height	0.5018	0.0065
Shoulder width - Grip width	0.1626	0.4084

Further insight can be gained by looking at the distribution of the grip widths of the participants, presented in the form of a histogram in figure 9. Grip width is specifically chosen because these numbers can be compared to the width of the wheelchairs that are sold by Life&Mobility. Wheelchairs are sold in 5 standard widths. Figure 10 shows the percentual distribution of wheelchairs sold by the width of their grips, as delivered by Life&Mobility itself. Grip height is adjustable on the wheelchairs of this company, which is the reason a comparison with measured grip height is not presented here.

Figure 9 is a histogram which means that bin sizes have to be chosen. Since a comparison is made with the wheelchairs as sold by Life&Mobility, which standard widths are separated by 5cm, the bin sizes of the histogram are also set at 5cm. The midpoints of the bins are aligned with the standard widths of the Life&Mobility wheelchairs in order to make a direct comparison.

As can be seen in the histogram, the bin with midpoint 44,1cm contains the largest group of participants (this bin is 5cm wide, ranging from 41,6cm to 46,6cm). This bin contains 20% more participants than the bins with midpoint 39,1cm and 49,1cm.
Most wheelchair that are sold by Life&mobility have a grip width of 44,1cm. These are sold 4,9% more often compared to 39,1cm grip width wheelchairs. Wheelchairs with 49,1cm wide grips are sold less than a quarter as often as 39,1cm wide wheelchairs.

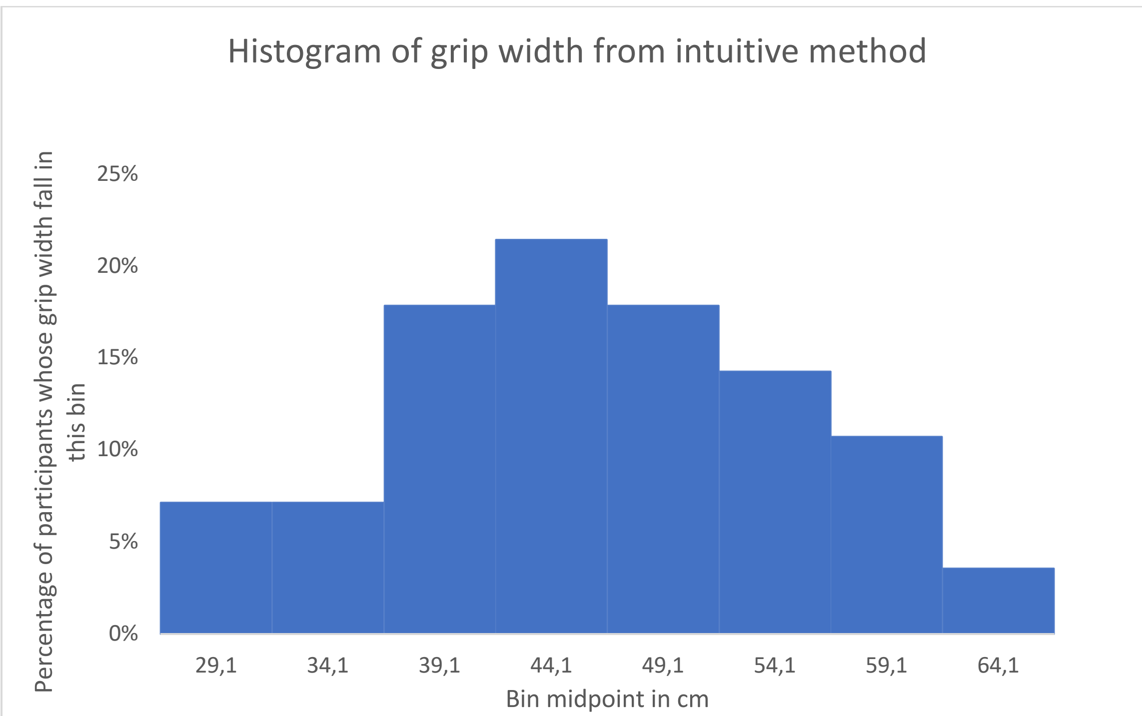


Figure 9 - Histogram of grip width of participants of the Intuitive Method of Phase 2. Width of each bin is 5cm.

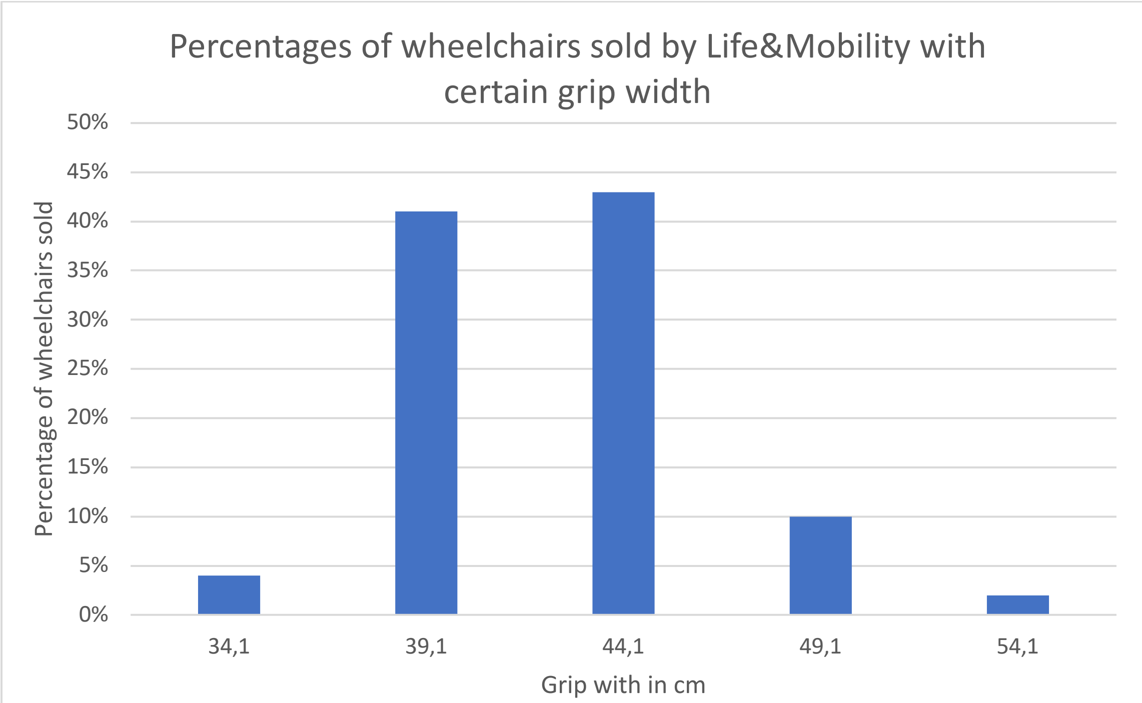


Figure 10 - Percentual distribution of wheelchairs sold by the width of their grips.

Interview method

The interview method is added to this study so as to be able to compare the intuitive method with an existing method. Therefore, the results of the interview method have to be analysed and implemented into a wheelchair for use in phase 3.

Participants in this method were asked to describe their preferred location of the charging port on a wheelchair. 28,6% out of 14 people mentioned they would prefer the charging port to be on the right side, 7,1% preferred the left side, 35,7% preferred either left or right (but not in between) and 21,4% preferred the charging port to be in the middle. 57,1% mentioned that they would prefer the charging port to have a height that is equal to or under the grips and 28,6% participants preferred it to be in the space between seat height and armrest height.

A visualisation is made to illustrate all participants' preferences, see figure 11.

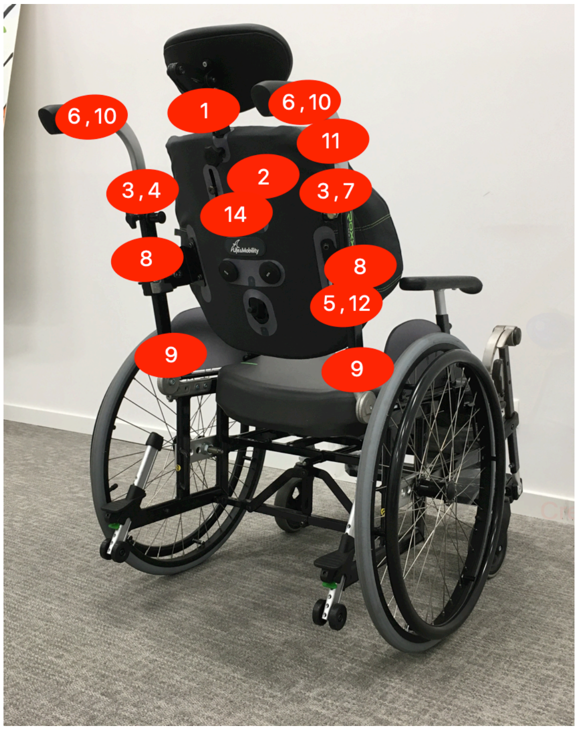


Figure 11 -Datapoints from the Interview Method. Each number represents one of the participants. Some numbers are visible twice in the figure when the participant was ambivalent about preferring the charging port on the left or the right backrest tube. Some ovals contain two numbers, separated with a comma, which means that two participants mentioned that same location.

Due to the majority of the participants expressing their preference for either the left or right side of the wheelchair (instead of somewhere in between) and more participants specifically choosing the right side instead of the left side, it is decided to place the charger on the right side.

Due to the majority of participants preferring a height that is around or somewhat under the grips, but also some participants preferring the charging port to be between the height of the arm rest and the seat, the height of the charging point is set slightly more towards the grip. Based on this analysis the interview wheelchair is constructed. In phase 3 it will be compared in terms of intuitiveness to the two intuitive wheelchairs, see figure 12 for the interview wheelchair (left), together with the two wheelchairs from the intuitive method (middle and right).

Note that it was not possible to use three wheelchairs with the exact same dimensions due to practical limitations. The interview wheelchair has a seat width and height of 42cm and 49cm respectively. The first choice intuitive wheelchair has a seat width and height of 47cm and 51cm respectively. The second choice intuitive wheelchair has a seat width and height of 42cm and 44cm respectively. The grips are height adjustable, so the grips on all the wheelchairs was adjusted to the same height.

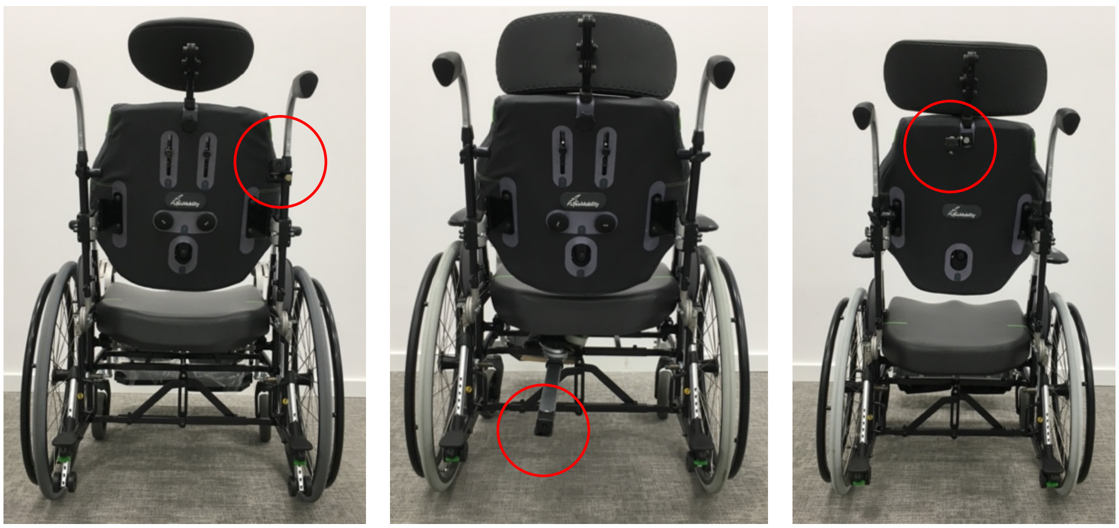


Figure 12 – Left: modification based on interview method (interview wheelchair). Middle: modification based on largest cluster from intuitive method (first choice intuitive wheelchair). Right: modification based on smaller cluster from intuitive method (second choice intuitive wheelchair).

Phase 3

Phase 2 resulted in three wheelchairs, each with a charging port in a unique location. The main goal of this phase is to compare the three wheelchairs in terms of intuitiveness in order to find answers to the hypotheses of this study.

Each participant used all three wheelchairs. After each wheelchair they rated the charging port location on the Quesi-questionnaire for intuitiveness. They also rated the wheelchairs on handiness and logicality. The results for each can be seen in table 5.

Table 5 – Questionnaire results of all three wheelchairs. Quesi-questionnaire result is the mean of the 5 questions which make up this questionnaire. All questions are asked on a 5-point Likert scale.

	Interview wheelchair	First choice intuitive wheelchair	Second choice intuitive wheelchair
Quesi-questionnaire (averaged)	4,52 (SD:0,66)	3,90 (SD: 1,16)	4,49 (SD: 0,62)
Handy	4,41 (SD: 0,98)	2 (SD: 1,10)	3,86 (SD: 1,15)
Logical	4,41 (SD: 0,68)	2,21 (SD: 1,26)	3,79 (SD: 1,15)

On each part of the data three hypothesis-tests will be conducted. Therefore, a Bonferroni-corrected alpha value of 0.05/3=0.0167 will be used.
Beforehand it was planned to use paired t-tests to do the comparisons that will be treated in the following section. However, no pair of results meets the requirements of normality, even with transformation. Therefore, a Wilcoxon matched-pairs signed-ranks test was used in all cases.

The first hypothesis states that the first choice intuitive wheelchair should be rated higher that the second choice. When tested, the score on the Quesi-questionnaire for the first choice intuitive wheelchair was statistically different when compared to the second choice intuitive wheelchair ($z(29) = -2.784$, $p = 0.0054$). Note that the score for the second choice wheelchair is higher, which does not match the hypothesis.

The second hypothesis states that first choice intuitive wheelchair should be rated than the interview wheelchair. The results show that the score on the Quesi-questionnaire for the interview wheelchair was statistically different when compared to the first choice intuitive wheelchair ($z(29) = 2.935$, $p = 0.0033$). Note that the score for the interview wheelchair is higher, which does not match the hypothesis.

Due to hypothesis 1 not being confirmed, an additional Wilcoxon matched-pairs signed-ranks test was performed. The results show that the score on the Quesi-questionnaire for the interview wheelchair was not statistically different when compared to the second choice intuitive wheelchair ($z(29) = -0.056$, $p = 0.9551$).

Phase 3 - explorative results

As can be seen in the introduction, intuitiveness can be hard to define and explain to someone. In order to check whether the participants of phase 2 thought that they were supposed to help design a wheelchair that is very handy or logical, participants of phase 3 were asked to rate the three wheelchairs on being handy and on being logical. Wilcoxon matched-pairs signed-ranks tests are used to find differences between wheelchairs in terms of handiness and logicality.

Handy

The results show that the score for the 'handy'-question of the interview wheelchair was statistically different when compared to the first choice intuitive wheelchair ($z(28) = 4.597$, $p < 0.0001$).
The first choice intuitive wheelchair was statistically different when compared to the second choice intuitive wheelchair ($z(28) = 4{,}069$, $p < 0.0001$).
The interview wheelchair was not statistically different when compared to the second choice intuitive wheelchair ($z(28) = 1{,}816$, $p = 0.0693$).

Logical

The results show that the score for the 'logical'-question of the interview wheelchair was statistically different when compared to the first choice intuitive wheelchair ($z(28) = 4.578$, $p < 0.0001$). The first choice intuitive wheelchair was statistically different when compared to the second choice intuitive wheelchair ($z(28) = -4{,}042$, $p = 0.0001$). The interview wheelchair was not statistically different when compared to the second choice intuitive wheelchair ($z(28) = 1.925$, $p = 0.0542$).

Qualitative analysis Phase 3

The quantitative analyses as seen above tell us with statistical tests whether there are differences between the wheelchairs in terms of intuitiveness, handiness and logicality.

Although that helps by giving an answer to the hypotheses, it does not give very in-depth information about the experiences of the participants while using the wheelchairs. Therefore, participants were asked to write down things they thought were positive or less positive about the three different wheelchair (and their charging locations), after they had used all of them. During the qualitative analysis a set of reoccurring remarks was established. The number of times these subjects were mentioned by the participant is presented in table 6.

*Table 6 – Counts of how many times each wheelchair was associated with certain themes. Items where two opposites are measured (Handy / unhandy for instance) are color-coded. Green: the positive term is mentioned more often that the negative term. Red: the negative term is mentioned more often than the positive term. Orange: tie. *Too low or participant has to bend down.*

	Interview wheelchair	First choice intuitive wheelchair	Second choice intuitive wheelchair
Handy / unhandy	5 / 2	0 / 7	1 / 4
Logical / illogical	4 / 1	0 / 4	5 / 0
Easy to find / hard to find	5 / 3	4 / 4	7 / 3
Too high / too low*	3 / 1	0 / 9	1 / 0
Gets in the way while walking	0	13	2
Good or fine position	5	0	3
Vulnerable	1	4	4

It can be seen that the interview wheelchair is primarily mentioned as handy, logical and easy to find. It's charging location is more often called a good or fine location than the other wheelchairs.

The first choice intuitive wheelchair is primarily mentioned as unhandy and illogical. Its position is more often mentioned as not on the right height (too low in this case) than the other wheelchairs and almost half of the participants thought that the charging port would get in the way while walking with the wheelchair.

The second choice intuitive wheelchair is primarily mentioned as being unhandy but logical and easy to find.

Post-hoc addition – wheelchair D

For phase 3 a fourth wheelchair was modified with a charging port. The charging port location is based on the biggest cluster of the intuitive method. This wheelchair represents a situation where the results of the intuitive method are not directly translated to a modification, but instead are interpreted and made into a modification accordingly. The motivation for adding this wheelchair is the location of the biggest cluster of the intuitive method. It is positioned far away from the frame of the wheelchair. It is possible that the participants wanted to reach for a location closer to the frame or the seat, but that the image of a wheelchair did not exactly match the Life&Mobility Roxx wheelchair that is used here. The movements while bending down can also have affected their estimation of locations. Also, it is not uncommon for wheelchairs with electric assist system to have their battery mounted under the seat. Therefore, the height and sideways translation of the charging port is kept the same, but it is moved forward until it is positioned almost under the seat, see figure 13.

Figure 13 - Wheelchair D with its alternative modification.

Wheelchair D is solely added for explorative reasons. 12 participants of phase 3 were asked to compare this last wheelchair with the three wheelchair they had seen up to that point. Their reactions were written down by the researcher. Remarks that were made often by the participants are counted. These results are visible in table 7.

Table 7 – Statements made about wheelchair, with the number of times these were made by participants.

Statements	*Count*
Wheelchair D better than all previous wheelchairs	2
Wheelchair D not better than the previous favourite	9
Wheelchair D is improved compared to the first choice intuitive wheelchair	9

Wheelchair D is improved compared to the first choice intuitive wheelchair due to less chance of hitting the charging port	5
Bending down is still mentioned as a problem of Wheelchair D	6

81,8% of the participants said that wheelchair D is better than the first choice intuitive wheelchair, but the same percentage of participants would still prefer one of the first three modifications (which automatically rules out first choice intuitive wheelchair). Almost half of the participants explained that wheelchair D was an improvement over the first choice intuitive wheelchair, specifically due to the reduced chance of hitting it. However, half of the participants mentioned that the attendant still has to bend down to connect the charger which is seen as a problem.

3. Discussion

In this study a new method for evoking intuitive knowledge was formulated and executed for the first time. For comparison, an existing method of interviewing participants was also used for validation. The knowledge from both methods is used to modify and improve wheelchairs. In the last phase, these wheelchairs were tested and rated by participants. Firstly, the results of these tests are discussed in order to check whether the hypotheses are supported.

Is the first hypotheses supported?

In the introduction it was hypothesized that when more participants act out an interaction in the same way (more consistent) that this interaction would be seen as more intuitive. This hypothesis is based on Still et al (2015), where more consistent interactions within a group of people are associated with a higher level of intuitiveness. If this hypothesis is supported, it is a first suggestion that the intuitive method indeed leads to intuitive information. It would be preferable for the intuitive method to result in design that are perceived to be more intuitive. Intuitive interactions are effective interactions (Mohs *et al,* 2006a), which is usually a preferable characteristic of products.

In our study, this means that the first choice intuitive wheelchair should be more intuitive than the second choice intuitive wheelchair in order to support this hypothesis. After comparing the two mentioned wheelchairs on perceived intuitiveness, a significant difference was found in this study. However, the score on intuitiveness for the second choice intuitive wheelchair is higher than that of the first choice intuitive wheelchair which is not in accordance with our hypothesis. Therefore, no support is found for the case of the intuitive method resulting in data with characteristics of intuitive knowledge. Possible explanations include the occurrence of demand characteristics, the need for different clustering analysis and the need for interpretation of the clusters instead of direct implement into products. These possible explanations will be discussed in upcoming sections of this report.

The second hypothesis states that the intuitive method will be able to outperform an existing method in terms of intuitiveness. To test his, the first choice intuitive wheelchair is compared with the interview wheelchair. However, the interview wheelchair was found to be perceived as significantly more intuitive during use. So, the intuitive method seemed not able to outperform an existing method.

One of the possible interpretations of the found results is that the intuitive method is simply not a better method for evoking intuitive information. But even when the interview method outperforms the intuitive method, it does not automatically mean that the latter is useless. The interview method lets participants verbally explain their ideas about products whereas the intuitive method lets the participant act out interactions. Acting out could be more suitable in certain situations, for example for analysing complex movements, although future research is needed to support this claim. A verbal aspect could also be added to the intuitive method, for example in the form of Thinking Aloud (Nielsen, 1995), in an effort to combine the strengths of both methods.

We know now that the first choice wheelchair is not perceived as more intuitive than the interview wheelchair. However, as this is a first implementation of this method, it might be the case that the second choice intuitive wheelchair should be considered as the intuitive method's main suggestion for designing an intuitive wheelchair, which is supported by the finding that the second choice intuitive wheelchair was perceived to be more intuitive than the first choice intuitive wheelchair. To see whether the second choice intuitive wheelchair can outperform the interview wheelchair their intuitiveness scores were also compared. No statistical difference in Quesi-questionnaire score was found. This suggests that the intuitive method is able to suggest a modification that is at least comparable with the interview method.

Future research could focus on investigating whether it is possible to directly extract the most intuitive suggestion from the data of the intuitive method. And, as seen here, an existing method might be matched in terms of intuitiveness, it is not outperformed yet.

Qualitative analysis phase 3

The above section compared the wheelchair in terms of intuitiveness. The qualitative analysis of the remarks participants made about the three wheelchairs can give more information about how the participants experienced the wheelchairs in order to guide our reflection on this study and possibly give us some suggestions for future research.

When looking at the things participants said about the first choice intuitive wheelchair compared to what was said about the other two wheelchair, a couple things can be said. The first choice intuitive wheelchair was never mentioned to be handy or logical. It was called easy to find just as many times as it was called hard to find. Two characteristics that set apart the first choice intuitive wheelchair when compared with the other two wheelchairs are that it gets more in the way while walking and it seen as positioned too low. In contrast, the other two wheelchairs were called logical and easy more often than they were called illogical and hard to find respectively.

The differences between the interview wheelchair and second choice intuitive wheelchair are less clear. The ratios for being logical/illogical and easy to find/hard to find are positive for both wheelchairs. Both were called a good or fine position more than once. A difference is that the second choice intuitive wheelchair has a negative ratio for handy/unhandy while the interview wheelchair has a positive ratio. The similarities again raise the question whether the second choice intuitive wheelchair is actually the best result of the intuitive method.

It remains unclear why it is possible that a charging position on a low position, away from the frame of a wheelchair is perceived as less intuitive while so many participants acted out plugging in the charger at that location; the location of the first choice intuitive wheelchair. The next section will talk about whether the first choice wheelchair can be improved by interpreting the data of the intuitive method before converting it into a modification.

Wheelchair D

Up to this point not a lot of evidence has been found that the intuitive method actually results in intuitive knowledge that can be used to design products that are perceived to be intuitive. Wheelchair D was added to phase 3 in order to see whether the data of the intuitive method, when interpreted, will outperform the data when it is implemented directly. In other words, wheelchair D is based on the first choice intuitive wheelchair, but instead of being mounted away from the frame it is brought forward to be mounted on the frame. If wheelchair D suddenly outperforms all the other wheelchairs it could suggest that the data from the intuitive method is still usable in the design of wheelchairs, but that it has to be interpreted before implementation.

As seen in the results, wheelchair D is seen as an improvement compared to the first choice intuitive wheelchair. However, 9 participants would still prefer one of the other two wheelchairs (the interview wheelchair or the second choice intuitive wheelchair). However, people were asked to give their opinion on wheelchair D. No questionnaire was used to measure its perceived intuitiveness, so no direct comparison in terms of intuitiveness can be made. This exploratory research suggests however that improvements can be made when the Kinect-data from the intuitive method is not converted directly into a modification.

In the following sections, limitations of this study will be discussed. An effort will be made to find an explain on as to why it was possible that the first choice intuitive wheelchair was supported by so many participants in phase 2 but not found to be more intuitive than the second choice of the intuitive method.

Limitations

Due to the differences between the interview method and the intuitive method, not everything could be kept consistent between the two. The wall-outlet used in the intuitive method was mounted at a height of 30cm, just like all the other plugs in the room. Since the interview method is purely a verbal method, no physical (prototype) wall plug was explicitly presented to them (only the ones on the walls in the room were still present).

This could explain why the largest cluster of the intuitive method was positioned at the bottom half of the wheelchair, while the responses from the interview method were mainly directed towards the top half of the wheelchair.
However, during phase 3, the prototype charger was plugged into a wall outlet at a height of 30cm. Since this is consistent with the intuitive method, it does not explain why the first choice intuitive wheelchair was perceived as less intuitive than the interview wheelchair.

Something that could explains these differences however would be the occurrence of demand characteristics, which means that participants try to satisfy what they perceive as the needs of the researcher (McCambridge *et al,* 2012).
During the intuitive method of phase 2, the prototype wall-outlet was one of the only physical aspects of the exercise that the participants had interaction with. Being a prototype with a transparent 'wall' and not an outlet in a real wall, it might have amplified its extraordinarity. Participants could have interpreted this object as a hint, in order to put the charging point on a lower point on the wheelchair than they intuitively would have done, which in turn resulted in the first choice intuitive wheelchair. This could explain why the first choice intuitive wheelchair was perceived as less intuitive, even though this wheelchair was based on the acted out interactions of a large portion of the participants. As such, it can explain who no support was found for the first hypothesis.
If aforementioned is the case, it underlines the importance of careful design of the intuitive method and the impact that physical objects have. Future research should take this into account.

Clustering

Another potential limitation could be the chosen clustering method. In phase 2 of this study, K-means was chosen as algorithm (where K stands for the number of clusters). The number of clusters is not chosen by the algorithm but has to be determined by the researcher. The was this done was by calculating the clusters for a range of K, visually inspecting the outcomes and choosing K which seems to fit the data the best and in a way

that aligns best with the information that was gathered during phase 2. However, other methods for choosing K could be considered, for example by calculating a metric such as Within-Cluster-Sum of Squared Errors (WSS), while correcting for cluster size differences, and choosing K accordingly.
A similar remark can be made about determining the most consistent cluster which was needed in order to answer the hypotheses. In this study, the biggest cluster was taken to be the most consistent. The WSS could also be used for this purpose as it takes into account the distance of each datapoint to the centre of its cluster. The WSS (corrected for differences in cluster size) of the first choice intuitive wheelchair is actually higher than that of the second choice intuitive wheelchair. This means that, according to the WSS score, the second choice of the intuitive method should have been the first, and vice versa. Indeed, we found a better evaluation of the second choice than of the first.

Alternatives to the K-means clustering method could also be considered. A K-means cluster results in a single point in space (the mean) which is interpreted to be an equal compromise between all the points in this cluster. However, it is possible that multiple datapoints should not be compressed into one point but into a shape. For example, the algorithm DBSCAN does not result in one mean datapoint, but each cluster can be any shape imaginable (Schubert *et al,* 2017). For instance, it could extract a cluster that follows the shape of the frame of the wheelchair. This could result in a deeper understanding of the data when compared with a simple means-cluster.

Another approach could be a more qualitative approach. As the results of this study are unexpected, it could be that an exact, quantitative approach is not the most suitable approach. For example, simply asking participants to act out an interaction and asking them what they are doing might result in data that gives wider insight in their ideas about wheelchairs than looking at the measured data alone.

So, as a summary, alternative analysis of the data could have resulted in different clusters and other first and second choice intuitive wheelchairs. Future research should take this into account and possible try multiple different ways of cluster forming and analysis.

Differences in cluster analysis do not explain why so many participants acted out interactions of a low location on the imagined wheelchair. However, it does indicate that looking at the second choice intuitive wheelchair instead of the first choice intuitive wheelchair might be a valuable exercise, since other ways of analysis could have come up with other clusters.

Learning effects

A single participant in this study only took part in either phase 2 or in phase 3 and never in more than 1 method of phase 2. This was done in an effort to reduce learning effects between the different methods and phases as much as possible. This does mean however that these groups of people are not the same. As explained in the method-section an effort was made to reduce the differences as much as possible. The following sections will discuss some differences that persisted.

All participants are deployed by Life&Mobility, a wheelchair company. Due to the Covid-19 pandemic, no other possibility was seen. In an ideal world without a pandemic the method would have been executed and validated among participants who are actual part of the target audience of the to be designed product. However, for validation purposes, it was deemed acceptable to use people from a wheelchair company, as long as the sample for phase 2 is comparable to the sample of phase 3. This way it could be tested whether the intuitive information found in phase 2 actually results in a modification that is perceived to be intuitive by a similar group of people.

It should be noted that the intuition of the participants in this study is likely to differ compared to the intuition of other groups of people, due to their specific knowledge and experiences. If people have more experience with Life&Mobility products and intuitive knowledge is build up during experiences, it can be assumed that their intuitive knowledge is shaped by product of Life&Mobility. This means that information found during this study, for example about a charging port location which is perceived as intuitive, might not be generalisable to other groups of people. This is something to take into account for future research.

During the experiment, most participants were very eager to express their ideas about possible improvements, sometimes even when they were not asked about this. It is not known whether this is an characteristic of the specific participant sample of this study and if this had any effect on the results. A follow-up study with participants who resemble the target group of the product more closely could therefore be a valuable exercise.

Some other things to consider are that the research had the form of a linear process. Phase 2 took 1,5 weeks to complete, followed by 1,5 weeks of data processing and preparation, followed by 1,5weeks of phase 3 execution. People who signed up directly therefore ended up in phase 2, while people who waited more ended up in phase 3.

During the intuitive method, participants are asked to act out interactions with an imaginary wheelchair. Not all participants were familiar or comfortable with this concept, which became clear for example when one participant clearly preferred to talk for multiple minutes and only acted out portions of the interactions in between talking. This was anticipated beforehand. To counteract this, visibility from outside into the research space was obstructed by window foil and a large flat screen tv at eye-level in order to lower people's fear of being seen by their colleagues. In contrast, the interview method did not require any such unorthodox behaviour. It allowed the participants to talk freely about their ideas without having to act out anything. Future research might want to take this into account and could maybe utilize an enclosed research space in order to mitigate these effects even more.

Handy and logical

During phase 2, the focus was to evoke intuitive knowledge in both the interview and intuitive method. It is the role of the researcher to guide this process, so the things he or she says will have their impact on the results of both methods. As explained in the procedure-section of this report, a script was made in order to keep the given information constant between multiple participants. During execution of both methods, it turned out to be difficult to explain to the participants what intuitive actually means (i.e. in the intuitive method participants were expected to do what felt intuitive to them). Participants sometimes asked whether they were supposed to act out interactions with a Life&Mobility wheelchair or with an alternative wheelchair. Therefore, in more than half of the cases, the word 'logical' was used. It is therefore a possibility that not 'intuitive knowledge' but 'logical knowledge' was gathered instead. In phase 3, each Quesi-questionnaire was accompanied by the question whether the location of the charging point seems like a logical place. The results of this item are comparable to the results of the quesi-questionnaire; the first choice intuitive wheelchair is rated less than both other modifications. The interview wheelchair is also not statistically different from the second choice intuitive wheelchair. These results suggest that it is not the case that the intuitive method resulted in one or more modifications that are perceived to be more logical than the interview wheelchair.

During phase 3, another question accompanied the Quesi-questionnaire: whether the location of the charging point seems like a logical place handy place (original Dutch word: *handig*. Another translation to English would be 'convenient'). Again, the first choice intuitive wheelchair is significantly lower rated than the other two modifications. The interview wheelchair is also not statistically different from the second choice intuitive wheelchair. These results suggest that it is not the case that the intuitive method resulted in one or more modifications that are perceived to be more handy than the interview wheelchair.

Post-hoc testing on Kinect-measurements

The Kinect-measurements collected during the intuitive method of phase 2 were analysed again in order to see what other information could be extracted.

The participants of phase 2 and 3 of this study are employees of Life&Mobility, a company which designs, produces and sells wheelchairs among other products. Among the participants were people from all departments. For example, some participants spend days assembling wheelchairs. Therefore, we feel it can be assumed that the experiences of the participant with Life&Mobility products shaped their intuitive knowledge. If a method is used that truly evokes intuitive knowledge, as is the goal for the newly developed method of this study, one would expect the data to show similarities to wheelchairs of Life&Mobility.

Measuring the distance between the hands at a moment where the participant holds the grips of the imagined wheelchair gives an estimate for the desirable width of the grips of a wheelchair. These results are compared to the 5 standard wheelchair grip widths that Life&Mobility sells.

The most commonly sold wheelchair of Life&Mobility has a grip width of 44,1cm. The largest group of participants held their hands at a compareble width when gripping their imaginary wheelchair. The second most commonly sold wheelchair of Life&Mobility has a grip width of 39,1cm where the third best sold wheelchair has a grip width of 49,1cm. The second and third largest groups of participants held their hands at a comparable width when gripping the imaginairy wheelwhair. This data does seem to suggest that participants in this study, who are employees of Life&Mobility, do have a Life&Mobility wheelchair in mind when acting-out interactions with an imaginary wheelchair. Although this does not directly prove that the intuitive method really evoked intuitive knowledge, it can be seen as a motivation for future research to validate the intuitive method.

Similarly, correlations that are calculated based on the Skeleton Joint Tracking data shine some light on what is possible with this data. A significant and moderate ($r=0.5018$) correlation between person height and grip width is found, which might mean that a longer person prefers a grip that is higher. On the contrary, no significant correlation between shoulder width and grip width is found.

As presented in the results section, the trajectory of the hand of each participant while plugging in the (imaginary) charger is extracted in order to support the accuracy of our data. Although subjective, the trajectories suggests that the datapoints that are used for clustering are actually extracted at the moment the participant changed direction, as was the goal. Also, future research could find out whether these trajectories could be used to determine an intuitive mounting orientation of the charging point on the wheelchair.

Reflections for future research

As was seen in the previous sections, more research is needed in order to verify that the novel method can be used to evoke intuitive knowledge in order to support product design. The coming section will handle some reflections on the current research that might be useful to future research. Some limitations will be mentioned as well.

The data from phase 2 had to be translated to physical objects and modifications for phase 3. Since no physical wheelchair had been part of the experiment up to that point, a choice of wheelchair had to be made. Life&Mobility was able to provide three similar wheelchairs of the type Roxx. This wheelchair was chosen because it does not contain any electrical system, tilt function or other components that could distract the participants.

However, it is possible that the participants of phase 2 imagined a wheelchair with more visible electric components. For example, a battery pack under the seat could have guided the attention of the participants to that location. No such guidance was present in this experiment.

As explained in the method-section the Quesi-questionnaire was shortened for practical reasons. The remaining 5 questions originate from the 5 different subscales of the original questionnaire. However, the resulting questionnaire is not validated. This means that it is unsure how accurate and possibly how reliable the questionnaire measures perceived intuitive use. Future research could mitigate this drawback by using a validated questionnaire.

The wheelchairs were fitted with the same charging port from Penny & Giles. This connector is not usually used by Life&Mobility as charging connector. Therefore, the extent to which participants were able to use previous experience with charging connectors was limited. Most electric Life&Mobility charging connectors are some form of round XLR-connector, while the Penny & Giles connector has 4 pins positioned in a trapezoid arrangement.

The housing of the charging port connector is black and all logos were masked off for the experiment. A few participants wrote in the general survey that the black connector was hard to distinguish against the similarly coloured frame of the wheelchair. The modification that was rated least intuitive, the first choice intuitive wheelchair, was mounted on a contrasting grey tube whereas the other two modifications were mounted on black backgrounds. Therefore, it is unlikely that this is the reason that the first choice intuitive wheelchair was perceived to be less intuitive.

The current study tried to find a location of a charging port which is intuitive during use. This is a spatial aspect of the to be designed product. The intuitive method uses measurements in three-dimensional space which makes it possible to suggest possibly intuitive locations. However, measurements in three-dimensional space of acted-out interactions do not tell the researcher what colour charging port would be the most intuitive during use for example. Future research could investigate which aspects of a product could benefit from the intuitive method and which should be investigated with other methods. Changing the way measurements are made and analysed, for example to a more qualitative analysis of (recordings of) the behaviour of users while acting out interactions, might allow the method to be used for the design of higher-level aspects like functions of a device.

Wider outlook

The current research set out to test two hypotheses. The first hypothesis should support the claim that the intuitive method actually evokes intuitive knowledge. The second hypothesis tests whether the intuitive method is able to outperform an existing method; the interview method. Both hypotheses are only partially supported and only when it is assumed that the second choice intuitive wheelchair should be seen as intuitive method's best effort (most intuitive knowledge).

As can be seen in this discussion section, multiple limitations where present. This means that additional research is needed to truly get support for the stated hypotheses. Findings and experiences in this study can guide future research in the right direction.

But what do we gain if we know that a new method can be used to evoke intuitive knowledge and can outperform the interview method? First of all, products can be designed to be more intuitive, which brings about benefits like more effective use. However, as was seen in this study, the intuitive method is able to suggest multiple possible solutions at once. Therefore, it might be useful during early phases of design processes, where the design of a product has not been determined yet and innovative directions can be taken.

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5. Appendices

Appendix A - Phase 1 – Guiding interview questions – caregiver

1. Could you describe a usual day of your job and specifically the interactions you normally have with a wheelchair, both with and without an occupant?

2. Do you use wheelchairs with electric push assistance in your work? If yes, are there are differences in terms of usage when compared to a non-assisted wheelchair?

3. To what extent does the possibility of using a wheelchair change the work of a caretaker, compared to a situation where you would not have the possibility to use a wheelchair?

    a. Follow-up question: And the wheelchair as a whole, what are the most important reasons for this device to exist?

4. What are the different things that a wheelchair should be able to do (for instance, should it be foldable?).

5. Are there things that you, as an attendant of a wheelchair, would like to change about wheelchairs that you come across in your work in order to improve them? Or, if you happen to use multiple wheelchairs in your work, are there things that are better about the one wheelchair compared to another?

6. How would you, from the perspective of the caregiver, describe a wheelchair? If possible, without mentioning how it looks like or what it is made of.

  a. Alternative: If a wheelchair stands in front of you and you have to explain what it is to someone who has never used a wheelchair, how would you do that?

7. In case you have experience with wheelchairs with electric push assist; could you describe the location where these wheelchairs are usually charged and how that works exactly?

Appendix B - Phase 1 – Guiding interview questions - occupational therapists

1. Could you describe the company you work at and what your job entails?

2. Do you come across wheelchairs with electric push assistance in your work? If yes, are there are differences in terms of usage when compared to a non-assisted wheelchair? For the occupant as well as the attendant?

3. To what extent does the possibility of using a wheelchair change the work of a caretaker, compared to a situation where you would not have the possibility to use a wheelchair?

    a. Follow-up question: And the wheelchair as a whole, what are the most important reasons for this device to exist?

4. What are the different requirements that people have for a wheelchair? (for instance, should it be foldable?).

5. Are there things that you, as an occupational therapist, would like to change about wheelchairs that you come across in your work in order to improve them? Or are there things that are better about the one wheelchair compared to another?

6. How would you, from the perspective of an occupational therapist, describe a wheelchair? If possible, without mentioning how it looks like or what it is made of.

    a. Alternative: If a wheelchair stands in front of you and you have to explain what it is to someone who has never used a wheelchair, how would you do that?

7. In case you come across wheelchairs with electric push assist; could you describe the location where these wheelchairs are usually charged and how that works exactly?

Appendix C - Phase 2 – Intuitive method – description and script

Description of the wheelchair, in bullet points:

- Is basically just a chair with wheels
- Makes the movement from A to B possible for the occupant
- The wheelchair has electric push assist, which means that the attendant does not have to push as hard as usual. It also means that there is an electrical system on the wheelchair, with a battery and electric motors. The wheelchair might have the requirement of being turned on before moving and there might be a speed adjustment.
- A charging port is present somewhere on the wheelchair.

Script

Introduction

- Explain that participant will be working with an imagined product

- Researcher acts out an example of putting water in an imaginary electric kettle, placing the kettle on its stand and tuning it on in order to boil some water.
- Participant is told that he or she can act out the interactions in a way that he or she would see fit and that there is no such thing as the wrong interaction.
- Researcher asks whether the idea of acting out interactions is clear to the participant.

Getting to know the wheelchair

- The participant is verbally given the description of the wheelchair, except the parts about the electric systems. The participant is explained that he or she is the attendant of the wheelchair
- The participant is asked to stand in the middle of the research area, the start position, and to hold the wheelchair. An example is given where the occupant might want to grab something from a table which is positioned at the edge of the research area. Subsequently, the participant is asked to walk to the table with the wheelchair. Afterwards, the participant is asked to walk back to the start position.

Adding the electric push assist and charging

- The participant is verbally explained the remaining parts of the description of a wheelchair, and the wheelchair is in the off position. Her or his task is to walk around the research area in a circle as wide as possible.
- The prototype wall-outlet is placed in the research area. Seen from the point of the Kinect-camera, it is placed approximate 70cm to the right of the middle and the front of the outlet is turned 35 degrees towards the middle of the area.
- The next interaction is explained in full before the participant is asked to execute it. The first action is to move the wheelchair next to the wall-outlet with the left side of the wheelchair facing the outlet. The participant is asked to hold the wheelchair for at least one second before continuing. Subsequently, he or she is asked to plug in the imagined charger into the wheelchair first before plugging it into the wall-outlet. The charger is described as a device that resembles a charger as used for most laptops.

- After completing the previous actions, the participant is asked to unplug the charger and park the wheelchair in the corner with the brakes engaged.

Appendix D - Phase 2 – Interview method – description and script

Description of the wheelchair, in bullet points:

- Is basically just a chair with wheels
- Makes the movement from A to B possible for the occupant
- The wheelchair has electric push assist, which means that the attendant does not have to push as hard us usual. It also means that there is an electrical system on the wheelchair, with a battery and electric motors. The wheelchair might have the requirement of being turned on before moving and there might be a speed adjustment.
- A charging port is present somewhere on the wheelchair

Script

Introduction

- Explain that the research has the form of an interview.
- The participant is told that he or she can explain whatever he or she wants in a way he or she would see fit and that there is no such thing as the wrong answer.

Getting to know the wheelchair

- The participant is verbally given the description of the wheelchair. The participant is explained that he or she is expected to imagine being the attendant of the wheelchair. A charger is described as a device that resembles a charger as used for most laptops.

Charging port location

- The participant is asked to describe where a charging port on a wheelchair would be.
- When the specified location is not clear, the participant is asked to clarify the location by telling where it is located compared to parts of the wheelchair

such as the seat and backrest. When the participant does not specify what the lateral position of the charging port is, this is specifically asked by the researcher.

Appendix E - Phase 3 - Power analysis

F tests - ANOVA: Repeated measures, within factors

Analysis:	A priori: Compute required sample size		
Input:	Effect size f(U)	=	0.495
	α err prob	=	0.05
	Power (1-β err prob)	=	0.9
	Number of groups	=	1
	Number of measurements	=	3
	Nonsphericity correction ε	=	1
Output:	Noncentrality parameter λ	=	13.7214000
	Critical F	=	3.1618612
	Numerator df	=	2.0000000
	Denominator df	=	56.0000000
	Total sample size	=	29
	Actual power	=	0.9079547

Appendix F - Phase 3 - Questionnaire after each wheelchair

1. I barely had to concentrate on using the charger.

2. I was able to achieve my goals in the way I had imagined to.

3. The way the charger worked was immediately clear to me.

4. It was always clear to me what I had to do to use the charger.
5. No problems occurred when I used the system.
6. The location of the charging port seems like a handy location.
7. The location of the charging port seems like a logical location.
8. Was this the first, second or third wheelchair you used? (fill in 1,2 or 3)
9. What is your participant number?

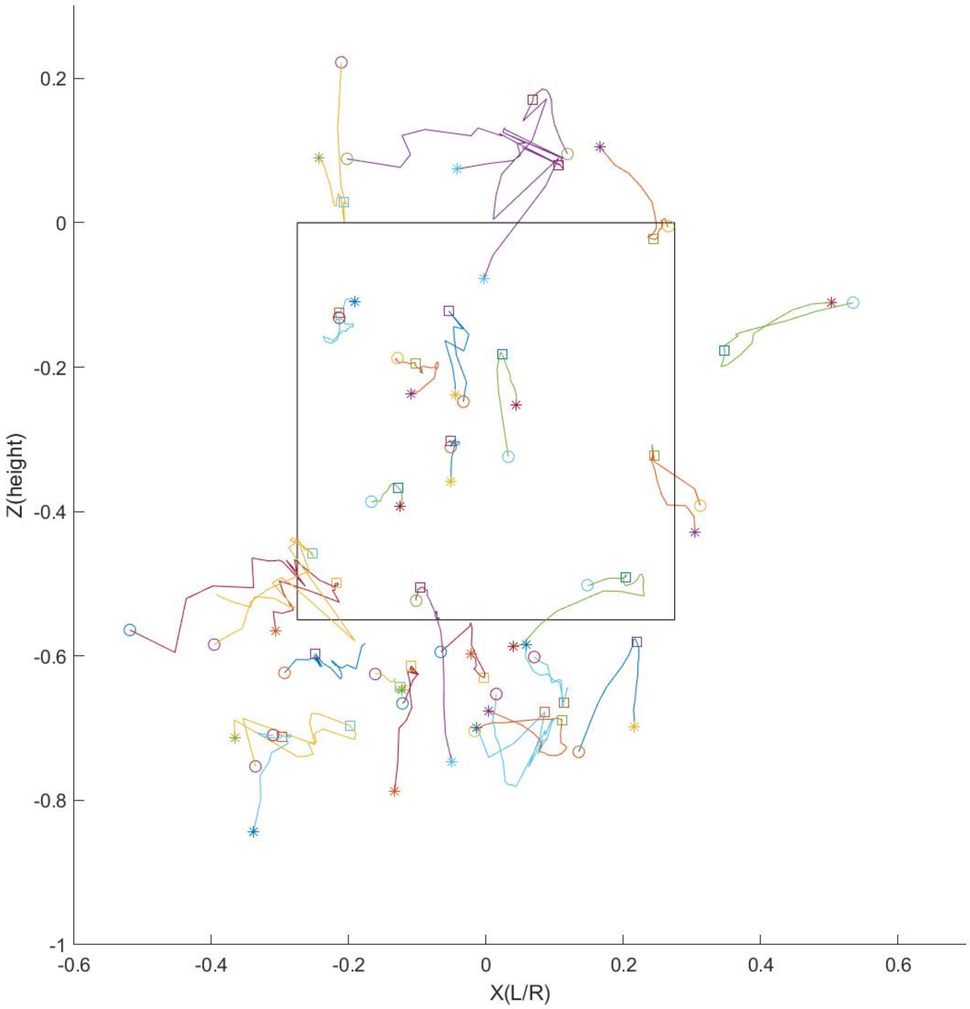
Appendix G - Phase 3 - General questionnaire

1. Are you usually left- or right-handed?
2. Can I ask you about your age?
3. How often are you attendant of a wheelchair (Daily/Weekly/Monthly/Less than monthly)
4. What is your participant number?
5. Which charging port was the most handy during use?
6. Were there things which you found good or less good about the charging point of wheelchair A. And if yes, what where those things?

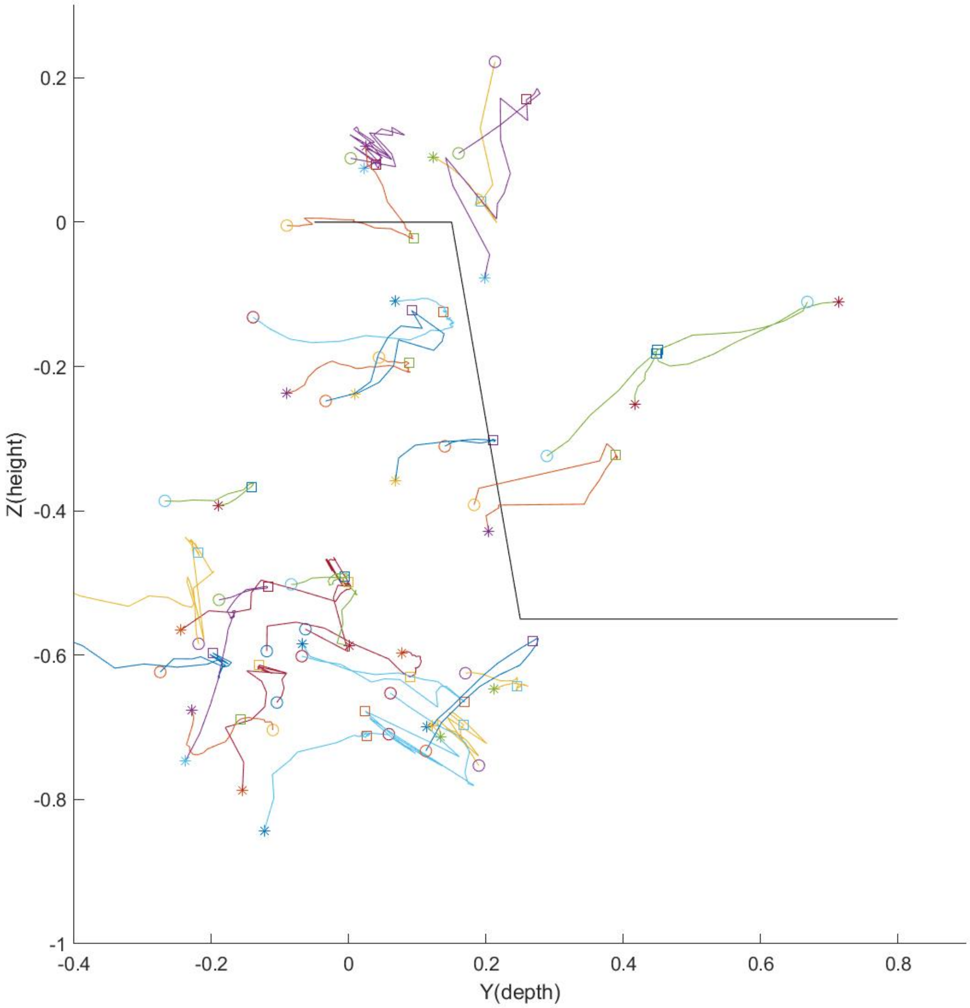
7. Were there things which you found good or less good about the charging point of wheelchair B. And if yes, what where those things?

8. Were there things which you found good or less good about the charging point of wheelchair C. And if yes, what where those things?

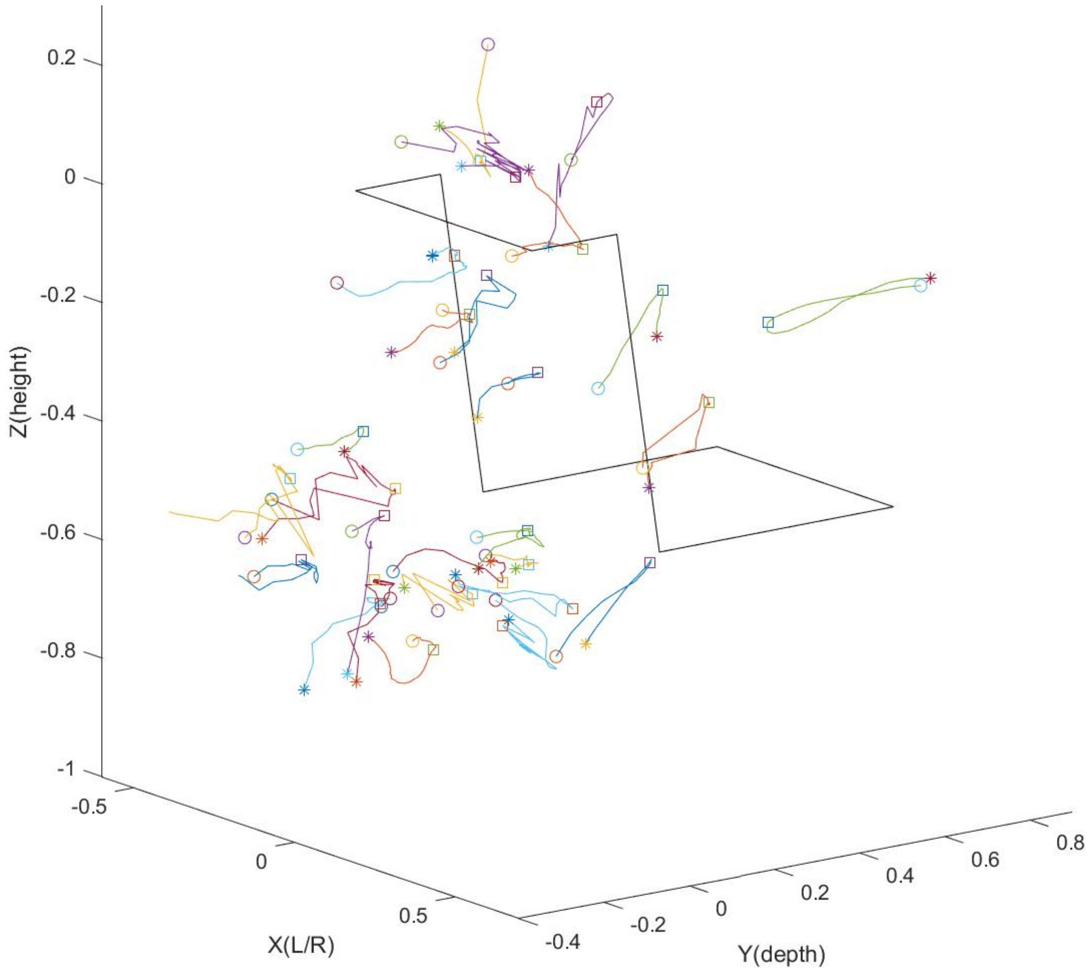
Appendix H - Phase 2 – Intuitive method - Trajectories



Trajectories of the hands of the participants while plugging in the charger, as seen from the rear of the imagined wheelchair. Asterisk: start point. Square: location taken as datapoint. Circle: endpoint. A frame of a wheelchair is drawn in the graph for clarity, with grips, back tubes and seat (with a width of 55cm), based on a Life&Mobility Roxx wheelchair.



Trajectories of the hands of the participants while plugging in the charger, as seen from the right side of the imagined wheelchair. Asterisk: start point. Square: location taken as datapoint. Circle: endpoint. A frame of a wheelchair is drawn in the graph for clarity, with grips, back tubes and seat (with a width of 55cm), based on a Life&Mobility Roxx wheelchair.



Trajectories of the hands of the participants while plugging in the charger, as seen from behind and to the right of the imagined wheelchair. Asterisk: start point. Square: location taken as datapoint. Circle: endpoint. A frame of a wheelchair is drawn i in the graph for clarity, with grips, back tubes and seat (with a width of 55cm), based on a Life&Mobility Roxx wheelchair.