

Embodiment of Prostheses

Becoming Part of the Body-Image

By

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Abstract

In this research, the possibility of prostheses becoming part of the body-image will be researched through comparing the embodiment theory with the extension theory. Extension theory argues that prostheses do not become part of the body-image, but remain an extension of the physical body and thus remain a tool. Prostheses are considered to be located outside of the bodily boundaries. Embodiment theory explains how prostheses could become part of the body-image, though not necessarily that prostheses can be part of the body-image. Some cases of prosthetic users show that people have let their prosthesis become part of their body-image. In this research, I will try to answer the question: to what extent is a prosthesis part of the body-image? Not all prostheses can become part of the body-image, only those that resemble a part of the normal human body. The most significant outcome is that personal preference (and thus choice) is a decisive factor in letting prostheses become part of the body-image.

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Introduction

Human beings are essentially intertwined with technology. This is made abundantly clear by simply going outside and looking around. When you look around in the Netherlands for instance, you will most likely see nothing that was not placed there to serve a purpose for human beings. A park, one could argue, is a natural thing. It has trees, bushes, grass and birds living in it. This park, however, was placed for people to go there and relax. It is, in this sense, a technological artefact, like an office building. The park, like the building, did not grow there itself. The same could be said for a body. The body is becoming something that serves us; it should be repairable in order for humans to live longer. Medicine has been developed to the point that most illnesses can be cured and, at the very least, death can be postponed. From minor conditions like a broken leg to anything as severe as cancer or aids, medicine has more and more answers. The body is something for us, something that needs to be taken care of for us to live longer and healthier lives.

Clark (2001) even argues that human beings are basically born a cyborg. “We cannot see ourselves aright until we see ourselves as nature's very own cyborgs” (Clark, 2001). He argues that human beings are already so intertwined with technology from birth that it is hard to separate humans and technology from each other. We are, therefore, already cyborgs.

This does not mean there is no boundary between human and technology, only that the boundary is becoming more vague. At some point there will probably be a person who claims that a technological artefact has become part of that person's body. A technology this is likely to happen with is a prosthesis, mainly because a prosthesis is not only created to be used as a tool, but also to fit a person's body, to become as close to being part of the body as possible. A prosthesis is a technological artefact that reproduces or restores normal human bodily functions for an individual, this will be explained in more detail later. Is it possible, or even already so, that a prosthesis is part of a person's body? To understand this, first let us discuss briefly what a body is and how a body can be seen.

Johnson (2008) described five different views on the body. The first view is the body as a biological organism (Johnson, 2008), which is the natural thing with which a person is born. The focus of this view is oriented inside the body of flesh and blood. The second view is the ecological body (Johnson, 2008), being the body in the environment. The body and its

environment are two things that are considered together rather than separate. The third view is the phenomenological body (Johnson, 2008), being the way a person sees and experiences his / her body. This is about the awareness of one's own body, also called body-image. Body-image is the way one sees, feels and experiences his / her own body and what is part of it. This will be explained in more detail in chapter 2. The fourth view is the social body (Johnson, 2008), being the way other humans see one's body. The fifth and last view is the cultural body (Johnson, 2008), which focusses on the way a body is shaped by cultural aspects. So, which view is best suited to investigate if prostheses can be part of a person's body?

The first view is directed inwards the body of flesh and blood. Prostheses do not consist of flesh and blood, which makes this view not suitable for the posed research question. This view is being used however when speaking of the body throughout this thesis. The second view is not suited either because it focusses on the combination of environment and the body. It would not help to know if a prosthesis can be part of the combination body / environment. The third view is about the way a person sees, feels and experiences his / her own body. In this light a prosthesis can only be part of the body-image when it is truly felt and experienced as one's own. This view is well suited for this thesis because its focus is on the individual and a prosthesis is a technology which is created to fit an individual. Working with the fourth view would mean that if many people see something to be part of another person's body, it is part of it. This is not a view I want to take because I think it is not for someone else to decide about what is part of me and what is not. Taking the last view would not be suitable because a prosthesis is not a cultural thing like piercings or tattoos. Reviewing it as such would not make sense. The point of view best suited for reviewing if a prosthesis is part of a person's body is by focussing on the body-image (the third point of view from Johnson(2008)).

The research question of this thesis is therefore; To what extent is a prosthesis part of the body-image? For answering this question, some sub-questions require attention first. The sub-questions are; What is a prosthesis?; Why can prostheses not be part of the body-image? ; What is body-image and how (if at all) can a prosthesis become part of the body-image? This is interesting from a mechanical engineering perspective. Most mechanical engineers design for values such as reducing costs, robustness and overall quality in their designing. Though these values are important, improving on the same values might not

always be wise. At some point another perspective, which would provide other values to design for, can be helpful to take a product to the next level. This is what this thesis will do. By looking at prostheses from a non-mechanical engineering perspective, and see what insights this can give.

What is a prosthesis?

Most people have an idea of what a prosthesis is and might have seen another person with one. Therefore, most people think they have a clear picture of what it is and what it does. But what is included and excluded in this picture? The current section will answer the sub-question; What is a prosthesis?

There are several different interpretations as to what a prosthesis is. Even different dictionaries use inconsistent definitions. For instance, the Oxford Dictionary defines a prosthesis as “an artificial body part, such as a limb, a heart, or a breast implant” (2018), the Merriam Webster defines it as “an artificial device to replace or augment a missing or impaired part of the body” (2018) whereas Collins defines it as “an artificial body part that is used to replace a natural part” (2018). When using the second definition, a hearing aid might be considered a prosthesis, but when using the third definition it cannot be considered as such, as it defines replacement of only the natural parts of a human¹. This definition also excludes people born without an arm, as the arm was never a part of their body to begin with.

According to Brey (2005) “prostheses is the name for any artifact that is used to restore bodily functions” in the broadest sense. This means that the function of a prosthesis is to restore normality². This includes restoring normality for people born with reduced bodily functions. A prosthesis thus provides a normal bodily functions that a person has lost or never had. This is its primary function. This basically means that people born without reduced bodily functions are the standard for people born with reduced bodily functions. A person is not his/her own standard.

Restoration is not so much in that a prosthesis heals the original tissue, but that it restores the original function by use of a technological artefact. Things such as glasses,

¹ For sake of length and possible complexity the focus will only be on human prostheses.

² Normality is a state of the body without reduced bodily functions.

artificial limbs, hearing aids and artificial bone-implants are examples of this. This is different from things like a cast or knee-braces, as they have the primary task to help heal the body.

Another important function of a prosthesis is to give a person the sense of wholeness³ (Norton, 2007). Creating this feeling of wholeness can be done by either focussing on recreating a natural look, or recreating a bodily function. Things like glass eyes, artificial limbs and in some cases breast-implants are an example of this.

With this information, the sub-question – what is a prosthesis? – can be answered. Still there are three more points that need to be addressed for clarification and to avoid confusion.

The first point is that there is a distinction “between a medical condition (such as being blind) and a social condition that it gives rise to (such as being unable to read the newspaper)” (Hanson, 2007). The focus in this thesis is directed to the first. A prosthesis follows the goal to recreate the function of the original body. A prosthesis (like glasses) helps cure a medical condition (seeing properly) and does not, as primary task, solve the problems of social conditions (reading the newspaper out loud). Prostheses are primarily focussed on the curing of individual medical conditions.

The second point is that only bodily prostheses are included in this thesis. For example, cognitive prostheses – prostheses that can possibly fix deformities in the mind – are not included in the definition. These have also not been developed yet, but will possibly be developed in the near future (Brey, 2000). Other things that are not included in this definition are transplantations. When someone receives a liver from another person, blood from another person or a heart valve from a pig, this is not seen as a prosthesis. An artificially grown body part (a technology still in development) is also not included.

The third and last point is about augmentation technology. You might imagine a scenario where a fictive person called Danielle is born with reduced function in her left leg. Danielle wants to have a fully functional leg so she gets medical help. She just wants to get out of the wheelchair and run. She selects a leg that is good for running. Eventually she is able to get out of her wheelchair and run. She quickly notices that her original (and healthy) leg cannot keep up with her new prosthetic leg. Danielle wants to run so bad, that she

³ With wholeness is meant in this thesis the feeling of being bodily complete. Not missing any bodily parts.

decides she wants to amputate her other leg to be able to run faster. It seems like the leg she got is not reproducing normality but is improving her performance.

Now what if I tell you this was a true story? Danielle actually exists (Express, 2018) and wanted to get the other leg amputated. The prosthetic leg is better than her original leg, or at least for her. As you can imagine, the same can be expected – in time – for the rest of the body. Eventually a body for a human can be recreated.

Prostheses are focussed on reproducing or restoring normal bodily functions, not on improving the human body. The fundamental difference is thus in trying to recreate the normal bodily functions (prosthesis) and attempting to improve human functions (augmentation technology). Augmentation of bodily functions can lead to situations that are not bound to any limits and are therefore not included in this thesis.

The answer to the sub-question; what is a prosthesis? is formulated as follows: a prosthesis is a technological artefact that reproduces or restores normal human bodily functions for an individual.

Relevance

Embodiment experience of prostheses is a largely neglected area of research (Murray, 2008), even since 2008 more research has been done towards the embodiment of prostheses. More and more users of prostheses have been interviewed and more users of prostheses have been writing about their own experiences. In this thesis, new experiences have not been researched or added since there is a sufficiently large body of experiences and stories available in the literature. This thesis is concerned with answering the following question; to what extent is a prosthesis part of the body-image?

Answering this question proves relevant, because “understanding the extent to which artificial extensions of the body are ‘incorporated’ [...] may be of great relevance to the design of prostheses for amputees and their use in rehabilitation” (Holmes et al, 2006). Murray (2004), as well as Preester et al (2009) and Preester (2011) support this claim. When it is clear if and how a prosthesis can become part of the body-image, the process of embodiment might be adjusted in order for more people to maximize the benefit they can get from their prosthesis.

The improvement of a prosthesis itself is where my interest lies from an engineering perspective. This is twofold, depending on the outcome of the question. When a prosthesis cannot become part of the body-image, I would like to see if modifications on the general technology could change this. When prostheses can become part of the body-image, it is interesting to determine where changes can be made in order for the process of embodiment to be improved. This will hopefully lead to a faster process of embodiment and a higher acceptance by the users of prostheses.

Method & outline

The research question of this thesis will be answered by reviewing existing literature. The reason for this is that there is already a sufficient amount of research conducted towards the topic. Also, many users of prostheses have previously been interviewed, which means it is sufficient to conduct a literature research on this topic. Also, reviewing literature allows me to have a broad focus on the topic. This broad focus fits the topic of this thesis better than a narrow focus. Relevant literature has been selected by looking in various online libraries, because most online libraries nowadays can provide more information than physical libraries.

The research question of this thesis is; To what extent is a prosthesis part of the body-image? Before an answer to this question can be formulated, first some sub-question need to be answered. The first sub-question – about what a prosthesis is – has been answered earlier. Other sub-questions will be answered throughout this thesis.

This thesis will start with answering the sub-question; why can prostheses not be part of the body-image? Several authors (Brey, 2000a; Ihde, 2008; Steinert, 2016) claim that technologies cannot be part of the body-image or advocate extension theory which leaves no room for technologies to be part of the body-image. The general concept of extension theory is that all technological artefacts extend human faculties. An extension is therefore a technological artefact that can be used and controlled in order to extend human faculties. The concept of extension theory will be explained in chapter 1. Although there are many different approaches on extension theory, this thesis will only explain the general concept of

extension, in order to substantiate the results of the research question. The reason for this is that a detailed analysis is not helpful in answering the research question of this thesis.

The second sub-question here is; what is body-image, and how (if at all) can a prosthesis become part of the body-image? Embodiment, in this thesis, is a process through which prostheses become part of the body-image. For something to be part of the body-image, it must unquestionably and undoubtedly be part of the way someone sees, feels and experiences their body. This is explained in more detail in chapter 2. In this chapter, the process of embodiment, the way something becomes part of the body-image, and the term body-image are explained in more detail. The goal of this chapter is not only to explain the general concept of body-image, but mainly to explain how something can become part of the body-image. The theory of embodiment will be linked to user experiences.

When all the terms are defined and both extension theory and embodiment theory are explained, an answer to the research question can be sought. This will be done in the conclusion. In this chapter, the difference between extension and embodiment will be elaborated. In short, the difference is that extension theory focusses on all technologies being an extension of human faculty and not part of the body nor the body-image, while embodiment focusses on a specific technology and how it becomes part of the body and body-image. Next, after having discussed aforementioned, an answer to the research question will be formulated.

Extension Theory

The term extension has been used in different ways by different authors. To be clear about the terminology, the term extension will be explained here. An extension is something that stretches, continues or adds something (Cambridge Dictionaries, 2019) to a human. In Thompson's et al (2009) words; an extension is a technological artefact that can be used and controlled in order to extend human abilities. An extension is seen here as a continuation in something non-corporeal. That means an extension is not part of the body-image nor is it part of the body, it is located outside the bodily boundaries. Bodily boundaries are the physical boundaries between the body and the environment. In other words, the location where the body stops and the rest of the world begins. Bodily boundaries are not only about the physical boundaries of the body, but also about the psychological boundaries of what a person sees as part of their body. Extension theory is mainly focused on the ecological body, the body together with its environment. This focus will be translated towards of the phenomenological body (body-image). Prostheses extend some aspects of a human. For instance, a hearing aid is an extension of the auditory senses. This means it can be seen as part of the hearing system, but not as part of the body. The hearing system is, in this case, only partially part of the body. The way in which a prosthesis extends a human is viewed differently by various authors.

The point that will be explained in this chapter is that prostheses are, and remain a mere tool and are therefore an extension of the body. The goal of this chapter is to not to explain in depth all current theories of extension, but only to explain the general idea of extension theory and to argue that prostheses are an extension. This chapter serves the purpose to answer the sub-question; why can prostheses not be part of the body-image? Brey (2000a) and Steinert (2016) already made a critical analysis of theories of extension. These two papers therefore form the basis for this chapter.

Extension theories

Firstly, Kapp (1877) (translated by Brey, 2000a) argues that technological artefacts are projections of human organs. Kapp means this quite literally, as all technologies look like

human organs. The functionality of things depends on its physical shape and form (Brey, 2000a). Technologies in this sense are regarded as an extension of human organs. This is the case for every technology, according to Kapp (Brey, 2000a). In this sense all technologies are a continuation / extension of human organs. Kapp (1877) argues that all technologies are based on, and modelled to organs. A bike is a projection of feet that move in circles for instance, a soup-bowl mimics the hand palm and a rake mimics spread fingers on an arm. In his paper, Kapp (1877) made a long list of technologies and explained, just like the soup-bowl, how all technologies are based on the human organs.

Though many technologies have similarities with human organs, Kapp's argument does not withstand closer scrutiny (Brey, 2000a; Steinert, 2016). Too many counter examples can be given of technical artefacts that do not resemble human organs or their function (Brey, 2000a; Steinert, 2016). A book, lighter, telephone and airplane are examples of such artefacts that do not resemble organs by function or shape⁴ (Brey, 2000a).

The second theory comes from McLuhan (1966) who claims technology extends human organ functions. McLuhan makes a division between two classes of extension technologies (Brey, 2000a). The first class is extension of the body, which means "extension of parts of the human body that are used for acting on or protecting oneself from the environment, or regulating bodily functions" (Brey, 2000a). This does not include the sensory system and the mind, these are part of the second class; extension of cognitive functions. The second class is about all technologies that extend the mind and the senses. McLuhan for instance, sees media as an extension of the visual function. McLuhan's claim is similar to Kapp's claim since they both claim technologies extend human organ functions. The biggest difference is that McLuhan leaves out the part that technologies also imitate the shape and form of human organs.

The third theory comes from Rothenberg (1993) who claims that technology can extend all human aspects that we know of how they work. Rothenberg means this quite literally; when you know how an eye works, you can extend it. This is what is being done with glasses for

⁴ Given the time that Kapp lived and the technological advancement made since then, it could very well have been the case that Kapp was right about technological artefacts back in his day. Since then, there have been so many technological advancements that his theory could simply be outdated.

instance. Things that we do not understand, like morality, cannot be extended. That means, a robot cannot make moral decisions for you, but it can do the laundry. In this theory Rothenberg (1993) makes two categories of extensions: extensions of action and extensions of thought. Basically, this resembles the distinction McLuhan (1966) makes, extension of action is similar to extension of the body and extension of thought is similar to extension of the mind. The difference is that McLuhan (1966) sees artefacts primarily as extensions of human functions while Rothenberg (1993) sees artefacts only secondary as such. Rothenberg sees artefacts primarily as extensions of human intentions and desires.

The fourth point of view comes from Brey (2000a) whose point of view will be described below. Brey used the above-mentioned three authors (Kapp, 1877; McLuhan, 1966; Rothenberg, 1993) as a basis for his theory of technology as an extension. Few authors have made attempts to compare different theories of extension – like Steinert (2016) – but Brey proved to be a useful source (Lawson, 2010). Lawson⁵ (2010) argues that a defining aspect of technology is that it extends human capabilities.

Brey argues that “neither Kapp, nor McLuhan, nor Rothenberg present a theory of technology as extension of human faculties that is both coherent and defensible” but that there is a notion of extension which is coherent and to which there are no counter examples. This means that Brey argues that the concepts, which are briefly explained in the section above, are not feasible. However, a more durable theory can be based on these concepts. The theory put forth by Brey is most similar to Rothenberg (1993). Rothenberg’s argument that technologies extend the human intentions seems somewhat off point, because intentions cannot be extended. The means by which human intentions are realized can be extended however. This is the core argument of Brey. To illustrate what Brey means, we could take the example of a person having the intention to eat an apple. This apple is right in front of him, hence he could use his arm to take it and teeth and jaws to bite and chew it. The body is used as a means to achieve an intention. The same goes for walking; when one wants to go and buy an apple, they use their legs to walk towards the shop. Therefore, the body is an instrument for transportation and consumption. The body is the first, and

⁵ Since Lawson (2010) bases much of his – for this thesis – relevant arguments on Brey, Kapp, Rothenberg and McLuhan, these authors are used instead of Lawson.

primary, original inventory of means⁶. Thus, the body is a means for realizing intentions. These means can be extended by technology. The body as a means for transportation can be extended; e.g. going to the supermarket by bike is extending the body as a means of transportation with a technological artefact. The bike is seen as an external means. External means are alienable means; they are not part of the original means. Original means are actually only the body, and all that is in it.

Technology (external means) can extend human means by either enhancing the existing capabilities, or by adding new capabilities. New capabilities would be things like lighters, because humans do not have the capability of creating fire with only the body. An enhancing external means would be a bike as it enhances the capability of humans traveling⁷.

Another external means is manual labour. When someone works for another person, that someone is a means to realize the intention of the other. External means are therefore not necessarily technological artefacts but could also be humans, animals and other living beings. Obviously, these cannot be seen as prostheses and therefore they are not relevant for this thesis. Nevertheless, what is relevant to note is the way Brey sees a body. He sees a body, though he does not explicitly mention it, almost as a technological artefact, something that is there for a human being to use. This view can be found in the work of more authors. Wigley (1991), for instance, sees the body itself become artificial because of the dependence on a prosthesis.

A human and a technological artefact can engage in a symbiotic relation when the functional unit can achieve more of something that neither can achieve separately. Brey uses a saw as an example. A human being alone cannot saw a piece of wood, nor can a saw itself. Together, however, they can.

To summarize Brey, “all artifacts extend the set of naturally given means (i.e., human bodily and mental faculties) by which human intentions are realized” (Brey, 2000a).

⁶ The body is almost experienced as a technological artefact which is ready to use. The way Brey writes about the body implies that he has quite a technological view on it.

⁷ Some technologies are a bit of both. Airplanes for instance create new capabilities in the sense that without planes humans cannot fly. On the other hand it enhances human capabilities in the sense that it provides faster traveling. Both enhancement of and creation of new capabilities applies to this technology.

Technology can either be a complementary or an amplificatory extension⁸. This concludes the point of view brought forth by Brey (2000a).

Although Kapp's argument did not hold, he was the first to develop a theory of technology that would be suitable for every technological artefact. Critics of his work, like McLuhan (1966), Brey (2000a), Steinert (2016) and many others, all found points that made his theory inadequate in some way. Some of these critics, like Rothenberg (1993) for instance, on their turn developed their own theory based on the initial concept of Kapp (1877) which enables the possibility to have one theory of technology, which is here referred to as extension theory, that can cover all technologies. Whether it is Kapp (1877) who argues that all technologies are based on human organs or McLuhan (1966) who argues that all technologies extend human organ functions, theories of extension try to define the concept in order for it to cover all technologies. Extension theory is in this sense as broad as possible. The difficulty with extension theory is that there is almost always some example to be found that does not fit the extension theory brought forth by an author. This has already been made clear by the various authors discussed in the previous section.

Prostheses cannot become part of the body-image

The fifth view on extension comes from Froese (2013) who argues that prostheses remain an extension. Froese does argue that prostheses should be part of the body-image though. The technology simply does not allow for something to become part of the body-image yet (Froese, 2013). For Froese (2013) prostheses still remain a mere tool for extension of the body. Prostheses can only become part of the body-image when the movement of it fits the intended actions of the user (Froese, 2013). An original "hand is adaptively coordinated with the actions of my arm and body (my fingers autonomously and correctly adjust their configuration depending on whether I am reaching for my keys or my coffee cup)" (Froese, 2013). He argues here that every original body part has some autonomy. This means every

⁸ "Prostheses replace, rather than add to, instruments in one's original 'tool set'. Prostheses may be (semi)permanently attached to one's body, in which case they become inalienable instruments" (Brey, 2000a). basically this means Brey does not include prostheses in his theory of extension. Still, Brey's work is a good reflection of extension theory in general.

body part does things by themselves. Like a liver for instance, cleans the blood from toxics like alcohol⁹. The liver does this autonomously, it is not told to do so by the mind. A prosthesis should have this little bit of autonomy in order to become part of the body-image. There is no such technology available yet. “A step in the right direction might be to design anticipatory human-computer interfaces” (Froese, 2013). This means that in the future we could become so technologically advanced that prostheses can become part of the body-image. For now prostheses remain a bodily extension (Froese, 2013) because the technology is not sufficiently developed for prostheses to become part of the body-image.

The sixth and last point of view on technology as an extension comes from Ihde (2008), who implies that prostheses remain an extension because they are not transparent but quasi-transparent. Quasi-transparent entails prostheses not providing the same information as the original body part. For instance, an artificial leg does not feel the warmth of sun-baked tarmac streets whereas an original foot does. Prostheses can give information to a person, but not necessarily the right information, not necessarily all the information and definitely not the same information as an original body part (Ihde, 2008). The information that a prosthesis provides is simply not the same as the information an original body part would provide. A distinction between intended and non-intended wrong information can be made here. An artificial leg that does not provide information about the temperature of the tarmac can be seen as unintended wrong information while a hearing aid that filters out background noise and amplifies the voice of the person which the user has a conversation with, can be seen as intended wrong information. Because of this quasi-transparency, a prosthesis is a technology which makes us increasingly cyborg. When the quasi-transparency changes towards transparency, the prosthesis would be part of the body-image (Ihde, 2008). The artificial leg for instance would transform into just a ‘leg’.

How does this theory of Ihde (2008) link with extension theory? Ihde (2008) argues that prostheses are quasi-transparent and that they, at least for now, will not become transparent. This transparency is necessary for something to be part of the body (Thompson et al, 2008). An original hand is fully transparent and therefore part of the body. Prostheses do not provide the same information that the original body part provides, which means it is

⁹ The liver has more functions, but that is not the point here.

not fully transparent. Only if a prosthesis gives the same information as the original body part, it can be part of the body-image (De Vignemont, 2011; Makin et al., 2017). Since this is not the case for prostheses according to Ihde (2008), prostheses cannot be part of the body, let alone be part of the body-image. Prostheses remain a mere tool or extension. It might be the case that technological developments would eventually allow a fully transparent prosthesis, but right now prostheses remain an extension. Both Ihde (2008) and Froese (2013) do believe that prostheses can become part of the body-image at some point.

Prosthesis as extension

The concept of extension theory is that all technologies are an extension of some human faculty. A prosthesis is in this sense also an extension of human faculty. It remains a tool, something outside both the physical and psychological bodily boundaries. It is by no means part of the body-image. The idea here is that prostheses are 'simply' an extension. It is simply an extension because it seems like there is a tendency in most authors that it is almost obvious that a prosthesis is an extension. In general, authors of theories of extension argue that technology is an extension (Kapp, 1877; McLuhan, 1966; Rothenberg, 1993; Brey, 2000a; Steinert, 2016)– and they give valid arguments as to why – while others argue that technologies cannot be part of the body-image (Ihde, 2008; Thompson et al., 2009; Froese, 2013) and therefore are an extension.

The general idea that technology is an extension of the human in some way is quite defensible, though this theory has its consequences as well. According to the general concept, like Kapp (1877), McLuhan (1966) and Rothenberg (1993) claim, every technology is an extension of some human faculties. Humans shape their environment in such a way that it meets their requirements. This shaping of their environment means the environment is not something in itself anymore, but something for humans. A park, like an office building, has a purpose for humans. A tree placed on the side of the road is therefore not a tree in itself, but a tree for human beings, since it was placed there for some reason. For this reason, the tree is no longer a natural thing but a technological artefact. In this sense, the tree would be an external means to achieve some human intention. A tree, in this sense, is a piece of technology as well.

Why can a prosthesis not be part of the body-image?

This chapter has given insight upon four different theories of extension. Two other authors have been discussed to further explain the concept of extension. This leads to an overview useful for understanding the general concept of extension theory. In essence, extension theory is about the idea that all technologies extend human faculties. Technology as an extension does not become part of the body-image. The general approach of extension theory is to argue for a theory that includes everything. This means that everything which is a technological artefact, or seen as such, is an extension of some human faculty.

What stands out is that there seems to be consensus among the authors of extension theory that extension theory should cover all technologies. Also, there is consensus that all technologies are an extension of some sorts. This is unconditional. There are no conditions presented that need to be met in order for a technology to be seen as an extension, all technology simply is an extension. The arguments back and forth are about the explanation of how every technological artefact is an extension. On this, there is no consensus.

An answer to the sub-question; why can a prosthesis not be part of the body-image? can now be given. A prosthesis cannot be part of the body-image because of two reasons. The first reason is that prostheses are an extension like all technologies, which freely translated, means that a prosthesis is an object outside the bodily boundaries. An extension is a tool; something to be used and discarded as so pleases a person. An extension is not by any means part of the body-image. This first reason is based on Kapp (1877), McLuhan (1966), Rothenberg (1993) and Steinert (2016). The second reason is that prostheses are not technologically advanced enough to be part of the body-image (Ihde, 2008; Froese, 2013).

Body-Image & Embodiment

The previous chapter focussed on extension theory, and showed that theorists of extension theory argue that prostheses cannot (yet) be part of the body-image. Extension theory differs from embodiment in multiple aspects. The biggest difference is that extension theory is about technologies that are not part of the body-image whilst embodiment focusses on the incorporation of prostheses in the body-image.

Embodiment is the process that leads to something being part of the body-image. When something is part of the body-image, it is unquestionably and undoubtedly part of the way one sees and experiences his / her own body. In this chapter this claim will be explained. First the term body-image will be explained and secondly, the term embodiment will be discussed in this chapter. After the discussion of different authors, the term embodiment can be defined as well.

There are many authors who have defined what it means for a technology to be part of the body-image. These definitions are not necessarily similar, seeing as according to Giummarra et al (2008) "Embodiment is not confined to the bodily self and may extend, for example, to a habitually used tool or prosthesis that effectively extends the body's area of influence". Murray (2008), on the other hand, makes a more confined definition of the term. He argues that embodiment is "the way in which individuals experience their own body". His definition is more specific to the individual and the body, not being so general as Giummarra's definition. Various authors in various ways use the term embodiment. The same goes for the term body-image. Merleau-Ponty's (1970), for instance, has a different definition than Brey (2000) for the term body-image. Both the terms body-image and embodiment are interpreted differently by different authors. In this section, the multitude of views on both the term 'embodiment' as well as the term 'body-image' will be elaborated on based on the existing literature. In this thesis the focus is on embodiment of prostheses in the broadest sense. The focus will not be on a specific type of prosthesis, like Lundberg et al (2011) who focusses on bone-anchored prostheses only or like Widehammar et al (2018) who focusses on myoelectric arm prostheses, but rather on embodiment of prostheses in general. This focus includes embodiment of prostheses like glasses, hearing aids and artificial legs for instance.

The theory that is explained in this chapter is that prostheses can become part of the body-image via the process of embodiment. In this chapter an answer to the sub-question; what is body-image, and how (if at all) can a prosthesis become part of the body-image? will be given. This question is twofold, first answering; what is a body-image? then answering the second part of the sub-question. Some user experiences will be viewed afterwards to see if this can give new insights and if these are coherent with the theory.

What is body-image?

According to Merleau-Ponty (1970) by means of the body-image, one's body is immediately known. When something is part of the body-image, it is without a doubt part of the way someone sees, feels, experiences and is aware of their body (Merleau-Ponty, 1970).

Merleau-Ponty's definition on body-image fits right into the essence of this thesis: to what extent can a prosthesis be part of the body-image, unquestionably part of the way one sees, feels, experiences and is aware of their body.

Brey (2000), in writing about the embodiment of technology, also defines the term body-image. The body-image is "an organizing structure contained in one's body that presents one with a unified understanding of one's body" (Brey, 2000). In essence, Brey (2000) argues that the body-image provides an understanding of what is and what is not part of one's body. Knowing the body-image provides a direct understanding of one's space of situation (Merleau-Ponty, 1970) which means "knowledge of the position of one's body parts" (Brey, 2000). This makes it possible for us to know where our arm is and how it feels. The knowledge of these things is what is called the body-image. Body-image is about those things that are directly known, felt and experienced as part of one's own body.

It seems that the term body-image then has a focus on the individual, which gives information about one particular person's body. Because of this individual focus, it seems like an arbitrary term, which differs from person to person. That means social context, gender and race of the individual can be relevant aspects for one's body-image. However, this is not the case as will be explained in the section below (these aspects are, however, important for embodiment (Murray, 2008; Lennon, 2010)). Rather, the body-image is a more general concept which does not change from person to person, as both Merleau-Ponty (1970) and Brey (2000) seem to imply. This means that differences in race, gender and social

background do not change your knowledge of what is unquestionably part of the body. This notion seems to fit people all over the world: people everywhere have a clear picture of what is part of their body-image. These individual factors (social context, gender and race) do, however, influence the way something becomes part of the body-image. Eg. They influence the process of embodiment.

Body-image is therefore about parts which are unquestionably part of someone (Merleau-Ponty, 1970; Brey, 2000). Whether it is someone's arm or someone's hip, as long as they feel and experience it as part of themselves, it is part of the body-image. Therefore, parts of which a person is not yet sure, are not (yet) part of the body-image. It might not be rational to experience a non-corporeal¹⁰ structure as part of one's body-image, but that is irrelevant for that person.

Body-image is the way in which we see, feel and experience our body (and what is part of it) and enables the way we perceive and operate in the world. For something to be part of it means someone is not complete without that something. Preester et al (2009) argue that the original body-image, e.g. the body-image one is born with, cannot be extended. This claim is supported by Makin et al (2017) who argue that the cognitive abilities of human beings are inherently constraint which makes it impossible to extend the original body-image. This means that Makin et al (2017) argue that human beings cannot embody a third arm, and Preester et al (2009) argue that a person cannot embody something which (s)he never had in the first place. The body-image can therefore not be extended. Only by replacing an original body part, something can become part of the body-image (Preester et al, 2009; Makin et al, 2017). On the other hand we have Giummarra (2008) who argues that in case of congenital amputees, prostheses can reconfigure the body-image. "Congenital limb defects occur when a portion or the entire upper or lower limb fails to form normally or does not form when the baby is developing in the uterus" (Stanford children's health, 2018). A congenital amputee is thus someone who was born with reduced limb function and / or size. Wigley (1991) would agree with the statement of Giummarra et al (2008) that prostheses can reconfigure to body-image. He argues that a prosthesis can reconstruct the body-image, transforming the (psychological) bodily boundaries with which the body-image is basically reconfigured. Given the evidence found in

¹⁰ Non corporeal things are things that are not originally part of a person's body.

the literature, Giummarra (2008) is being used to argue that the body-image can be reconfigured.

Via the process of embodiment a prosthesis can, according to the authors discussed throughout the next section, become part of the body-image. Though there is often no explicit mention of the term body-image and the meaning of the word embodiment is different for each authors, from the authors discussed in the next section it follows that embodiment is a process which can lead to prostheses becoming part of the body-image.

A term that is often used in embodiment theories is 'body-scheme'. This term refers to a more unconscious space of situation of technological artefacts, like the feathered hat example of Merleau-Ponty (1970). This example is about a man who has a big hat with large feathers on top of it. When he walks through a building, the hat does not hit anything while the man does not constantly check where the edges of the hat are. He knows where the edge is and can manoeuvre through the building based on this knowledge. This is similar to knowing where your arm is. The same man can also manoeuvre through the same building without hitting his arms on anything. This is what is called the body-scheme; immediate knowledge of the space of situation of certain artefacts and your body. This also means that a person does not feel the artefact anymore. The man is so accustomed to his feathered hat that he knows where it is like his own body parts and does not feel it anymore. This will be explained in more detail later in this chapter.

This is quite different from artefacts being part of the body-image. Preester et al (2009) claim that for something to be part of the body-image, it must be more than a tool which you do not feel anymore. The difference between body-scheme and body-image is that parts of the body-image are inside the bodily boundaries while parts of the body-scheme can be outside the bodily boundaries. Another difference is that artefacts can temporarily be part of the body-scheme, e.g. only when in use, while parts of the body-image cannot.

Now an answer to the first part of the sub-question; What is body-image? can be formulated as: Body-image is the way in which a human sees, feels and experiences the body and what is immediately know as part of the body.

Different points of view on embodiment

The first point of view in embodiment of technology comes from Gibson (1979) who argues from an ecological approach. He argues, “when in use, a tool is a sort of extension of the hand, almost an attachment to it or a part of the user's body, and thus is no longer a part of the environment of the user” (pg34)¹¹. When in use, the tool becomes part of the space of situation. It becomes a knowing part of the body. When the tool is no longer in use, the tool becomes part of the environment again (Gibson, 1979). Gibson's view on tools can be used for prostheses as well (McDonnell et al, 1989).

Gibson thus argues that a prosthesis is part of the user when in use. When it is not in use, it is again part of the environment. Embodiment for Gibson (1979) is about tools being more than an extension of the body. A tool can also become a knowing part of the body as will be explained later on in this chapter by using Preester et al (2009 and Preester (2011). Becoming a knowing part alone is not enough to be part of the body-image though. I shall clarify this with an example. John is a carpenter; he uses his hammer every day for all kinds at work. Since he is so skilled in using his hammer, this hammer gives him information (about the depth and position of the nail for instance), which makes it a knowing part. If at some point in time the hammer breaks for whatever reason, he would simply go to the store and get a new one. John would not feel as if a part of him broke, but as if his tool broke down. If John would forget his hammer at home, he would most likely borrow someone else's hammer for that day. Of course John can feel attached to his hammer to some extent, but that does not make it part of the body-image. John's hammer can be easily replaced or borrowed. The hammer is and remains a tool, and can be seen (and experienced by John) as an extension of his body. This example shows that an artefact (the hammer) is part of the body-scheme but not part of the body-image.

For something to be part of the body-image would mean that something is always an actual part of it. A hand is part of the body-image, whether it is used or not. When not in use it is still part of the body-image. The same goes for a prosthesis.

So the question is then, why can I not lend out my arm? Do I not do that when I work for someone? John for instance lends out his body to his boss in exchange for money. This sort of lending out body parts is not what is meant. But when John would have a prosthetic

¹¹ His theory will not be explained further, for it is not so relevant for this thesis.

arm, could he not lend it out to his colleague the way he lends out his hammer? The answer is obviously no. Prostheses are different from tools in this sense because they have to be personalized (like glasses, they correct the function of the eyes but the amount of correction is different for different people). Tools on the other hand, though they can be personalized, do not need to be personalized in order to work properly. This shows that lending out a tool is different from lending out a prosthesis.

To sum up, Gibson (1979) argued that tools are part of the body-image when in use. When a tool is not in use it is not part of the body-image anymore. This view is applicable to prostheses as well (McDonnell et al, 1989), which means that a prosthesis is part of the body-image when it is in use (Gibson, 1979). The example above has shown that this is not the case. The tool can however be part of the body-scheme, but not part of the body-image.

The second point of view on embodiment comes from Murray (2008) who takes the experience of people who have a prosthesis as a basis. He makes claims about embodiment based on experiences of interviewees. His main point is that perseverance in using prostheses helps overcome inconveniences of the prosthesis. This can lead to embodiment (Murray, 2004; 2008).

Embodiment is not something that stands on its own. It is influenced by a variety of aspects such as social roles, identity, society, culture, gender, racial- and ethnic identities (Murray, 2008). All these aspects influence the way in which a prosthesis becomes part of the body-image. Murray makes the connection between personal background and embodiment. In some way this makes his research arbitrary, and in other ways it makes it very useful. It can be seen as arbitrary because a different group of interviewees could bring forth different aspects and concerns regarding embodiment. This could be because of the simple fact that different people have different experiences with technological objects.

On the other hand Murray's (2004; 2008) papers confirm the relevance of his results regarding the aforementioned aspects like social context, gender and race. Murray's work also proves relevant because he sees the actual users as experts. This point of view brings forth different aspects of embodiment, aspects that broaden the ongoing discussion in the field. Since many authors, discussed later on in this chapter (Giummarra et al, 2008; Preester et al, 2009; Preester, 2011), use Murray's work, he makes an invaluable contribution to the discussion and will therefore be discussed in this thesis.

Murray argues that an analysis of embodiment of prostheses is relevant for two reasons. “First, the rehabilitation community working with prostheses users often talk of the need to transform the prosthetic limb from an ‘inert supplement’ or an ‘extracorporeal structure’ into a corporeal one”. Therefore, it would be informative to know if the prosthesis user could achieve such an experience. Second, if it is achievable, it could “aid identification, for rehabilitative purposes, of the process and steps necessary in order to achieve this experience” (Murray, 2008). Basically he argues that if prostheses can be part of the body-image, it would be helpful to know how it becomes part of the body-image. Knowing how a prosthesis becomes part of the body-image can be helpful in the process of embodiment for others¹².

Murray continues by criticizing the technological view on embodiment of Fraser (1984). Fraser argued that while organic limb movement and artificial limb movement is similar, the artificial limb is part of the body-image¹³ (Murray, 2008). This is slightly different from the argument Ihde (2008) makes. He argued that the prosthesis must be the same, not similar to the original body-part. This difference is quite significant because two different things (a prosthesis and the original body part) are almost never exactly the same, but can be similar. Ihde (2008) in this sense does not leave room for embodiment, while Froese (1984) does.

Murray argues that Fraser’s method might not be the right one, but the conclusion – that artificial limbs can be part of the body-image – might be correct. Since Fraser’s (1984) work, there have been other insights more relevant. Murray (2008) is one example of this.

A problem with prostheses, mainly artificial limbs, is that they are simply not the same as the pre-existing corporeal structure (like Ihde (2008) also argues). This can cause problems like a lack of physical strength to utilize the prosthesis properly (Murray, 2008). This leads to discomfort for the user which on its turn causes non-use (Murray, 2008). That way the prosthesis is clearly not part of the body-image. Murray claims that by perseverance in use the discomforts of prostheses can be overcome. Overcoming these discomforts can lead to embodiment. This raises the question whether or not a lack of perseverance is the same as

¹²It seems like Murray (2008) is looking for certain criteria and conditions that are necessary for / present during embodiment. Knowing these criteria means that the circumstances for embodiment for others can be re-created. This way embodiment can be optimized as a process.

¹³ This is a bit short and gives no right to the more elaborative argument made by Fraser(1984). This is however the part, in short, which is relevant for this thesis.

rejection of use, and thus non-embodiment. To clarify this, let me give an example. Michel has an intrinsic motivation to use a prosthesis. This also means he accepts any discomfort that can accompany the use of the prosthesis. James on the other hand has no intrinsic motivation to use a prosthesis. He does not like the technology. He rejects the technology not because of any discomfort, but simply because of the technology itself. If James were to practice every day with his prosthesis, he would still not like the technology itself. Because of Michel's liking towards the prosthesis he will be more likely to embody the prosthesis compared to James who does not like the technology. This example shows that both do not lack perseverance, while the embodiment experience is most likely different for both. While Michel wants the prosthesis to work, to become part of him, James does not want the prosthesis to work, nor let it become part of him. This shows that perseverance is not always an argument that can lead to embodiment. In general, perseverance could be helpful in the embodiment process, but is not necessarily the main decisive factor.

Other important aspects of the embodiment process are society, cultural background, gender-, race- and ethnic identity (Murray, 2008). Murray did not discuss these aspects in depth but only mentioned these aspects to be of influence in the process of embodiment.

To summarize, Murray (2004; 2008) argues that perseverance can lead to overcoming any inconveniences with prostheses, which can lead to embodiment. Perseverance is not the only thing though. An analysis of his interviews has led to the conclusion that society, cultural background, gender, race and ethnic identity have an important part to play in the embodiment process. It seems likely that these aspects of an individual are important to take into consideration.

The third point of view on embodiment of technology comes from Giummarra et al (2008) who discusses how phantom limbs experiences affect the embodiment of artificial limbs. They write their article with a focus on the neural and sensory mechanism of the body. From this perspective, they claim that when a person loses one's limb, the neural aspects of the limb can still be there. This means a person can still feel pain in the limb that is no longer there. This phenomenon is called phantom pain. This pain indicates that there is still such a thing as a phantom limb present. A phantom limb is a limb that was amputated, but still feels as being there and being part of the body (Cheriyedath, 2018). A phantom limb feels like it is still there and still functioning the way it normally does (Cheriyedath, 2018). As

Giummarra et al (2008) puts it, phantom limbs are “generally perceived to occupy body space, being of a particular size, shape and posture”. A phantom limb feels like it is still there for a person, but it is in fact not there because it has been amputated. This ‘still being there for the person’ seems very relevant for Giummarra et al (2008). So relevant they argue that experiencing a phantom limb might be necessary for normal functioning of a prosthesis, because the nervous system still functions like it would without an amputation. This would enable an artificial limb to be experienced as one’s own¹⁴ (Giummarra et al, 2008).

From this, it would follow that only a normal functioning prosthesis can be experienced as one’s own while a non-functioning prosthesis cannot be experienced as one’s own. A non-functioning prosthesis cannot be experienced as one’s own because the prosthesis does not provide functionality, but rather creates difficulties. A prosthesis brings along some difficulties in most cases (Murray, 2008). Difficulties that cannot be overcome can cause dis-embodiment¹⁵ (Murray, 2008). One difficulty that cannot be overcome is the non-functioning of a prosthesis. Other inconveniences like weight and easiness of use can be overcome (Murray, 2008).

This implies that the phantom limb experience is necessary for a prosthesis to become part of the body-image. Phantom limb experience only happens in case of amputation, which means embodiment can only happen in the case of the replacement of an original body part. This claim raises the question about non-visible body parts that are replaced by artificial ones. As an example, an artificial hip-bone will be used as an example. A hip is not visible and is replaced immediately by a prosthetic-hip in most cases. A person whose hip is replaced will most likely not have a phantom limb experience. Does this mean that this artificial hip is most likely not part of the body-image? In the argumentation of Giummarra et al (2008) it would probably not be part of the body-image. But as we can see later in this chapter, many others would not agree.

Another interesting implication of Giummarra’s statement is that people born with limb absence can most likely not embody a prosthesis. People born with a limb absence cannot have an experience of phantom limbs since there has never been a limb there to

¹⁴ When a prosthesis is experienced as one’s own it is not yet part of the body-image. It can however still become part of the body-image. When this sense of ownership is not felt, the prosthesis will not become part of the body-image. This claim will be explained later on in this chapter.

¹⁵ Dis-embodiment means the prosthesis will not become part of the body-image.

experience. The neural system of that specific person is not accustomed to a limb being there. Murray supports this claim (2008). One of his subjects, who was born without a limb, “judged the prosthetics forced upon her at an early age as more stigmatising than her unencumbered body. With her prosthetics she felt she looked like ‘a little Frankie’ (a Frankenstein monster), and felt more natural without them” (Murray, 2008). Giving her a prosthesis gave her the feeling of being abnormal / not being herself. She does not feel like it is normal to have a limb. Since a prosthesis’ job is to recreate an arm, the prosthesis cannot ever really be part of her. The informant does not feel like the prosthesis is to any extent part of the body-image. Her state of normality is to be without prosthesis (which in this case means living without legs and above elbow stumps). On the other hand, Giummarra et al (2008) argue that congenital amputees also report the experience of embodiment of prostheses. Murray et al (1999) found that someone with congenital amputation can also have the experience of prostheses being part of their body-image. This shows how people have different experiences with prosthetic embodiment. Personal preference¹⁶ and background seem important aspects to be considered for a prosthesis to become part of the body-image.

Still, Giummarra et al (2008) conclude that phantom limb experience may be necessary for a prosthesis to become part of the body-image. The nuance in their argument is, that for congenital amputees a prosthesis is a reconfiguration of their original body. Although Giummarra et al (2008) did not explicitly mention it, they imply that this reconfiguration of the original body makes room for the experience of a phantom limb which was not part of a person’s original body. So a person born without an arm, who is given a prosthetic arm could have the experience of a phantom limb when the prosthetic arm is not attached to the body. This means congenital amputees could also embody prostheses. If a prosthesis can reconfigure the body-image, why can any other piece of technology not also reconfigure the body? This would mean that basically every piece of technology can be part of the body-image, surely that is not what Giummarra et al (2008) mean to imply. This is however not the case as Makin et al (2017) argue. They argue that the neurocognitive abilities of human beings, regarding the embodiment of technology, are inherently

¹⁶ Personal preference is voiced by making a choice.

constrained to the normal body. This means that all parts of a normal body can be part of the body-image and that congenital amputees can embody prostheses.

To sum up, Giummarra et al (2008) argue that phantom limb experience is most likely necessary for embodying prostheses. Having this experience means the neural system still experiences the limb that is not there anymore. The prosthesis can then be experienced by the neural system as if it is the real limb.

The fourth point of view comes from Preester et al (2009) who argue that prostheses should be part of the body-image¹⁷. Prostheses should become part of the body, which can only happen under certain conditions (Preester et al. 2009). One condition is that a “prosthesis becomes a knowing part, in other words, something that shares in the knowledge of the body” (Preester et al, 2009). A knowing part of the body is a part of the body which shares in the knowledge of the body and something which withdraws in the sensory and motor system of the body. Eyes for instance provide information about location, colour and movement, they are part of the sensory and motor system of the body. Eyes are therefore a knowing part of the body. The same can be said for a hand or a leg. For something to be part of the body-image, it must be more than a knowing part. Embodiment is about more than withdrawing in the sensory of the body – like in Merleau-Ponty’s (1970) example of the blind man’s cane¹⁸ – or to share in the bodily knowledge (Preester et al, 2009). The reason for this, they argue, is that tools share these characteristics (withdrawing in the sensory system and share in bodily knowledge) but tools are not part of the body-image.

An additional characteristic of prostheses is that one becomes so accustomed to it that one does not feel it anymore. The person using the prosthesis does not constantly feel the prosthesis, (s)he is not constantly aware of it. This is a phenomenon which also occurs

¹⁷ In this statement they claim there is a goodness of some sort in the embodiment of prostheses. They leave out as to why prosthesis should be part of the body-image, other than stating there is a tendency in many authors to claim that prosthesis should become part of the body-image. Thus Preester et al (2009) claim that embodiment of prosthesis is simply good. Because prostheses are good, they should become part of the body-image.

¹⁸ The blind man’s cane of Merleau-Ponty (1970) is an example about a blind man whose cane becomes a part of his sensory system. Imagine a blind man who uses his cane to determine his position in the house, street and pub for instance. The cane not only reveals his position to him, but it also gives him information about any obstacles that might be in the room. Non-blind people would use their eyes for this in most cases. The cane of the blind man – just like the eyes of a non-blind man – is part of the sensory system of the man. It provides sensory information to the blind man about his environment. This example shows that non-bodily parts can become part of the sensory system of a person.

with bodily parts. A person is not always aware of his/her arm, they know it is there but simply do not feel it's presence all the time. Preester et al (2009) found evidence for this in the work of Murray (2004). Murray's work describes an interview of a man who says that he is surprised of how little he feels his prosthesis. The absence of feeling this prosthesis is a phenomenon that is commonly observed with original body parts (Merleau-Ponty, 1970). Preester et al (2009) pose the question as to whether this (not feeling the prosthesis) is enough for something to be part of the body-image. Again they use the argument of a tool that "can feel close to not being there" (Preester et al, 2009). Let me use an example here to explain the argument. Imagine Lucy, who is a secretary with a primary task to respond to phone calls. She receives over one hundred phone calls a day and each call takes an average of 3 minutes. That means she is on the phone for at least five full hours a day. Lucy uses a hands-free phone set, one that is attached to her ear, so that she has both hands free. Lucy is very accustomed to this hands-free phone, so accustomed that she sometimes forgets to take it off at the end of the day. This shows that Lucy does not feel the hand-free phone anymore. It is not a part of her, but she does not feel it being there. It also shows that a tool can feel close to not being there, which means that a prosthesis needs to be more than that in order to be part of the body-image. Lucy's headset is part of her body-scheme, but not of her body-image.

Becoming a knowing part implies that a prosthesis should, to some extent, replace the sensory system of the part it replaces. This is in line with Giummarra's et al (2008) work presented earlier. The presence of a phantom limb means the presence of the sensory system - at least a part of it. The amputated limb had a sensory system, which was removed together with the limb. The sensory system of the limb is still felt as if it is still there. This phantom limb feeling – which can be considered a void – can be filled with a prosthesis. This is the second condition that is given in a later work of Preester (2011); a prosthesis can only be part of the body-image when it replaces a corporeal structure. This means the body-image does not change or extend, but parts of it are being replaced. An important implication of this condition is that the body-image cannot be extended. Preester et al (2009) even claim that there is no such thing as a prosthetic extension of the body-image. A prosthesis is part of the body-image, or remains a tool. There is a fine line that separates the two, but there is no extending the body-image.

The third condition is that one must feel some sort of ownership over the prosthesis (Preester, 2011). The same way that someone would say 'this is my hand', (s)he would say the same about the prosthesis. That feeling of ownership is required.

Preester et al (2009) and Preester (2011) argue that prostheses should be part of the body-image. Summarizing the above: there are three conditions for this: the prosthesis must become a knowing part, must not be felt all the time and the user must have a sense of ownership. As explained above, this means a prosthesis can only be part of the body-image when it replaces an original body part. This way the prosthesis can use the pre-existing sensory system as if it was there, and fills the void of the missing body part.

Basically embodiment, for Preester et al (2009) and Preester (2011), is about being more than a mere tool. Each condition which they give is reflected on tool-use. If the same is true for a tool, there must be more to embodiment of prostheses. Preester et al (2009) and Preester (2011) are looking for something which separates prostheses (that can be part of the body-image) from tools (that cannot be part of the body-image). They found the difference to be that tools do not replace original body parts while prostheses can. Embodiment is therefore about incorporation of non-corporeal structures that replace original body parts into the body. The example of the hip earlier is a good example of a non-corporeal structure, which is put inside the body to replace a body part. This artificial hip could be part of the body-image according to Preester et al (2009) and Preester (2011) as it meets the conditions discussed.

The fifth and last point of view comes from Makin et al (2017) who focusses on improving the effectiveness of augmentation technology by focusing on embodiment. For Makin et al (2017) embodiment is "the ability to process information through external objects at the sensory, motor and/or affective levels in the same way as the properties of one's own body parts". This means that if the information a prosthesis provides is processed in the same way as the pre-existing corporeal structure, the prosthesis is part of the body-image.

Makin et al (2017) argue that human cognitive capacities are inherently constrained. This means that difficulties occur when something is added to the body. A thing added to the body is what they call augmentation technology, which is not a prosthesis like it is defined in the introduction but an improvement of the body. For prostheses however, Makin et al (2017) see no real problems as to why it cannot be part of the body-image. Only for

augmentation technologies the limitations of human cognitive capacities need to be taken into account.

Makin et al (2017) argue that embodiment of augmentation technology is not possible because of human cognitive constraints. There have however, been cases where perseverance has led to use of three limbs at the same time (Utterback, 2004). This person learned to write a word on the wall using three hands at the same time. This person might prove the contradiction of Makin's et al (2017) claim.

As can be seen from this, research and development on prostheses is still very much relevant. However interesting the topics are that are brought up by the human augmentation vs replacement debate, we will not be going into the topic of human augmentation for the sake of this thesis. This would be an interesting topic for further research.

Definition of embodiment

Now that the most relevant views on embodiment have been discussed, a definition of the embodiment for this thesis can be made.

The way in which something becomes part of the body-image is through embodiment. Embodiment is concerned with many things like race, gender, social background, personal beliefs and replacement of body-parts. According to the different authors prostheses can become part of the body-image via perseverance (Murray, 2004, 2008), only when in use (Gibson, 1979), only under certain conditions (becoming a knowing part; ownership; multisensory integration; replaced bodily parts only) (Preester et al, 2009; Preester, 2011), only when the prosthesis replicates a normal body part (Makin et al, 2017) and possibly only in combination with phantom limbs or when the prosthesis reconfigures the body-image (Giummarra et al, 2008). These authors, besides providing separate definitions of embodiment, show how prostheses could be part of the body-image. Embodiment is thus defined in this thesis as: the way in which something becomes part of the body-image, in a spatial, functional and emotional sense. The obvious question is then, how do prostheses become part of the body-image?

There are different ways in which prostheses could become part of the body-image as the different authors in this chapter show. These descriptions share some similarities, but

there are also some notable differences in views. In the following, the definition of embodiment will be constructed from the resemblances in the five points of view that were explained earlier in this chapter.

The first similarity in these papers is that embodiment can only be achieved when the prosthesis resembles a part of a normal body (Murray, 2004, 2008; Giummarra et al, 2008; Preester, 2011; Makin et al, 2017). People who are born with reduced bodily functions could also embody prostheses according to this argument. The second similarity, brought forth by Giummarra et al (2008), Preester et al, (2009), Preester (2011) and Makin et al (2017), is that a prosthesis can only be part of the body-image when it is experienced the same way as an original body part. When it is experienced the same way as the original body part, the prosthesis can become a knowing part as Preester et al (2009) and Preester (2011) define it.

These two similarities are most relevant for embodying prostheses. By perseverance in use, like Murray (2004, 2008) argued, the process of embodiment can also happen. By simply attaching a new arm, it is not immediately part of the body-image¹⁹. Such processes take time, it is like a relationship between humans; you do not (in most cases) immediately marry someone you see for the first time in the western world. Perseverance in use is therefore helpful in speeding up the embodiment process. Somewhere in the process of embodiment a person can realize (s)he does not feel the prosthesis anymore (which is a common thing with original body parts). This is not a condition however for embodiment, it is a result of long-time use of the prosthesis. This is why tools that are used very extensively can also feel like not being there, as the example of Lucy (the secretary with the headset) showed. At some point in the process, a person will develop a sense of ownership over the prosthesis as well, like Preester (2011) argued. This however, is not a condition but a result. At some point a person will say, this is mine (prosthesis). Later in the process a person could say, this is my arm. So, embodiment is the process that leads to prostheses becoming part of the body-image.

¹⁹ Under the circumstance a prosthesis can be made for the individual.

How (if at all) can a prosthesis become part of the body image?

In this chapter five views on body-image have been discussed. These views were quite coherent. The term body-image was defined, by several authors, as things (including body parts) which are unquestionably felt, seen and experienced as part of one's body. When this thing is not present anymore, a person feels incomplete. As if losing a leg in an accident: without the leg the person does not feel complete.

Secondly, in this chapter five different views on embodiment have been discussed. These five views have been criticized and compared to each other. It became clear that there are some arguments that have been used by different authors, in different contexts. These arguments have been translated and compared in this chapter to define the way prostheses can be part of the body-image.

An answer to the second part of the sub-question can be formulated here; How (if at all) can a prosthesis become part of the body-image? The answer to this question is simply via embodiment. Embodiment of prostheses is not something that happens by simply giving a person a prosthesis. This process takes time. However long this takes, if it occurs at all, depends on a variety of aspects that are mostly related to a specific person. Some of these aspects concern the society that a person lives in; cultural background, gender, race and ethnic identity. Based on theorists of embodiment it is argued that the process of embodiment can only start when the prosthesis resembles a normal body part because of restrictions in human cognitive abilities. This does not mean that people who are born with reduced bodily functions cannot embody prostheses. As the combined argument of Giummarra et al (2008) and Makin et al (2017) show, prostheses can reconfigure the body-image which makes room for the possibility of embodiment of normal body parts. Another requirement for a prosthesis to become part of the body-image is that it must be experienced the same way as a normal body part. Eventually the prosthesis can become a knowing part of the body. Accordingly, a person will get the sense of ownership over the prosthesis, a sense of ownership similar to the sense of ownership over the original body part. As the prosthesis is in basis not a natural body part, a person needs to get familiar with the prosthesis. This can be done by perseverance in use (Murray, 2004, 2008). Somewhere in this process a person does not feel the prosthesis anymore, while it is still there. This is an experience that is very much observed with original body parts.

Now that the theory of embodiment is explained, user experiences are viewed to see if these experiences can bring new insights and whether or not these experiences are somewhat coherent with the theory.

Embodiment experiences

Elizabeth Wright (2009) is an artist who wrote about her experience as a prosthetic user. In doing so, she discusses prostheses in both a semi-philosophical and in an artistic manner. The most interesting passage for this thesis is the following.

“I have congenital limb deficiency: my right arm and leg are both shortened, and I procured a prosthetic leg and arm as a toddler. During this process of adjusting to and incorporating prosthetic limbs into the schema of my body²⁰, I rejected the prosthetic arm and accepted the prosthetic leg. At this young, tender age, I made a functional and aesthetic choice as to the integration of objects into or onto my body. In full rejection of the prosthetic arm I was rejecting not only its supposed functional purpose, but also its true symbol of “normalisation” of my body – the synchronisation of my body. The prosthetic leg, however, was accepted, not just as a functional object that enabled me mobility, but also on an aesthetic and phenomenological level. It has become an integral part of my identity” (Wright, 2009).

Wright (2009) describes here that a prosthesis (a prosthetic leg) has become part of her body-image while another (the prosthetic arm) was rejected by her as such. This case is interesting for a number of reasons. First of all, Wright suffered from congenital limb deficiency. This means Wright never had the experience of having a fully functioning arm or leg. The prostheses she received were more than she ever had. She had half an arm and leg, and with the prostheses she has a full arm and leg. It is therefore hard to make the claim that she really replaced an original part of her body. So how could she have let a prosthesis become part of her body-image? Here the argument of Giummarra et al (2008) and Makin et al (2017) provide the answer as explained earlier in chapter 2. A prosthesis can

²⁰ This is what I call body-image.

reconfigure the body-image (Giummarra et al, 2008) in order for that prosthesis to become part of it. Though not every prosthesis can reconfigure the body-image, only those parts of a normal body (2 legs, 10 fingers, 2 arms, 1 head and 2 eyes for instance but not a third arm, eye or leg), because human neurocognitive abilities are inherently limited (Makin et al, 2017). Most humans are not able to let parts that are not part of a normal body become part of their body-image. For Wright, her prosthetic leg reconfigured her body-image in such a way that the prosthetic leg became part of her body-image. She thus has the neurocognitive capacity to let a part, which is part of a normal body, become part of her own body-image.

The second point of interest, repeated by Wright (2009), is that she received the prostheses when she was very young. This, for her, seems an important issue while it does not seem to be an important issue for most users. Murray (2004,2008), who conducted multiple interviews with prosthetic users (experts), did not find evidence of this. One of his interviewees even posed the exact opposite: she felt like a little Frankenstein monster with her prosthesis that was given to her at a young age, as explained in this chapter. The difference between Wright and the interviewee is that the interviewee did not have any limbs to start with. Still, this shows embodiment is a matter of personal preference.

The third and last reason rendering her case interesting is that she received two prostheses, a leg and an arm, of which she chose to let only one become part of her body-image. Wright (2009) describes she chose to let her prosthetic leg become part of her body-image, and not her prosthetic arm. The key here is in the word 'choice'. This shows that, like with the example of James and Michel, personal preference plays an important role. This goes further than what Murray (2004, 2008) argued about social roles, identity, society, culture, gender, racial and ethnic identities. Wright's passage shows that it comes down to personal preference (choice), which is of course influenced by the aspects Murray (2004, 2008) noted. Interestingly enough, her personal preference led her to embodying only her prosthetic leg and not her arm. This shows how important choice in the process of embodiment is.

Another user experience case is the one of Danielle (Express, 2018) (the girl who wants to amputate her other healthy leg). She also poses an interesting case is the sense that she chooses what parts can and cannot be part of her body. Although her case shows signs of augmentation rather than prosthetics, she clearly makes a choice in which parts she wants to be part of her body-image. She sees her body in a rather technological manner.

This becomes clear by the way she speaks about her body. Her original leg is holding her back in achieving her goals, whilst her new leg allows her to achieve her goals. The new leg is, in her mind, thus better suited for her. She would prefer to remove the original and replace it. She does not like her original leg anymore and therefore it does not really feel like it is part of her anymore. She would rather have a prosthetic leg be part of her body-image than her original leg. She clearly chooses which parts can and cannot be part of her body-image.

Another case that shows the importance of choice in embodiment is the case of an interviewee of Murray (2008) discussed earlier in this chapter. She reported to feel like ‘a little Frankie (Frankenstein monster)’ when wearing her prosthesis. Because of this, she chose to not use her prostheses, and does not see them as part of her body-image. She tried using the prostheses enough to argue that it was not a lack in perseverance in use that caused her to not embody the prostheses. She most likely made the choice for herself that she does not want the prostheses to become part of her, they do not feel like part of her nor will they ever feel as such. In the spatial sense, a prosthesis can reconfigure the body-image (like Giummarra et al (2008) argued) in order for the prosthesis to become part of it. For congenital amputees (like Wright (2009) and the interviewee of Murray (2008)) a prosthesis can basically expand the bodily boundaries (though only so far as the boundaries of a normal body because of restricted neurocognitive capabilities (Makin et al, 2017)). This means replacement is not the only starting point for the process of embodiment. It seems like reconfiguration of the body-image is not for everyone though. Murray (2004) for instance found that the congenital amputee he interviewed did not show signs of embodiment. Given the restricted neurocognitive abilities a human being possesses (Makin et al, 2017) and the important factor of choice, it is not irrational to assume not everyone can, wants or chooses to reconfigure their body-image so a prosthesis can become part of it.

A very clear example of a prosthesis which has become part of someone’s body image is an interviewee of Lundberg et al (2011) who says “There is something missing, one part of me is missing and I miss it physically in a way I haven’t done before, not after the accident either. And this happened after I got the prosthesis (OI-prosthesis) that is more me than ever, that makes me feel more whole as a person”. This is a clear example of a person who has incorporated a prosthesis in his body-image because he states that he feels complete with rather than without his prosthesis. Other interviewees of Lundberg et al

(2011) make similar statements such as: “I don’t think about having the prosthesis in that it doesn’t feel like a prosthesis. [...] It has come so far that the brain has also gradually begun to believe that I have a real leg”. Other interviewees give similar statements that all show that it is in fact possible to have a prosthesis which is part of the body-image. This is not as simple as it might seem. Some interviewees also had some struggle with their prosthesis. A good example of this is the interviewee who stated “The other prosthesis ruled my life, it was my master in a way, it’s inevitable ... it affected my mood and my interest in doing things that I knew would demand an extra effort. You had to weigh the pros and cons and that’s all gone now. Now it’s actually me ...I am in command and not the left leg (S-prosthesis) and that’s a big difference” (Lundberg et al, 2011). This interviewee had to overcome the difficulties that accompany most prostheses. This is what Murray (2004, 2008) also wrote about. By perseverance in use, and eventually getting another prosthesis, the interviewee was able to let the prosthesis become part of the body-image. Interestingly these interviewees all got a prosthetic limb of some sort, which could become part of their body-image. None of these users report anything about prostheses like hearing aids or glasses. This could have two reasons; the first reason is that these kinds of prostheses cannot become part of the body-image according to the theory explained in chapter 2. Secondly, users of this type of prostheses are not taken into consideration in the research. In any case, the finding that only part of a normal body can become part of the body-image is coherent with the literature presented earlier.

Though not all three cases mentioned above show that a prosthesis has become part of the body-image, they do show that choice in the matter is a decisive factor. Other researches on prosthetic embodiment (Widehammar et al, 2018) also show that personal preference towards prostheses is quite an important factor. Many of the interviewees in Lundberg et al (2011) and Widehammar et al (2018) mention that personal preference and therefore choice is a decisive factor for being able to let a prosthesis become part of the body-image. Because this choice is such an important factor, it is not illogical that not everybody lets prostheses become part of their body-image. Some people simply choose to not let a prosthesis become part of their body-image.

Conclusion

In the previous chapters, it has been made clear what extension and body-image entails. Chapter 1 explained the concept of extension theory. This chapter discussed authors who advocate this theory and advocate that prostheses cannot be part of the body-image. Extension theorists in general argue that all technological artefacts are an extension of some human faculty. From this point of view a prosthesis remains a tool which is not part of the body-image. The first chapter answered the sub-question; why can a prosthesis not be part of the body-image? Chapter 2 continued with explaining the term body-image. Body-image means everything which is unquestionably part of the way someone sees, feels and experiences their body. The way in which something becomes part of the body-image is through embodiment. Embodiment is a process which takes time and effort. This process is likely to accelerate if the prosthesis replaces an amputated body part and / or by perseverance in use. Theories of embodiment presented in chapter 2 showed how a prosthesis could become part of the body-image, but did not show that a prosthesis can become part of the body-image. The user experiences that were also presented did show that some people have a prosthesis which is part of their body-image. The user experiences are quite coherent with the theory of embodiment. One thing stood out in these user experiences, which is that personal preference is an important factor in the process of embodiment. The two general theories are quite different from each other but there is a connection between these theories that is helpful in answering the research question. Both theories are also briefly criticised.

Linking extension and embodiment

In short, extension theory is concerned with all technologies being an extension of human faculty while embodiment is about prostheses becoming part of the body-image. There are two major differences between these two concepts. The first difference is that embodiment is about specific technologies (prostheses) while extension is about all technologies. The second difference is that an extension technology is something that is not part of the body-image, while embodiment is about how technologies can become part of the body-image. There is a third difference in extension and embodiment. Both extension and embodiment

are about the location of a prosthesis compared to the body. Extension theory sees prostheses as outside of the bodily boundaries while embodiment is concerned with letting a prosthesis be perceived inside the bodily boundaries. Though the actual location of the prosthesis is the same, the psychological location is different. This is quite a big difference between extension and embodiment, the starting point of where to place technology compared to the body is directly opposite in both approaches. This is one reason that these theories cannot both be used for the same technology. Let me explain this in more detail.

As described in chapter 2, Preester (2011) argues that for something to be part of the body-image it must be more than a tool. In her paper she seeks the things that really distinguish a tool (or any other kind of technological artefact) from a prosthesis that is part of the body-image. Gibson (1979), Murray (2004, 2008), Ihde (2008), Preester et al (2009), Preester (2011) and Froese (2013) would all agree that embodiment is about a technological artefact which is more than a tool. All of these authors have their own point of view on this matter and would not all agree that something can, in fact, be part of the body-image. They would agree though, that for something to be part of the body-image, it must be more than a tool or any other technological artefact.

According to Kapp (1877), McLuhan (1966), Rothenberg (1993) and Steinert (2016) all technological artefacts are an extension of human faculties. Although these authors differ in their beliefs as to how exactly technological artefacts extend human faculties, they all argue that all technological artefacts are in a way an extension.

So first, for something to be part of the body-image it must be more than a technological artefact. Secondly, all technological artefacts are an extension of some sorts. Following logic, this means that for something to be part of the body-image, it must be more than only an extension. Next, it could be argued that a prosthesis can be both an extension and can be part of the body-image. There is only one problem here. When something is an extension, it is not part of the body-image. Prostheses can therefore not be an extension and be part of the body-image. This means that when a prosthesis is part of the body-image it is not an extension anymore. Basically this means almost all technologies are an extension, only those who are part of the body-image are no longer an extension.

Comment on extension and embodiment

These theories have been discussed from the view of the authors arguing in favour of these theories. This does not mean that these theories are without criticism. For instance, Kiran et al (2010) criticized extension theory on multiple aspects. One of these points is that extension theory inadequately exposes human technology relations. Heersmink (2012) on his turn, defended extension theory against criticisms of Kiran et al (2010). Regarding the aforementioned criticism, they reply that extension theory adequately covers the human technology relations. There are several authors who criticize either embodiment or extension theory, and again also several authors who, in turn, defend the approaches. These were left out intentionally because these critiques back and forth lack constructivism in answering the research question. However, both theories do have some downsides that require mentioning.

Based on the insights this thesis has given, it does not hold that every technological artefact is only an extension. Clearly, there is something else as well. Wright (2009), Danielle (Express, 2018) and interviewees of Lundberg (2011) and Widehammar et al (2018) all show the experience of having a prosthesis which is part of their body-image. Extension theory does not readily offer an explanation for this. The general approach of technology as an extension is not suitable for all technologies. There is enough evidence that prostheses can become part of the body-image and are, therefore, no longer an extension.

Among theorists of embodiment, on the other hand, it seems there is no consensus about how prostheses can become part of the body-image. This is shown by the diversity in various authors discussed in chapter 2. In their work, there were many different views on whether and how prostheses (or other technologies) can become part of the body-image. Many different points of view show that there is no consensus in how a prosthesis actually becomes part of the body-image. More research might help to create a strong theory of embodiment.

Ultimately, there is truth in both theories. Most technologies are an extension, and prostheses can become part of the body-image. It must be said here that Brey (2000a) mentioned this, though he did not mention how prostheses can become part of the body-image. This leaves only the research question unanswered.

Conclusion

User experiences have shown that some people have incorporated a prosthesis in their body-image. Link between the presented cases and the literature was made in order to see if they are coherent. This leaves only the research question unanswered.

The research question of this thesis is as follows: To what extent is a prosthesis part of the body-image? Not all prostheses can become part of the body-image, only those that replace a missing part of a normal body. A prosthesis can in fact become part of the body-image for a congenital amputee as well as an amputee, but things like glasses and hearing aids cannot become part of the body-image. The most important aspect in letting a prosthesis become part of the body-image is personal preference. A person can choose whether or not that person wants a prosthesis to become part of their body-image. It is, however, by no means a certainty that a prosthesis becomes part of the body-image. In the process embodiment there are some things that can help to speed up and / or increase the likelihood of a prosthesis becoming part of the body-image. One of these things is when the prosthesis replaces a part of the body which the individual naturally had. So when someone loses his / her arm, the prosthesis that replaces the arm is more likely to become part of the body-image. During the process of embodiment, perseverance and the experience of a phantom limb can also help to speed up and / or increase the likelihood of a prosthesis becoming part of the body-image.

The most significant discovery of this research has been that someone's personal preference – and therefore choice – plays a decisive role in whether or not something can become part of the body-image.

Summary

This thesis started by introducing the body and different point of view one can take on it. After choosing the body-image view the term prosthesis was explained since many different definitions exist. The definition of the term prosthesis was defined as a technological artefact that reproduces or restores normal human bodily functions for an individual. Chapter 1 introduced various points of view that argue a prosthesis cannot be part of the body-image. One of the two general approaches in this chapter was extension theory, where the general argument is that all technologies are an extension which means technologies are

not part of the human but the environment, and authors who claim prostheses are not (yet) developed thusly that they can become part of the body-image.

The second chapter continued to explain how prostheses are able to become part of the body-image. The term Body-image itself was also explained in more detail. It was defined as the way one sees, feels and experiences his / her own body and what is part of it. The way in which a prosthesis can become part of the body-image is through the process of embodiment. This process is explained in chapter 2. Basically the authors explain how something could become part of the body-image, but not necessarily claim that prostheses can become part of the body-image. The final step towards formulating an answer to the research question was to include user experiences. These user experiences showed that prostheses can become part of the body-image. The most important factor for letting a prosthesis become part of the body-image is personal preference and therefore choice.

After having explained extension theory and embodiment theory, a comparison of both theories could be made. In explaining these differences it became clear that there are already people who have a prosthesis, which has become part of their body-image. Sticking to extension theory therefore does not hold. This means that almost all technologies are an extension of some human faculty. A prosthesis, however, can also be part of the body-image which means that it is not an extension anymore.

This led to answering the research question of this thesis; to what extent is a prosthesis part of the body-image? The answer is basically that prostheses that replace parts of a normal body can become part of the body-image if a person chooses to let it become part of their body-image. Some other aspects (like perseverance in use) can help speed up the process of embodiment.

Limitations, future recommendations and practical use

This research has some limitations since there no new information has been presented. Information, which was available, has simply been merged and compared. Though the input information is not new, the outcome of this research is useable. The outcome of this thesis can be used to improve the prostheses. First of all, this thesis has illuminated the bottleneck in the process of embodiment, which is the user, the one for whom the prosthesis is made in the first place. This insight can help improve the experience of users of prostheses in

multiple ways. First of all, a more psychological perspective of the matter can be an interesting viewpoint for possible further research. This could provide insight in how the process can be adjusted so that prostheses are more likely to become part of the body-image. Another improvement could be to simply explain to the user how important his / her choice in the process of embodiment actually is. Opening the debate with the user could also bring to light more things that could aid the process. It must be noted that the conclusions from the user experiences, which are a large part of the conclusion of this research, is based on a rather small group of users. It is recommended that the practical use be combined with a form of research so that the conclusion can be finetuned or more substantiated. The proposed research here is the following; explain new users of prostheses that their own choice is important (this is the practical use of this thesis) and observe the results of this compared to a group to whom this information is not given. This research could make this thesis' conclusion stronger.

The second improvement stems from a mechanical engineering perspective. In designing prostheses, the engineers could for instance develop a more customizable design so that every prosthesis could better fit the demands of a specific individual. This way a person could be tempted in wanted to let the prosthesis become part of the body-image.

So the practical use of this thesis is for both engineers and medical staff who contribute design and implementation of prostheses.

An interesting study might be to immerse into the opinions of people who do not feel like the body they are born with fits in their body-image. There are cases of people who feel overcomplete for instance. From one point of view, the natural body can be seen as a collection of parts or a collection of functionalities. When someone sees their body as a collection of parts or functions, those parts or functions could be exchangeable. In this thesis, I assume that a person's body is already part of the body-image. But one could argue that the body needs to become part of the body-image as well. It is not necessarily pre-given that a body itself is part of the body-image.

Another research that might give interesting insights would be to examine experiences of users of non-bodily prostheses. Non-bodily prostheses can be considered as, for instance, hearing aids, glasses and pacemakers, things that are not part of a normal body. Basically to actively seek people who use non-bodily prostheses and see what signs of embodiment they show. This could then be linked to this research and investigate if Makin

et al (2017) for instance are right to argue that these non-bodily prostheses cannot be part of the body-image.

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