Bionic Limbs and Body Ownership:

Conceptualizations about the body and the relation of the users with bionic limbs

By

Marinakis Yannis

Master Thesis

Submitted to the Faculty of

Behavioural, Management, and Social Sciences

of the University of Twente

for the Master of Science degree

in

MSc Philosophy of Science, Technology, and Society – PSTS

Supervisor: Prof. dr. Ir. P.P. Verbeek

Assessor: dr. Marianne Boenink

November, 2016

Abstract

This thesis answers to the question: Considering discussions from the phenomenological tradition and postphenomenology theoretical framework regarding body perception, how do bionic limbs urge us towards new understandings about body ownership? In order to answer to this question, the text is divided in three main chapters: First, I examine the multiple levels of difference between traditional prosthetic limbs and bionic limbs by providing a historical overview of prosthetic limbs and the current agentic nature of bionic limbs. Second, supported by scientific evidence regarding the perception of prosthetic limbs, I examine how an analysis from the theories of Merleau-Ponty would approach the perception of prosthetic limbs. I argue that his theory is insufficient and provide three critical points, two of them are found in literature and one is my contribution. Third, I analyze bionic limbs from a postphenomenological point of view and, I also use empirical research found in literature to support my claims. Specifically, I argue that due to the multiple levels of agency and experience bionic limbs may incorporate or provide a more suitable approach would be to conceptualize the body ownership of users of bionic limbs as hybrid. For this purpose, I introduce the term 'hybrid body ownership', which summarizes the experience of the discrepancy in meanings among involved actors regarding what can be a non-corporeal body part, the other actors' agency, and the experience of bodily owning something that is not completely yours.

*Keywords***:** Prostheses, Bionic limbs, Phenomenology, Postphenomenology, Body Ownership, Hybrid Body Ownership

Acknowledgments

And if you find her poor, Ithaca won't have fooled you.
Wise as you will have become, so full of experience,
you will have understood by then what these Ithacas mean.
Cavafy, C.P. (1984). Ithaca.

This thesis would be incomplete without acknowledging the contribution of certain people outside the writing process. Moving to a new country and studying in a non-native language can be factors of stress. Despite that, the University of Twente (1961) provides the necessary facilities and the trained staff to accommodate the needs of its students. Although most of the professors have contributed in feeling more comfortable in the learning process, Johnny Soraker is one of the most approachable professors, and with his welcoming and inspiring teaching has eased a part of this process. Johnny keep up the inspiring work. Also, Marianne Boenink's thoughtful comments to earlier versions of this text contributed in giving to it a better-constructed argument. One of the reasons that I chose the University of Twente to pursue my master's degree was due to the fact that on my previous studies I had read Peter-Paul Verbeek's work on Philosophy. In September 2014, his introductory course to the fundaments of the philosophy of technology did inspire me and assure me that I had made a good choice. It was a year and a half later that he approved my request to be my thesis' supervisor. Despite his heavy schedule in doing things that matter, he has provided me with invaluable insight and knowledge which shaped my thought and most importantly have provoked the birth of new thoughts that are fundamental in writing approximately 70 pages.

On a more personal note, I believe that our life is shaped from all the experiences we have accumulated from our previous years. In this sense, I could write a whole book on how deeply, and often unknowingly, different persons have inspired me but I will leave this task for another time. However, I can briefly mention that my time in Enschede would have been immensely different if I had not encountered the friendship of Chirag, Jurjen, and Thijs, and of members from the local Greek community, among others Savvas and Dimitris. To a greater extent, this master and this thesis would not have been completed without the care that my family has given me over the last two years and a quarter of a century before that. To my siblings, each of you have contributed in your own way in making things easier. To my parents, without whose trust I would have had a very different life now, a plain 'thank you' seems rudimentary yet I know that its written form seems somehow significant to them, Μαμά, Μπαμπά, ευχαριστώ. Last, I would like to thank Raia for accompanying me on our journey, which like Homer's ones, can offer miracles and wonders when not intimidating us before it returns us to whatever is to be called a home.

Table of Contents

Chapter 1 – Introduction

Prostheses, as a term, can include different technologies, devices, or artifacts. Coming from the Greek verb προσθέτω, which translates to 'to add', prosthesis can mean anything that is added to one's body. In that sense, it can include prosthetic dentistry implants, cochlear implants, contact lenses, artificial limbs, or any other integrated or detachable technology. In recent years, prostheses have had noticeable developments. Only a few decades back, prostheses were mostly rigid artifacts and the main interest regarding them was how to make the technology more comfortable and more functional for the user. A series of social, engineering, and scientific developments have created numerous devices that are highly functional – compared to the older ones – and technologies that attach to the body in different ways. However, due to the recent and largely different developments among these technologies, I would consider it a misconception to focus on each technology separately because each technology relates in different terms with the user, has different meanings embedded in it, and often results in different approaches on how to solve emerging issues. This thesis will not examine each of those technologies separately, nor should it as I believe, and certainly will not have a generalized conclusion that would be the same for every prosthetic technology. Hence, this thesis will not focus on prostheses in general but on prosthetic limbs.

One of the reasons that the focus will be on prosthetic limbs instead on prostheses in general, is that each technology has different purposes, uses, and carries different meanings. To this extent, a deeper focus will be on bionic limbs instead of on traditional prosthetic limbs. Nowadays, a prosthesis user can find a great variety of prostheses on the market. While throughout history prosthetic limbs were mostly plain artifacts, like wooden limbs or metal crafted artifacts, in today's market a user can acquire a prosthetic that can have an artificial skin, which actively provides sensory feedback, embedded microprocessors, which calculate the movement and adapt the mechanisms to make the movement smoother, myoelectric control over the prosthesis, and a huge variety of different technologies, which will be examined in the first chapter. These technological advances require a separate philosophical analysis because, as I will show in more than one level, traditional prostheses and bionic limbs require different approaches. Hence, bionic limbs have a priority in this analysis.

Overall, the purpose of this thesis is to understand and describe how the use of bionic limbs should push our conceptual boundaries towards new directions. With this work, I do not desire to provide a normative opinion regarding what we should do with the development of bionic limbs and the relevant technology, but rather to create new concepts which would question our current theoretical framework about the user, the technology, and the involved agency of other actors. Ultimately, this thesis explores the dynamics involved with the different conceptualizations about body ownership, and how they are

questioned by users and other involved actors. This exploration will take places on three separate but related levels: how bionic limbs differ from other prosthetic limbs; how the complex dynamics of society's actors are involved with the technology; and how the technology is itself perceived by its users

1.1 Social relevance of this research

While prosthetic limbs exist for hundreds of years and have different variations, scopes, and meanings, bionic limbs are a relatively new technology. At the same time, medical issues related to the use of prosthetic limbs seem to make their use a growing trend. Blood circulatory deceases, cancer-related illnesses, and amputations due to accidents or wars create an environment where prosthetic limbs become more and more important for the society (Jain & Robinson, 2008; Kurichi, Bates, & Stineman, 2010; Ziegler-Graham, MacKenzie, Ephraim, Travison, & Brookmeyer, 2008). Especially for bionic limbs, there are promising estimates about the market's economic growth for the next years (Saenko & Todorovic, 2015). The prevalence of the medical reasons push scientists, engineers, and medical personnel to have a better understanding of the technology and what they can offer to improve the use of bionic limbs. In this direction, scientists and engineers push to improve the technology in every different aspect. From how to be more comfortable to the user to how to make bionic limbs look more humane, more mechanically efficient, or to look more robotic in order to cover different market trends. On the one hand market trends and medical estimates, and on the other hand recent and continuous efforts to develop the technology suggest that there will be further promising progress of bionic limbs. However, scholars, in their efforts to analyze complex relations emerged due to the development of prostheses, use theoretical tools that were developed in different historical eras and the analysis may be outdated.

Scholars often try to understand the use of prosthetic technologies from various philosophical aspects. Additionally, scholars from disability ethics argue on the ways that a technology can be inclusive or exclusive and the possible implications (Dyer, Noroozi, Redwood, & Sewell, 2010), whether there should be participatory design where a user should co-design such an important and emancipatory technology as is the case for an impaired person (Hussain, 2010). Each of the analysts' examinations and work can offer a different direction and criticism towards what it is an interesting and crucial topic. From a different angle, there is also strong philosophical work published from phenomenologically oriented studies. Building on the work of Maurice Merleau-Ponty (2012), scholars try to understand what is the relation with prostheses and their users (Murray, 2004; Murray, 2008; Mills, 2013). Continuing in this vein, Don Ihde, a postphenomenologist, examines the way that different prosthetic technologies may shape and mediate the

experience of the user (2002; 2012). Furthermore, postphenomenological analyses for prostheses can be found in the work of Kirk Besmer (2012; 2015), and, of more relevance to my thesis, Lucie Dalibert (2014), who, among other technologies, focused on prosthetic limbs. However, and largely due to the rapidly evolving technology, scholars do not take into consideration the different technologies and the ways that these technologies should question established concepts regarding the scope, variety, and depth of the user's experience. In this sense, while there are significant social reasons in why we should focus on prosthetic technologies, the theoretical tools used, in the case of phenomenological studies, were developed in a time and era where the technology and the social values were very different. As a result, the analyses often focus on the experience of the world with the technology, which is often the case in postphenomenology, instead of how it questions different aspects of the user's body. Thus, the focus is on the external world and the relation to humans, how the experience may be altered or not contributing to the well-being of the user. Additionally, the aforementioned scholars do not focus on how different the experience of a non-corporeal object may be if the object feels as a part of the body. This thesis will try to deviate from this tradition and will focus on how bionic limbs challenge our understanding, not of the world and the relation of the user towards it, but on the user and the way she may perceive her body ownership.

1.2 Methods to analyze bionic limbs and body ownership

This thesis focus is on body ownership. Body ownership is the feeling that one's body differs from objects of the world. The body is a distinct object, meaning that while there is a vast variety of objects that someone can meet or interact with but one's own body always has a different meaning in the terms that is always experienced differently. While the body is a means to experience the world, the body itself comes as an object that can be experienced as well. At the same time, body ownership can be a matter of change meaning that different conditions can result in altering this sense of distinctive nature that is experienced. Someone may lose her body ownership for certain parts of her body, due to neurological conditions, or can even extend the ownership that she feels for certain objects originated from the world, as a bionic limb. This thesis will focus on the issue of body ownership and how it may occur when a bionic limb comes to replace a body part. Specifically, it will examine how a new relation regarding body ownership may occur, and will focus on the conceptualizations by different actors, and the user of a bionic limb, of this enriched body ownership.

Regarding the data examined in order to analyze such a relation, this thesis will examine a wide variety of fields and concepts. First, there is the literature review which covers many different aspects of

prosthetic limbs and bionic limbs. The literature involved gathers historical data of the development of prosthetic limbs and their course towards bionic limbs. In understanding the differences between bionic limbs and prosthetic limbs in today's world, this thesis also examines the conceptualizations of insurers and manufacturers as are shown from reports, policies, and warranties of products. In order to understand the relation that a user may have with prosthetic limbs and bionic limbs, there will be an examination of mixed empirical data. For this purpose, there are used interviews found in the literature regarding the experience and feelings of prosthetic limbs users (Murray, 2004; Murray, 2008; Mills, 2013). To further clarify the feeling that a user may have regarding prosthetic and bionic limbs, I use scientific studies that gather quantitative data regarding the brain activity of users who wear prosthetic limbs (Giummarra, Gibson, Georgiou-Karistianis, & Bradshaw, 2008). Additionally, to clarify the thin line between incorporation and body ownership, will be examined studies from De Preester et al. (De Preester & Tsakiris, 2009; De Preester, 2011) as she provides a scientific understanding on why these two terms can be different. While there would have been plenty benefits in pursuing original field-research like interviewing users of bionic limbs, the technology is still in development and the users are hard to find with the limited potential that a master student has.

Regarding the methodology of the analysis, the authors referred in this text have strong ties with phenomenology. The studies of Murray (2004; 2008) and Mills (2013) have a phenomenological approach of interpretation of their data and concepts. As mentioned already, phenomenology has a great impact in the literature about artifacts and regarding prosthetic technology; this involvement has good reasons. Merleau-Ponty, a notable phenomenologist, has inspired plenty works and analyses on how our perception is shaped by how the body experiences and perceives the world. For this reason, his work is a recurring basis for many scholars who examine prosthetic limbs and their work is instrumental in analyzing bionic limbs. To comprehend how bionic limbs connect with body ownership first will be provided a thorough understanding of Merleau-Ponty's contribution to the literature. However, in his analysis, he does not emphasize specifically in artifacts but uses them as means to convey his message. In addition, the artifacts he is using as examples are fundamentally different from bionic limbs. A pipe, a car, a feathered hat, or a blind man's stick do not provide the complex technologies that bionic limbs can offer. While bionic limbs can meet all the conditions to be part of one's own body, the phenomenology of Merleau-Ponty falls short to analyze this relation. Postphenomenology comes to assist the effort in clarifying the complex conceptualizations involved. Exploring additional implications with a postphenomenological framework, the research of De Preester et al. (2009; 2011) and of other scholars from postphenomenology (Ihde, 1990; 2002; Verbeek, 2008) offer a good basis in this descriptive examination of bionic limbs that occurs in this thesis. However, postphenomenology does not have all the necessary theoretical tools to examine a relation where a marketable product, in which the agency of different actors continues long after the purchase, is

part of the own body. For all these reasons, I saw as a necessity to introduce the term 'hybrid body ownership' to explain the complex dynamics that are involved in an artifact that can be felt as own, yet the user does not have the dominant agency over the artifact.

1.3 Research focus

To examine all the different concepts briefly presented here, this thesis' main research question is: *Q Considering discussions from the phenomenological tradition and postphenomenology theoretical framework regarding body perception, how do bionic limbs urge us towards new understandings regarding body ownership?* To answer this question, I will divide the analysis into three main parts.

The first chapter will examine the history of prostheses and the variety of reasons for their development towards bionic limbs. The research question of this chapter will be: *What is the historical and technological development of prostheses, and how do bionic prosthetic limbs differ from traditional prosthetic limbs.* The response to this question will serve the purpose of indicating why bionic limbs are different and why there should be a distinct philosophical analysis regarding bionic limbs. Understanding the development of prosthetic limbs will benefit us to comprehend how different are 'traditional prosthetic limbs' from 'bionic limbs'. For this reason, the first chapter will include all the technical aspects, e.g., important parts of prosthetic limbs, distinctions among neuroprosthetics and computer-assisted prostheses, and a not extensive overview of the medical reasons for which one might need a prosthetic limb.

In the second chapter, I will use the theoretical work of Merleau-Ponty and will argue that despite the relevance of phenomenology for a discussion regarding prostheses, the development of bionic limbs may require a more updated theoretical framework. Starting from the basics of his philosophy, I will examine how different scholars and scientists use phenomenology to understand how an embodiment relation can be achieved. Overall, the second chapter will answer the question: *how can Maurice Merleau-Ponty's work help us analyze prostheses regarding body perception and cognitive embodiment, and what criticisms can be made regarding his analysis when applied to the topic of bionic limbs?* After thorough investigation of Merleau-Ponty's work and an examination of how cognitive embodiment is favored by using bionic limbs, I will provide three criticisms, two of which can be found in the literature and one is of my own, to discuss how his analysis falls short of to understand the concept of bionic limbs and body ownership.

In the third chapter, where lies the weight of my thesis, I will answer to the criticisms made in the second chapter and using theoretical tools related to postphenomenology to analyze the concept of body

ownership and related to bionic limbs. For this purpose, the third chapter will respond to the question*: How does the embodiment of bionic limbs connect with body ownership, and how do bionic limbs question established concepts regarding body ownership.* The response to the criticisms of Merleau-Ponty's work when it approaches bionic limbs is crucial because it gives us the necessary tools to unlock a quite complex issue not examined in the literature, i.e. a postphenomenological analysis of bionic limbs and body ownership. At the end of this chapter, I will use the term 'hybrid body ownership' as a theoretical tool which allows us to conceptualize the novel issues which are the outcome of the relation a user may have with the agentic nature of bionic limbs. After the third chapter, there will be the conclusions of this thesis alongside with some concerns about the future of bionic limbs and body ownership.

Chapter 2 - Traditional and bionic prosthetic limbs

Prostheses have a long history within different historical contexts of different societies with the oldest artifact, an Egyptian toe of the right foot, dates circa 950 BC (Garber, 2013). Nowadays, prostheses may include a wide range of technological artifacts that have multiple functions, but for hundreds of years, the technology was quite basic. For instance, the Egyptian Toe, a rather delicate prosthetic artifact that offered among others an assistive function, is not remotely close to what functions current technology can provide. After thousands of years of technological development, prostheses can integrate advanced technological systems. The current prostheses' industry has notable developments to offer that are worth examining and distinguish the artifacts from previous prosthetics. A modern prosthesis can integrate electronic systems and computer-based technologies that supports not only a better movement for the user, but additionally greater control over the technology, can offer neuromuscular control, and, as the time passes, an increasing amount of sensations from the technology, all of which will be examined in the next pages.

It is crucial to examine how assistive artifacts attached to the body developed to bionic prosthetic limbs. The question that I will answer in this chapter will be: *What is the historical and technological development of prostheses, and how do bionic prosthetic limbs differ from traditional prosthetic limb.* In order to achieve this task, I searched a wide variety of academic papers from the medical field, reports regarding prostheses, and historical studies which allow me to address this research question. In the analysis that resulted the literature review, I present the historical development of prostheses and four main influences crucial on their trajectory. Furthermore, I delve into the current technology of bionic prosthetic limbs and why they are different from traditional prosthetic limbs. After the presentation of bionics, I will provide examples and studies about what can happen with such a technology and why the conceptualization of the examined technology offers multidimensional agency which makes a philosophical investigation urgent.

2.1 Historical context for prosthetic limbs and four influences for their development

We can trace the history of prostheses to ancient narratives regarding human mythology. In the Aztec mythology, Tezcatlipoca, the Lord of the Smoking Mirror, had a prosthesis made of reflective obsidian that would emit smoke (Bassett, 1980). But it is on the other side of the planet where the first written mention of a prosthesis is found. In the books of Vedas in India, for which their estimated written form is dated between 3000 to 1800 B.C., the myth says that the leg of the warrior queen Vipshala was amputated to

receive a prosthetic iron leg only to return to battle when she recovered (Vanderwerker, 1976). Nonetheless, it is in ancient Egypt where the first actual prosthetic was devised, the great toe of a right foot (Nerlich, Zink, Szeimies, & Hagerorn, 2000). This prosthesis, developed from between 950 and 710 B.C., was attached to the body with two wooden and one leather part which had sewed hinges for improved flexibility. While the scientific analysis showed that the wearer used the prosthetic toe ante mortem, the ancient Egyptians believed that in the afterlife the body had to be complete as it would be reanimated. This toe is not only the oldest found prosthesis but it has been proved to be functional by current users who had similar amputations (Finch, 2011; Finch, Heath, David, & Kulkari, 2012). A more recent case can be found on the reported incident of Herodotus, about a Persian prisoner who, to escape his captivity in 484 B.C., amputated part of his own leg and attached a wooden part that assisted him to walk for approximately 50 kilometers before once more captured and executed (Thurston, 2007). Following many other similar cases that are found in the literature (Thurston, 2007), in the 16th century, we meet Goetz von Berlich, a German knight whose left arm was torn apart from his body by a canon shot at 1504 in one of the battles he participated. With a carefully crafted prosthetic hand, the fearless knight manipulated the gear mechanisms of his prosthesis which allowed him to grip his sword. Yet, engineering and technological aspects are not the sole reason for the development of prostheses.

While historical narratives can provide us with multiple examples of the mechanisms used but also the materials and the ingenuity of craftspeople who created a functional prosthetic, the medical developments of each historical era played an important role. As researchers claimed when they found the toe from ancient Egypt, there is evidence of sufficient knowledge of treating wounds in certain parts of the ancient world (Nerlich et al., 2000). Advancements in the medical field, how to treat wounds alongside with the development of engineering, were crucial; in these developments, Ambroise Pare contributed greatly. Pare was a surgeon, and a barber, in the mid-16th century who had an innovative approach regarding amputations and the conduction of surgery. During his serving time close to high-rank officials in the military, he introduced ligatures instead of cauterizing the wound, to achieve hemostasis; he further developed the technology of prostheses by introducing mechanisms that would allow the wearer to manipulate his limb, and he introduced the socket between the prosthetic artifact and the body for the user to be more comfortable (Sellegren, 1982). Starting from Pare's improvements on prosthetic limbs, the treatment of wounds, especially during war times has been an important factor in the course of prostheses' development. For instance, during the American Revolution (1775 – 1783), one surgeon had to serve in every regiment, while in The Napoleonic Wars (1792 – 1815), the military surgeon Baron Dominique-Jean Larrey placed surgical teams near the front lines to reduce the time between the wound infliction and its treatment (Manring, Hawk, Calhoun, & Andersen, 2009). Nevertheless, it was during the American Civil War (1861 – 1865) that the need for prosthetics increased radically. There is an estimation of around 46,000

amputations that took place during the civil war (Jones, 2012). During that war, amputees were seen as valuable personnel despite their amputations. A brigade of amputees, known as the cripple brigade, formed in order to assist the military progress (Brueggemann & Lupo, 2008). Similar advances occurred in the next wars that were to come, in World War I and World War II, during which the total number of casualties was radically increased but health care for wounded soldiers was established and improved (Manring et al., 2009).

Arguably, there is a connection between wars, military industry, and the overall healthcare system. Wars, besides creating fields of battle, offer a great opportunity for applied research where innovations prove to be a decisive point for the course of battle. However, military injuries, in combination with military medical practices, were not the only factor that increased rehabilitation using prostheses. Reznick (2008) provides an overview of the different social factors that contributed to the development of prostheses. First, the industrialization of societies required more male and female workers but resulted in increased work-related amputations. Industries tried to avoid discarding the workforce after an injury, thus, prostheses' demand was increased (Reznick, 2008). A second reason Reznick (2008) argues played a significant role was the public image of amputees. With the establishment of Paralympics in the 1960s, society witnessed amputated athletes with excellent performance who could create an interesting spectacle in competitive sports. As Reznick elaborates, the social changes that occurred gradually led companies to have an increasing interest in developing technologies that would surpass their competitors. To sum up, social factors such as industry development, sports spectacles, prostheses' manufacturers, and media coverage contributed to improving rehabilitation in practical terms and social acceptability, as well as, altering the image regarding amputees.

In conclusion, there are four influences that structured the development of prosthetics from the ancient times until the 20th century. Primary, it was the development of the medical field such as treatments and methods. A second reason was the development of engineering and mechanics that was evolving during each era. From the hinges sewed together on the 'Egyptian toe' to the gears of Ambroise Pare and the professional athletes with prostheses, the degrees of freedom that a user may have and the number of tasks one can accomplish are crucial for the use of prostheses. Thirdly, there were advances in the military field. The evolvement of the battlefields and the increased numbers of soldiers participating in wars provided several cases where new technologies could be applied in order for one side to have a benefit over the other. Lastly, there were different interrelated factors such as industry development and related injuries, as well as, the social perception of disabilities. All these influences emerged due to different reasons, such as medical, military, or other factors but all have definite links with the society and the different meanings and uses of each society. This brief historical section had the dual purpose first, to inform the reader about the

historical trajectory of prostheses and second, to distinguish the main reasons for their development. Connecting the historical evidence, we can see that society played a major role in the development of prostheses and may create different meanings and purposes for such a rehabilitating artifact. As the reader will see later on this text, there are some similar factors regarding the development of bionic limbs, e.g., medical, military and so on, and I will show in many cases in this text how the society plays a role in the formation of prostheses. Yet, besides the different causes for which prostheses have been developed, there are differences regarding the causes of amputations and differences regarding the standardization of the technology, issues that further complicate the current prostheses industry.

2.2 Causes and issues of the treatment for amputations

Since this thesis will focus primarily on limb amputees and prosthetic limbs, it is crucial to have a basic understanding of the different causes of amputations and what may be the issues regarding the treatment. The purpose of this section is not to provide a medically detailed examination of limb amputations but to offer a basic insight regarding prosthetic limbs. The main reason is that, besides the different causes that require different procedures and methods of medical treatment, a detailed review of these issues would not offer substantially to the effort of this thesis. Nonetheless, as the text progresses, details regarding specific medical treatments or particulars regarding the technology, will be added when judged necessary. This insight will inform the reader about the complex procedures and processes which result in a user using a prosthetic limb and additionally will show the estimated prevalence of use of prosthetic limbs for the coming years. For a more elaborate etiology, and further facts on different kind of amputations (e.g., below the shoulder or elbow, finger(s) or toe(s), below the knee, etc.) the reader can study Jain & Robinson (2008) for upper extremity amputation, and Kurichi, Bates, & Stineman (2010) for lower extremity.

As I will show on the next pages, the main reasons that amputations take place in the western world are limited to blood circulatory problems, mainly diabetes and arteriosclerosis, trauma-related injuries (car accidents, industry related, or soldiers injured in the fields of battle), and secondary causes as cancer, infections and other rarer diseases or deformities that result to a dysfunctional limb. For instance, in the United States, there are two million people living with a limb loss (Ziegler-Graham et al., 2008). Of that number, around 54% of the amputees' main cause for amputation was from diabetes, and 45% of the amputations were performed as a result of a trauma (Ziegler-Graham et al., 2008). To put this into perspective, according to the International Diabetes Federation, from the total US population, 9.3% is diagnosed with diabetes until the year 2015 (International Diabetes Federation, 2015). In Europe, the

percentage does not show a great difference with 8.5% of the population being diabetic (Tamayo et al., 2014). A research conducted in the Netherlands showed that for people with diabetes the chances that they may need an amputation is 12 times greater than with those without diabetes (Fortington et al., 2013). The last study is important since it compares the trends were similar high percentage ten years earlier with Diabetes being in 94%, and trauma and cancer-related issues forming a 6% (Rommers, Vos, Groothoff, Schuiling, & Eisma, 1997). Other reasons for amputations can vary from cancer, and other diseases, to birth defects but the overall percentage remains critically low to elaborate for the purpose of this thesis. While there are differences between countries that have a different approach regarding trauma regulations in the workplace or diabetes prevention culture and the trends may vary from period to period or from region to region, amputation statistics may show increased percentages in people from lower-income classes, as was found in California, US (Stevens et al., 2014). Furthermore, there is a different level of demand for prostheses dependent on the type of amputation, whether is it for upper extremity or for lower extremity, and, also, regarding the part of the limb that is missing, e.g., whether it is below the elbow for upper extremity or it is just a finger (Kurichi et al., 2010).

Besides the case of trauma injuries which require immediate amputation like traffic accidents, industry-related injuries, war injuries and so on, there are cases where a person was born with a deformity or other born related factor, or had an injury that resulted in a permanent dysfunctional limb. Reasons like these make the body dysfunctional and the subject may decide for an amputation as a prosthetic limb would be a preferable choice for her. For example, Erez Avramov chose to amputate his leg when he realized that his injured leg may take years to recover or may not recover at all (Avramov, 2015). In a similar direction, some people choose to amputate one or more of their limbs in order to enhance their abilities. This practice, which aims to enhanced abilities, is a rather later trend and its percentage remains low, however, there are discussions about what would mean for a person to choose to amputate her limb (Kiss, 2015). For example, there is a disorder which scientists have named Body Integrity Identity Disorder (BIID) at which a subject feel alienated from parts of her own body. Subjects feel uncomfortable to such extent with a part of their body that they even mutilate themselves if doctors refuse to perform the desired amputation (Muller, 2009). While some scientists claim that BIID is a neurological disorder, it belongs in a category of its own because it raises different ethical questions about the use of one's own body (Muller, 2009; Slatman & Widdershoven, 2010).

Due to the complexity and plenty of reasons regarding an amputation, in order for the manufacturers to reduce the costs and provide efficient, structurally, and quality standardized components, there are efforts to reach an agreement regarding the classification of the amputations but also the classification of the components. However, international standardized materials that would be customized to the needs of the

user were only recently established. For example regarding knee prostheses, clinicians would prescribe a limited number of prostheses because they are tested in the real world and are more trustworthy when compared to the latest developed knee prostheses (Balaraman & Singh, 1995). In the same paper, the authors propose to create a classification scheme which would include functions and mechanisms in a hierarchical way i.e., functions and mechanisms of different prostheses for different body parts. This would help designers and scientists to make the required improvements in separate parts for example how an examined hip prosthesis may function when it operates with a knee prosthesis. In a paper published in 2011, scientists discuss the absence of classification for (internal) joint prostheses which reflected in a lack of efficiency from manufacturers which, in turn, resulted in insubstantial changes whereas, as they argue, there should have been a great improvement (Robertsson, Mendenhall, Paxton, Inacio, & Graves, 2011). Indeed, the International Standard Organization (ISO) puts great effort to classify prostheses' components, to establish a commonly accepted terminology regarding prostheses and amputations, and structural and quality standards (ISO/TC -Prosthetics and Orthotics, n.d.). Yet, ISO institute is only one of the different standardization institutes that classify prostheses; this fact complicates the situation as different manufacturers and countries oblige to different regulations. In this regard, despite the acknowledged development that there has been the last few decades, the fact that there are different priorities from different actors and different standards for a variety of technologies and practices obstructs the development of prosthetic limbs (Balaraman & Singh, 1995; Robertsson, et al., 2011).

Besides the technical part, since each human body is different and every condition needs a different approach, all prostheses are custom fitted to the needs and condition of each user and are designed specifically for each user. A prosthetic technology has to be devised by taking into account specific desires of the user, as for example the aesthetics and the possibility of copying a real body part, e.g. natural hands (McGimpsey & Bradford, 2010), or different issues of functional nature, e.g., a prosthetic leg should have the same height as the healthy leg, or whether the prosthetic limb will be inside the body (endoskeletal) or outside the body (exoskeletal) (Schmuch, 1998). This custom nature of prostheses makes it difficult to create a general approach on how every prosthetic limb should look like or function. Youngsters, whose body is still developing, have different needs from an overweight middle-aged farmer, who uses his prosthetic limb to continue his previous lifestyle. Hence, for prosthetic limbs, it is not only important what type of cause, i.e., disease, trauma, and so on, led to the amputation, but additionally, the needs that a person may have in order for a prosthetic limb to achieve its goal, that is, to contribute and to assist the user in regaining whatever may have been lost from her life.

As seen in this section, prostheses may be needed for various reasons. Different users may have different traumas or diseases and may be in need of a prosthetic limb. Highlighting the increasing

prevalence of prosthesis use is valuable because we can see that prostheses are not artifacts used in a specific region of the world rather their use transcends different cultural differences or ways of living. Still, the fact that in the western society the main reason for amputation is cardiovascular issues, which have increased incidents with increasing ratio among the population, suggest that prostheses will be needed for the years to come. Especially in the western society, where seems that there will be a more or less stable economy for the foreseeable future, prosthetic limbs' use will increase as the technology will accommodate the user for any potential disability. For this reason, it is important to note that the standardization of prostheses remains an important topic. This shows that while everyone can use a wooden object to achieve body balance, prostheses need to adapt to certain categories, that is, ISO certificates, the decisions of prosthetists on which prosthesis to use, and the custom needs of each user, which escape the simplified procedures of the past. Manufacturers, medical personnel, and prostheses' users are intertwined in a complex and long process which is shown in many cases in the next pages. As we will see in the next chapter, these issues play a significant role regarding the relation that users develop with the prosthetic device. However, before proceeding to the examination of these issues, in the next section of this chapter, I will elaborate on bionic limbs, their differences, and classifications when compared to traditional ones.

2.3 Current developments regarding prostheses

After presenting the history and development of prostheses, as well as some basic understanding regarding the causes and complexities of their technology, this section will describe what bionic limbs are, so as to help the reader to understand the differences between traditional prosthetics and bionics. I will classify traditional prosthetic limbs on their negation, meaning that they are the ones which do not integrate any type of advanced technologies, like neuromuscular control, computer-based technologies, and/or any kind of electric transmission from the device to the user. From the preview of the history of prostheses, we can see that traditional prosthetic limbs existed for hundreds of years, while bionic limbs, which incorporate more advanced technologies that are still under development, are highly different from traditional prostheses. For these advancements on the field, there are different drivers which do not differ much from the reasons seen previously for the development of traditional prostheses during the centuries. The development of current bionics falls in a similar pattern with a combination of social reasons as for example, the increasing acceptability of prostheses' users; on socio-economic terms, a fragmented market of the manufacture companies for prosthetic devices which gives rise to competition among them (McGimpsey & Bradford, 2010); healthcare system improvements; the causes for amputation which require a systematic approach to the case (blood circulatory problems as diabetes, ageing population, and war injuries soldiers

of developed countries). Lastly and to a great extent, are the technological advances on the field, a reason that, as we saw, played a major role in prostheses of previous centuries. Nonetheless, there are drivers that were not present on the history of prostheses, as for example, the constant effort to reduce health care costs (McGimpsey & Bradford, 2010), which can be achieved when the devices provided have improved durability, efficiency; reasons that result in a better lifestyle for the user and reduce the health care system's efforts.

The general aim of both types of prosthetic limbs is the same: to compensate for the loss of a limb. However, there are different ways for achieving this compensation. Traditional prostheses can be plain materials that can offer a basic stability or functionality, made from wood, metal, or plastic and can offer the necessary bodily balance so as for the user to be able to move. The last few centuries, traditional prosthetic limbs have had mechanisms and gears that can be handled by the user. For example, a traditional prosthetic arm can have the mechanisms handled by the other hand, which would allow the user to make some basic movements, like grabbing an artifact. Bionic limbs, as well, can offer similar functions such as body stability regardless if they are turned on or not. But additionally, bionic limbs incorporate electronic mechanisms which enrich the functional spectrum. The scientific field of studying bionic limbs is called biomechatronics and is highly interdisciplinary. Covering fields such as prosthetics, electronics, biotechnology, hydraulics, computing, medicine, and lately, nanotechnology, researchers seek to apply technology that would function with the muscles, bones, and nerves of living organisms (Dehghani, 2010). To this direction, a bionic limb responds to the movements of certain muscles, may prepare the next step, and even may provide artificial sensations, all of which are performed due to the function of electronics in accordance with biologists, doctors, and other researchers. In this sense, the main difference between traditional and bionic prosthetic limbs is not the general purpose, i.e. compensate for the loss of a limb. Their main difference is the spectrum of tools, scientific and engineering fields, and methods used, which are required to build an artifact and that will incorporate at least some sort of electronic technology. In this sense, a C-Leg that has electronic micro-processors and a neuro muscular controlled prosthetic limb with artificial sensations can both be bionic limbs, while the ingenious prosthetic limbs of previous centuries which were controlled by mechanisms and gears fall in the category of traditional prosthetic limbs.

Moving on to a more detailed examination of different prostheses, a modern prosthetic limb may have different levels of variations according to their use and may incorporate different components based on their potential use. Firstly, there are prosthetics that have a thoughtfully researched design but do not incorporate any electric mechanism and they belong to the category of Non-Microprocessor-Controlled (NMC) prostheses. These prosthetics differ from a plain piece of wood or metal, or in the more recent designs titanium limbs, in the terms that their advanced design transform them to become more functional.

For instance, a lower extremity amputee would have to pay around from $5,000 to $10,000 for a below the knee prosthesis that allows the user to stand, walk, or climb the stairs (McGimpsey & Bradford, 2010). Other designs for prosthetic legs, that may allow the user to run at a functioning level can cost from $12,000 to $15,000, while at the same price, a prosthesis may embed mechanical devices that allow the user to have stance control, and provide better movement to the user (ibid.). The prices mentioned are indicative and can be a subject of change as the technology or the market develops, or between different prostheses brands.

Bionic limbs differ from traditional prostheses, since they offer more than just mechanical features, such as deeper cognitive embodiment, but since this is instrumental to this thesis, I will examine it at length in the next chapter. Starting with Computer-assisted devices, they can incorporate microprocessors that recognize the specific situation under which a user is in. By using these sensors, the limb calculates and adjusts the different mechanisms that are necessary for each task, e.g. to climb a staircase. This adaptation provides the benefit for the user to learn how to use the device in a smoother way as it reduces the cognitive process and body adjustment that she will have to do. Their price range can start from $20,000 and reach approximately $50,000 - $70,000. C-Leg, a product designed and manufactured by Ottobock, is a prosthetic leg which has microprocessors storing information about the user's body necessary movements throughout the day and *remembers* the adjustment of the mechanisms. This memory helps the user to perform better in the everyday tasks where repetitive movements are required. Close to computer-assisted prostheses are myoelectric arms which operate with sensors that use electrodes which recognize different muscles' movements causing the arm to open or close. Myoelectric arms can incorporate computer technology with the price starting from $20,000. While the cost of a C-Leg can be high for users, in one of the few studies that compare NMC with a C-Leg, the overall repair and service costs of the first outweigh the costs of the latter one for the same number of years (Brodtkorb, Henriksson, Johannesen-Munk, & Thidell, 2008).

However, even the more advanced computer-assisted prosthetic limbs cannot offer a crucial option for amputees, i.e. the sense of touching. In 1974, the fist neuroprosthetic limb was developed at the center for Engineering Design, University of Utah (Jacobsen & Jerard, 1974). Over the last decade, there have been a few similar type of devices that can offer brain-controlled prostheses, and, additionally, provide sensory feedback to the user (Leuthardt, Roland, & Ray, 2014). In this way, the user not only can control the attached prostheses but can also recognize the different materials she is handling. One of the techniques in which the thought-controlled limb — and surgically implanted limb — can be manipulated is by sending small charges of electricity directly to the brain. In a second technique, the sensors, instead of being hardwired and integrated physically in the users' body, have receptors that work at the edge of the body, where the limb was to be extended. For instance, if an amputee has the amputation at the shoulder level, the receptors attach to the spots where the nerve endings to that point are located. This technology creates

to the user the sense of touching, perceiving different surfaces in a more 'natural' way than with a rigid traditional prosthesis. Recent developments show that artificial skin is feasible as well (Tee et al., 2015). However, sensory feedback and artificial skin are still in early stages and their use is on testing stage. Lastly, the price for neuroprosthetics can exceed $100,000 (McGimpsey & Bradford, 2010), making their affordance quite exclusive related to other prostheses.

Most of the prostheses that have been presented so far, especially those which will be examined in this thesis, are quite expensive. While there is an effort for reducing the overall costs, the technology demanded at this stage requires a certain amount of costs in order to be built. Costs may include the prosthetist who will make the custom parts of the device, the doctors' attendance and overall medical attention to the users, the mapping of neural endings for the users who would want a neuroprosthetic, and so on. A response to the increased cost of prostheses could be the 3d-printed ones which decrease few of the costly procedures. A 3d printer reads the body dimensions, e.g., for the missing arm upon which the prosthesis will be attached, and in a few hours to days can print the required arm. Despite the fact that a 3d printed prosthesis can be an affordable solution for the user, the technic has a few drawbacks which are not easily to overcome. The plastic based material is not so durable as a titanium limb which is used in a few neuroprosthetics. There are companies which are establishing a market that can create a relatively durable device, but then again, the research for non-3d printed prostheses and their functionality has been longer established. This means that in the case of 3d printed device some expectations may be unrealistic at this point of the research. Overall, it may be correct that it allows the user to have more freedom for the type of prosthesis they may use, nonetheless, the available sources do not suffice for a reliable research at this point.

This section provides an overview of different prosthetic limbs like computer-assisted, neuroprosthetics, or 3d-printed prosthetic limbs. I also claimed that there are some similarities regarding the development of bionic limbs such as technological, social, healthcare, and so on. Acknowledging the current price framework for different categories of prosthetic limbs is crucial for the manner in which we can approach the technology and its use. Additionally, we saw different complexities such as durability, difference in how the movements of the wearer are performed, embedded memory in the hardware, co-ordination between the hardware and muscle movements, which provide an overview of the technological requirements of each category of prosthetic limbs.

2.4 Cost Coverage, insurance policies, and the user

This section focuses on the cost coverage and provides a brief knowledge of insurance policies and different actors who participate in the process of delivering a bionic limb to the user. A crucial factor for any type of prostheses is whether the user has to buy the device solely on private funds or the health care systems cover part or the total cost. The differences among countries can be significant, not only between developed and developing countries but among developed countries as well. Researchers argue that a prescribed prosthesis will benefit the users and will, overall, reduce the total healthcare costs (McGimpsey & Bradford, 2010). However, since this thesis will not focus on a comparative study of different healthcare systems, the focus will be on the example of the United States. The US is a justifiable example because there is an established healthcare system; the users can have access to different insurance policies that are adjustable to their conditions; different companies of bionic limbs have established a sustainable market; there is a big percentage of amputated soldiers where the bionic limbs research is thriving; and there is a big percentage of civilians who undergo an amputation every year. In addition, there is a sufficient amount of data in English, a language I can understand.

Pointing the policies under which a user can acquire a prosthesis is crucial not only because of the improvement of the life of the user, but because the coverage of costs is decisive whether the user can afford an expensive device or not. However, it is important to notice that the focus on the US example cannot lead to safe conclusions universally applied regarding the healthcare system and bionic limbs. Each country has their own policies and this is one limitation of this text. Nonetheless, the crucial topic is not the healthcare system, like the use of private funds to acquire a bionic limb, rather how deep the agentic nature of bionic limbs can be and the manner in which different actors participate in many levels to the relation of the user with her bionic limb. In this sense, in different historical eras there was some sort of a healthcare system for amputees, e.g. for soldiers in the American civil war, but the current healthcare system can make a decision on whether a user would have a traditional prosthetic limb or a bionic limb. Consequently, this decision process may deprive from the users the ability to have artificial senses, move more effectively, or the chance of incorporating the bionic limb in what a user may feel as her own body. For these reasons, the coverage system is highly important because it shows the complexities that a user may have to cope with before or after acquiring a bionic limb. Introducing the coverage and insurance issues for the US at this point of the text will help the reader to shape an opinion on the type of complexities a user of bionic limbs has to cope with. Additionally, it will further distinguish traditional prosthetic limbs and bionic limbs and shows that the agency of the insurers may affect the spectrum of experience of the user.

In the US there are four different means of covering for a prosthesis (McGimpsey & Bradford, 2010). The first one is from private funds of the user, or from insurance companies which may reimburse part of the whole amount of the cost. The other three categories, depending on the case, can be from the

federal government health insurance program, a combination of federal government and state governments insurance policies, or, if the user is a Veteran injured at war, from the Department of Defense. In the same report of McGimpsey and Bradford, from the "20 major insurers" (p. 11) which were surveyed, all use an insurance cap. Yet, we read:

> "A recent poll of 468 Amputee Coalition of America members revealed ongoing insurance reimbursement problems: 24 percent of responders reported that their private prosthetics coverage had been reduced during the past three years and 4 percent said it had been eliminated entirely. For 48 percent, there had been no change, and 24 percent said they have no private insurance." (ibid., p. 11)

Due to a large amount of costs that are to be covered, often for consecutive years, insurance companies or government projects may adapt their policies depending on their general finance state. The aforementioned fact that prostheses need to comply with certain regulations and standardizations to have quality checks and the nature of the technology which requires that all prostheses should be custom to the user to be functional, do not help in reducing the cost by mass produced prostheses. Additionally, there are different considerations regarding what is considered *medically necessary*. Due to the fact that the developments regarding prostheses are recent, there can be a variety of different insurance policies which results in a varying amount of cost per user. Furthermore, different policies apply to different conditions. For example, a user seeking to buy a myoelectric or computer-assisted limb needs to meet certain criteria to get financially covered. The BlueCross BlueShield of Mississippi, a mutual insurance company for the state of Mississippi, US, suggests that the user should have a certain physical activity in her daily living for the user to get used to the prosthesis (Premera - Blue Cross, 2016). However, the section "Policy Guidelines" (ibid.) states that:

> "Orthotics, Prosthetics, or Prosthetic Components added to a Conventional Prosthesis are not Covered when: It is considered experimental or investigational or used for experimental or investigational therapy or interventions; it is used only for recreational, sports or athletic activities; it is available over-the-counter or off-the-shelf without a prescription."

The policy justifies their exclusion for myoelectric limbs if the user is participating in sports or athletic activities on the fact that their durability is poor so they propose a more durable prosthesis, without processors. Similar restrictions can be found in product warranties of different prostheses, which state that the product should be treated with care or else there cannot be a refund of the product. When a user has to buy a prosthesis, she would need to deeply consider her life and lifestyle. For example, C-Leg is a prosthesis used by runners while someone who would want to have a durable prosthesis, designed for manual work,

may decide to use a plain mechanical prosthesis that leans towards the traditional ones. This decision over the lifestyle and life that one has to pursue adds to prosthetic limbs (traditional and bionic) an additional meaning: how important and complex decisions for prosthetic limbs may be for the human being. Nonetheless, this decision, about a desired lifestyle, is not always covered by insurers. A prosthetist examines the specific situation that each potential user is in and then categorizes the user for a specific coverage. This examination may lead to appeals from the users' side as she may need a specific prosthesis to continue her previous lifestyle, still, the appeals are options that a user may not be aware of or may not be fruitful.

The decision process and post purchase regulations with which a user may have to comply in order to keep having the opportunity to use certain technologies can be mitigated for the user by using own funds as means for acquiring the prosthesis. The option that a user may have a prosthesis funded by his own funds can be excessive as a study conducted by the U.S. Department of Veteran affairs (Blough et al., 2010) showed that the average lifetime cost for the medical care and different upper limb prosthesis that a veteran of Afghanistan or Iraq war may need is estimated to be $823,299. The combination of compliance with different regulations as well as the sustainability of highly technological artifacts can create different reasons for the abandonment of the prosthesis. As we saw, the fact that the coverage of costs may be dependent on different regulations among insurers can be an important point for the procedure of acquiring a prosthesis. At the same time, different reasons like the cost, maintenance, battery usage, durability, may lead to the abandonment of the prosthesis (Biddiss & Chau, 2007). This gap between the high total cost accompanied by problems regarding users' funds and coverage insurance issues may further increase the abandonment of the prosthesis by the user.

These regulations and decisions play an important role scarcely examined in the literature but they are highly important and central to this thesis. The user not only will have to cope with the problems that have resulted from the amputation but additionally, will have to adapt to the power relations that will regulate not only the prosthesis but also the lifestyle that the user may have from that point on. The examples provided here do not focus whether the amputee is physically able to continue on her previous lifestyle, rather whether with the acquirement of a specific type of prosthesis the user would have to comply with certain rules regarding her lifestyle that were unprecedented to her. The decision processes of insurers, manufacturers and so on, described above conceptualize prostheses as instruments, and not as technological artifacts with which the user often perceives and experiences life and the world. As I will show in the second and third chapter, the experiences provided with a bionic limb can result in a certain sense of body ownness which makes the bionic limb being more than just an instrument. Thus, the problem is not whether the user can or not participate in a series of activities given her new physical abilities and limitations, rather that

decisions based on the technological function of the prosthesis which will form the lifestyle of the user regardless how she may feel about a technological artifact which as we will see later can be part of her body. Eventually, these decision processes help us to conceptualize not only how different traditional prosthetic limbs may be when compared to bionics, but additionally how the user may experience the discrepancies of the meanings which accompany the meanings of these decision processes.

To conclude this section, prostheses' cost may be covered by different methods such as private funds, insurance coverage, or government funding. However, when examined carefully, there are different issues that may emerge. Insurers or prosthetists may have a different opinion on what prosthesis a user may obtain, the reimbursement of costs can be a matter of change or be obstructed, the user has to make a choice regarding the lifestyle that she would pursue with her prosthesis, a decisive choice for what type of prosthesis is covered, and so on. These issues regarding the decision process about which technology a user will acquire create an unprecedented factor when contrasted to traditional prosthetic limbs. As with bionics the outcome is fundamentally more complicated and implicates the life of the user because there are technological limitations. The nature of the limitations can be economic or of differences in conceptualizations regarding the prosthesis. Even if a user decides that she would use her own funds, the cost can be excessive for an impaired person. Costs, prosthesis functionality, as well as problems with their durability, may result in an abandonment of the prosthesis by the users. Instead of the user having to cope with all these different issues, the abandonment may feel as the more suitable option.

2.5 Conceptualizing the differences between bionics and traditional prostheses

In this section, I will show what is the contribution of bionic limbs, when compared to traditional prostheses, regarding our conceptualization of them. The fact that a user has lost, or never had, a limb presents her with crucial decisions about what should be her activities from now on. For example, if the user has a myoelectric hand then she would consider carefully her movements on the beach as sand can be damaging to the technology. These decisions are crucial for how a person sees herself and what her limits may be but are not solely decisions of the user. To list few of the steps regarding the process for acquiring a prosthetic limb: the prosthetists evaluate the situation; the user has to decide what sort of lifestyle would want to pursue; manufacturers have to create a sustainable market by creating multiple products with some being advanced and others not. These choices complicate the production and goal of bionic limbs. Whereas Goetz von Berlich wanted a prosthesis with which he would grab a sword and go on with his lifestyle, the fact that bionic limbs can offer several choices, upon which the user does not always have a say, complicate the

situation. A bionic limb is not just a product targetted massively to end-users rather is a product created by the agency of different actors. For what is more, this agency can shape decisions that are made regarding one's physical activity.

If Goetz von Berlich was not a respectable knight, he would probably settle with a less delicate and less functional artifact, if with anything at all. This artifact could be a plain prosthesis, a hook of its time yet the decision process would be less complex than the modern one. Verbeek, in the preface of his book 'Moralizing Technology' (2011) noted that ultrasounds not only provide the parent(s) with the first look of their unborn child but also give them the ethical decision of what would be their next step if the unborn has a detectable disease. A bionic limb places the participant actors in choices that else wise would not be present with a supportive wooden stick. A user has to decide what type of life would like to pursue with his prosthesis in accordance to what type of prosthesis she can afford. Manufacturers have to create a diversity of products to differentiate their brand from others' and stay always one step ahead yet some artifacts can be too expensive for most users. Insurers need to have a sustainable policy that would allow them to keep providing their services and they cannot fulfill users' wishes in having the top notch technological product if they wish to but are not eligible.

All these actors, have a different opinion on what may be the preferable choice for their own interests. For example, insurers and medical experts pose that myoelectric limbs are not necessary for every user, yet the fact that this decision cannot be made by the user may be problematic. As I will show in the next chapter, sensations, or control over ones' body and handling of different objects, not only help the user to prevent her from doing any harm to the prosthesis but also help her to perceive and shape her environment. Thus, actors' decisions do not only reside on the functionality and instrumentality of the technology but, additionally, direct the user on how her perceptions will be shaped. Goetz von Berlich's artificial hand assisted him in maintaining a desirable social status, yet, his prosthesis did not incorporate as much agency as a bionic limb. The difference between a plain functional metal prosthetic limb of his era and the delicate artificial hand that he used lies to the fact that him, as a respectable knight, could acquire this handcrafted and durable prosthesis. While indeed allowed him to maintain his life and social status, bionic limbs can offer more than just maintaining a certain status; they can offer sensations. By providing electronic systems resulted from an interdisciplinary scientific field, bionic limbs can incorporate technologies that enrich the perception of the user.

In the case of the Egyptian toe, the most ancient prosthetic part discovered, its use was twofold. First to offer the stability and flexibility to the user that would allow her to walk, but also the necessary completion of her body to pass to the afterlife. This completion was provided by the prosthetic toe which had a symbolic meaning. Nowadays, at least in the western world, such beliefs are not popular in the society.

Bionic limbs do not incorporate a meaning related to the afterlife, but carry multiple meanings in this life; meanings that agents may not always share. For example, agents may conceive prostheses as instruments, a type of an assistive product, that helps the user in retaining a certain kind of well-being. However, as I will show in the next chapter, under certain conditions, users may conceptualize prostheses as part of their body and not just as instruments. Their conceptualization of body part can reach multiple social meanings as well. As Murray (2008) notes, a prosthesis user did not want her limb to be touched by others without her consent as she identified it as part of her body. For that user, her prosthetic limb was more than just an instrument but a mode of bodily being. This discrepancy among meanings, between the prosthesis as an instrument and prosthesis as a body part, may be crucial in users' life, their general well-being, or the manner in which they obtain or purchase a prosthesis. In this sense, and as I will elaborate extensively in the remaining of this thesis, bionic limbs not only mediate and shape the environment and the experiences of the user in the way that Merleau-Ponty would argue, but additionally the way that the user conceptualizes the agentic nature of bionic limbs when they are a part of the owned body.

To sum up, prostheses incorporate the meanings of the historical era they belong to. Developed in their historicity, prostheses can have different purposes and different meanings. The Egyptian toe was created to support the afterlife of its user. Bionics' historicity translates that they should not be seen as cold objects of the world, as one-dimensional objects that offer the user a certain purpose. Multiple meanings can be embedded in the artifact. A meaning that is created by some users is that their prosthesis is part of their body, while a different meaning is created by insurers and manufacturers who conceive the technology as an instrument or as a marketable product. In addition, the agents of these different meanings shape the technology, and the users' experiences, as manufacturers and insurers would desire the technology to be conceptualized merely as an instrument and not as part of the users' body.

2.6 Conclusion

In this chapter, I introduced a basic history of amputations and the way that humans have tried to tackle long-lasting impairment. While prosthetics existed for thousands of years, it was only during the last three centuries that advances in engineering, medicine, healthcare system, and changes of social perspectives allowed the sector to constructively provide a respectable lifestyle for the users. In the last decades, technology has provided computer-assisted, myoelectric, or neuroprosthetic limbs, with which a user can walk downwards and upwards the stairs with a reduced discomfort or even required control over the limb. For what is more, a neuroprosthetic limb not only can incorporate a computer that would make the necessary

adjustments but can also provide a necessary and dearly missed component for an amputee, the sensation of feeling. The artificial sensation is vital for the user because it will provide a basic understanding of her surroundings recognizing what may be potentially harmful to her and the prosthesis. Meanwhile, the fact that prostheses can be quite expensive may lead to difficult choices by the user as if she cannot purchase different prosthetic limbs, she may be limited in refraining from certain activities. At the same time, the coverage of costs by insurers is decided on different factors that may be *medically necessary* or prostheses that are not suitable for every person and her lifestyle. All this result in a dependency of the user on the cost of the device, the manufacturers and their product scope, insurers, or even prosthetists. This dependency is translated to an agency of the actors who participate in the process who make decisions of regarding the boundaries of ones' future lifestyle.

In this chapter, I responded to the question: *What is the historical and technological development of prostheses, and how do bionic prosthetic limbs differ from traditional prosthetic limbs*, by showing the multidimensional and agentic nature of bionic limbs compared to traditional prosthetic limbs. In the next chapter, I will outline the basis that will help me put my philosophical analysis in play. By introducing the basics of phenomenology and consequently delving deeper in the work of Merleau-Ponty, we will see that the body has a huge role in the shaping of our perception. Additionally, using studies from the literature, I will associate bionic limbs with cognitive embodiment to show how bionic limbs can be felt as a part of the body. From this, I will conclude with three criticisms which focus on why Merleau-Ponty's theoretical framework can be insufficient to examine the many levels that bionic limbs contribute to.

Chapter 3 - Phenomenological investigations of prostheses

The previous chapter explored the historical development of prosthetic limbs, and their development towards bionic limbs. The latter, while vastly different from a traditional prosthesis, can be a subject for novel philosophical issues that may need our attention. This chapter will initiate a discussion of these issues, i.e., to conceptualize the philosophical issues that may be at stake. As a first step to conceptualize these philosophical issues, this chapter will answer the question: *how can Maurice Merleau-Ponty's work help us analyze prostheses regarding body perception and cognitive embodiment, and what criticisms can be made regarding his analysis when applied to the topic of bionic limbs?* Drawing arguments from the work of Merleau-Ponty, I will examine and criticize his argumentation applied to bionic limbs.

Phenomenology has been an important theoretical framework to analyze prosthetic technologies. Especially Merleau-Ponty argued that the understanding of our body can be altered based on the different uses we have to our environment and, as a consequence, to different artifacts. In other words, different instruments can felt as embodied and be more than just a mere extension, i.e., artifacts add on how we perceive the world. A feathered hat, a blind's man cane, a car, or a typewriter are examples discussed mostly on the premise that they shape our perception or our bodily movements, and the oft-unnoticed knowledge of our surroundings and environment (Merleau-Ponty, 2012). As Brey noticed (2000), Merleau-Ponty does not focus on technology or technological artifacts. Indeed, the focus of his earlier work is mostly on how our body is a fundamental parameter for a thorough understanding of how our perception is shaped. Instruments, artifacts, and technologies are used as examples only to validate his argumentation. The tradition of phenomenology places emphasis on analyses regarding sensations in combination with our body and its experiences. Bionic limbs provide an interesting case study of sensations and philosophy can provide valuable insights. Additionally, prostheses that use artificial sensations contribute to what our body can experience, but also, in experiencing the body itself. This chapter aims to demonstrate how it is possible to use Merleau-Ponty's work to conceptualize the mechanisms of bionic limbs. Also, Merleau-Ponty's work can help us analyze the manner in which bionic limbs contribute to the user's own body in terms of the *lived body*, and the manner in which body ownership can be a part of this analysis. While Merleau-Ponty's work has been instrumental in numerous studies regarding the body and prosthetic limbs, this chapter argues that there are some limitations to the depth an analysis based on his work can provide.

In order to structure my answer for the question posed in this chapter the coming pages will have the following structure: the section 3.1 will focus on the way that Merleau-Ponty have posed issues regarding the body and our experiences through it. This section will provide the theoretical framework that

will make this argumentation understandable. The section 3.2 will focus on how cognitive embodiment is linked with phenomenology and the way that the presented argumentation can offer a basis for a Merleau-Pontean analysis to bionic limbs. In the section 3.4, I will provide three criticisms of Merleau-Ponty's work, two found in the literature and one of my own. In this section, I analyze bionic limbs from a Merleau-Pontean point of view and will proceed with criticizing his argumentation as insufficient regarding the case of the agentic nature of bionic limbs and the way body ownership is shaped. The overarching aim of this chapter is to lay the groundwork for the next chapter in which I will explore the complex meanings of bionic limbs regarding the users' body and body ownership, using frameworks taken from Postphenomenology.

3.1 Phenomenology in Merleau-Ponty

Among the varied work of Merleau-Ponty, his most significant book was 'phenomenology of perception'. This work had the ambitious plan to criticize the fundaments of philosophy as developed after Descartes. Both empiricism and idealism have a common starting point: to separate the physical from the mental only to favor one over the other (Smith, 2007). Merleau-Ponty criticizes both dominant philosophical narratives — empiricism and idealism — and tries to establish a new center for philosophy: the unity of the body with the subject. This body-subject is the first and foremost condition for our perception. Merleau-Ponty abolishes the dominance of mental processes over bodily experiences or vice versa, claiming that the body *is* the subject and it is *our body that perceives* claiming "I perceive with my body" (Merleau-Ponty, 2012, p. 247), which means that the body-subject is always involved with the world, and is the center of perception. Thus, the contribution of Merleau-Ponty, at least in phenomenology of perception, is that he unifies the two different trends, perception, which is a mental process, with the body, which is a physical entity, under one concept: the body perceives. Through this conceptualization, the dualisms of empiricists or idealists become obsolete, as the Cartesian cogito is always embodied.

Merleau-Ponty focuses deeper in the phenomenological examination of the body and in phenomenology of perception, he thoroughly examines the body and its relation to the world. As Tomas Carman elucidates in the foreword to Phenomenology of perception (Merleau-Ponty, 2012, p. viii), central in Husserl's work, who is the principal mentor of Merleau-Ponty, is the concept of intentionality, which means the direction of consciousness, the 'aboutness' of *something*. Intentionality means, for example, that memory is not something abstract; it has to be a memory of *something*, e.g., a memory of a tree. Therefore, intentionality is a mental act regardless of whether there are actual objects in the outside world. This is the reason why it is possible to categorize an object that is first encountered, for example seeing an eight-foot

table *as* a table. Perception shapes it and categorizes it to be a table due to my understanding of the world in general, and of tables specifically. At this point, Merleau-Ponty deviates from Husserl's work in this regard, because for him intentionality is not a mental process, but constituted by "noncognitive — indeed often unconscious — bodily skills and dispositions." (Merleau-Ponty, 2012, p. x). After all, perception is not a mental task but exists in the world as embodied. What for Husserl is the *lived body*, for Merleau-Ponty is the *corps vécu*; a subject that perceives because the cognition is always related to the body and could not be any other way. These arguments of Merleau-Ponty give the body a significant place in how we can analyze the world as *now* the body is a starting point to explain the world. Moving away from the mental, Merleau-Ponty places the body at the very beginning of how humans can know the world from where we direct our intentionality.

The body is not like other objects, something that can be touched in the same manner as with all the other objects (Carman, 1999, p. 207). Humans exist in the world in an organic way, "determined by the nature of our sensory and motor capacities to perceive the world in a specific way" (Moran, 2000, p. 423). In this manner, one's *own body* is distinctively different from other objects, organic and non-organic. This is an important difference between Merleau-Ponty and Husserl, as Husserl's intentionality is a cognitive process that forms our experiences and understanding. By contrast, Merleau-Ponty views intentionality as embodied: there is no distinction between the mental state and the body. Rather, the body forms the body-subject, a subject that is co-constituted alongside with our body. Merleau-Ponty gives great importance to the *lived body*. He argues that it is not the objective body that wanders in the world and trying to reach artifacts. Rather it is the *lived body* getting accustomed to the environment, creating memories, and learning how to respond to surroundings (Moran, 2000, p. 420). "The thing is constituted in the hold my body has upon it; it is not at first a signification for the understanding, but rather a structure available for inspection by the body" (Merleau-Ponty, 2012, p. 334). It is through the *living-around-the-object* and sensing them that shapes our understanding. For instance, through the sensation of touching, which in *phenomenology of perception* plays an instrumental role, I can perceive the limits and boundaries of objects, and enclose them in meaningful representations. In the way my body and its sensations are developed since birth, I am able to perceive and understand the world. Finally, it is *what is* a part of the *lived body as the own body* when contrasted to other objects of the world, which makes the wandering in the world meaningful. This means that the *lived body* is not only the locus of the experienced sensations, but additionally, this experiencing occurs in my own body as I cannot have an experience of another body besides my own. The *lived body* gives the possibility that all the experiencing occurs in my body and not in any other object, other bodies included (Merleau-Ponty, 2012). If a part of the body is altered or disabled, it affects the way with which the *lived body* experiences the world.

Moving around objects and understanding their limits does not only shape our understanding about the world, but also provides us with an understanding of our *own* body, and its limits and abilities. Merleau-Ponty conducted several scientific studies to understand how our body is constituted by comparing 'healthy' subjects to 'disabled' ones. One such study involved a soldier from the First World War, Schneider, who had suffered brain injury. In this case, the focus was on how Schneider's motor skills were affected and how his body schema was combining with his motor skills. In these analyses, Merleau-Ponty used the concepts of body schema and body image. First, body schema is the experience of the body as a unity, a series of movements that are not constantly perceived, the experience of one's body as an object that can move in space. In the concept of the body schema, the user *has* the body and all the functions that it can provide, for example walking down the road. In addition to the body schema comes the concept of body image which is a system of beliefs and attitudes regarding our own body (Slatman & Widdershoven, 2010). Body image summarizes in how a person feels about the body that she *has.* In this sense, in the body image the person realizes that she *is* the body next to the idea of *having* it. The body schema offers what Merleau-Ponty called in phenomenology of perception "motor intentionality" (Merleau-Ponty, 2012, p. 113). What Husserl called intentionality is thus translated in Merleau-Ponty's thought; it is through the body schema, the motor skills the body has, that *it is* in the world:

> "I know that the objects have several faces because I can move around them, and in this sense I am conscious of the world by means of my body. At the same moment that my usual world gives rise to habitual intentions in me, I can no longer actually unite with it if I have lost a limb." (Merleau-Ponty, 2012, p. 84).

To concretize his argumentation, he provides several examples for the importance of body schema for his analysis: "I have an absolute knowledge of where my pipe is, and from this I know where my hand is and where my body is" (Merleau-Ponty, 2012, p. 102). Thus, for him, body schema and the embodied cognition as a condition for perception are one and the same: "the theory of the body schema is implicitly a theory of perception" (Merleau-Ponty, 2012, p. 213).

Merleau-Ponty examined more case studies from the medical field (Merleau-Ponty, 2012, p. i), such as the phantom limb, to further analyze the body schema and consequently body intentionality. Phantom limb cases are the ones where an amputee continues to have a sensation of their lost limb but a patient still senses the limb as to be in his body schema. Merleau-Ponty explicates the importance of the body schema through the example of the phantom limb (Merleau-Ponty, 2012), which is the example of a disruption of the knowledge of my body around its objects which needs to be re-adjusted. A knowledge that needs to be learned again in order to recognize the increased distance that the body has to perform in order to reach an object. Merleau-Ponty argued that an amputation disrupts the body schema (Merleau-

Ponty, 2012). For example, when Merleau-Ponty removed one leg from an insect the injured animal started immediately adapting to the new situation. Nonetheless, when the two insect's legs were tied together its movement was significantly hindered (Merleau-Ponty, 2012, p. 80). For Merleau-Ponty, when we examine people with disabilities, we can see the disturbance that is caused to a healthy body and he uses these exemplars as premises he can build his generalized arguments. As Dermot Moran (2000) says:

> "One of Merleau-Ponty's most useful methods was to examine cases where our normal, assumed relation to the world breaks down. It is failures of the system which reveal most clearly how the system works. These systems, these matrices of habitual action through which we approach the world, are not transparent to consciousness and can never be uncovered simply by reflection. We need to study people with malfunctioning systems in order to make manifest the nature of the system, which, when working properly, is invisible" (p. 419).

Besides the pathological cases that he was interested in, he also examined plenty examples regarding artifacts that were perceptually important (Merleau-Ponty, 2012). The example of his smoking pipe is already referred, but he also used the example of a typist who uses a typewriter, when he has accomplished a certain efficiency and his motor skills have adapted to the necessary movements, has incorporated in the body knowledge the required movements as he posits his body in such a way that certain results are occurring (Merleau-Ponty, 2012, p. 145). In a different type of relation to artifacts, Merleau-Ponty also referred to the case of a blind's man stick (Merleau-Ponty, 2012, p. 119). When a blind person uses her cane, she extends her tactile experience by 'feeling' the floor as well as the corners that she needs to be aware in order to move efficiently. It is an instrument through which the environment is perceived. Through these examples, which can be found in phenomenology of perception, Merleau-Ponty shows how the artifacts shape the perception of the user as in the case of the blind's man cane, or they create a new bodily knowledge.as with the typist and her typewriter. Using Merleau-Ponty's and Don Ihde's arguments Philip Brey (2000) notes the two interconnected categories of embodiment of artifacts: "An artifact may either become a means through which motor skills are expressed or a means through which perception takes place" (p. 54). The case of the typewriter is an embodiment that the body incorporates in its movement, a mean to express them, and the blind's man cane are means through which the perceptual skills are manifested.

In this section, I referred when needed to Husserl but mostly to Merleau-Ponty. The main purpose of this section was to provide the theoretical framework required to analyze the body and bionics. Merleau-Ponty's contribution comes in the form of his conceptualization of the body in the distinct way that "the body is our general means of having a world" (Merleau-Ponty, 2012, p.147). In contrast to Husserl's distinction between two concepts about the body, Merleau-Ponty unifies the cognitive processes with the

body structure and raises the significance of bodily movements and our body's relation with artifacts. With this contribution, Merleau-Ponty overcomes the essentialist approach regarding the body and places it in an interactive relation with the objects that can either be extensions, or become incorporated in the body of people. In the same direction, the *lived body* is the *own* body, an object distinct from other, organic and non-organic, objects. In the next section, I will examine the cognitive embodiment and the incorporation of prosthetic limbs to see how the body image and the body image can associate with prosthetic limbs.

3.2 Cognitive Embodiment of prosthetic limbs and the importance of sensorimotor feedback

Prosthetic technologies have received increasing attention not only from philosophers but also from scientists who examine the relation of the technology with the subject. Cognitive embodiment summarizes the way that users of different artifacts, like prostheses, can perceive and conceptualize the artifacts. In the cognitive embodiment, users may feel an artifact to be a part of their body. This feeling can be observed by a number of different methods, from interviews with patients to studies regarding how the brain activity of the user may be altered due to the use of the examined artifacts. The association of embodiment with prostheses has been examined by many philosophers, including Merleau-Ponty, and to examine the scientific approach of it, the cognitive aspect, is crucial to validate my argumentation. I will first examine empirical studies from a phenomenological interpretation, after which the evaluation of the embodied relations with users and prostheses from a scientific point of view will be introduced. Scientific studies offer the required theoretical background to solidify the phenomenological analyses. The biggest contribution of these scientific studies comes in the form of supplementing the qualitative methods used in the phenomenological tradition.

Craig Murray has analyzed the experience of prosthetic limbs from a phenomenological point of view (2004; 2008). His work is important in the field of the cognitive embodiment of prostheses since it gives us an insight on the users' perspective on their prosthetic limb many of whom experience an incorporation of their prosthesis on their body. At first, participants may feel unaccustomed to the changes of their body, but as the time goes by they get used to it. As one recent amputee claims: "the brain had not yet become accustomed to the change in mass […] but now it's not so noticeable" (Murray, 2004, p. 967). If the patient puts extra effort into learning how to operate the different mechanisms, the procedure becomes more "intuitive" as another patient claims: "once moving, in general, it's pretty much a matter of, well, I want to go from here to there, and I just walk. It's intuitive now" (ibid., p. 968). This habituation to the

prosthesis may lead to cases like one user who has been so accustomed to his prosthesis that forgot it was not attached to his body, "I […] got up, and forgot I did not have my limb on. I fell on the floor […]" (ibid., p. 968). More importantly, some patients explain the process with which this habituation takes place: initially, "it feels unnatural, so you're aware of it. That feeling [has] decreased over the years, so perhaps in some ways, I'm less aware then" (ibid., p. 968), or "though I've not got my lower arm, it's as though I've got it and it's part of me now" (ibid., p. 970). Some users perceive their prosthesis as an extension of their body, despite the fact that the specific artifact did not provide sensory feedback: "my prosthesis is an extension of my body. (I can actually 'feel' some things that come into contact with it, without having to see them. […]) It must 'feel' as close to not being there as possible" (ibid., p. 970). Additionally, one female user even attributed social meanings to her prosthetic limb claiming it was part of her personal space in a similar way as it is expressed by the physical body:

> "...many amputees feel that their artificial limb is somehow part of them, a simple example of this is that I wouldn't like just anyone putting their hand on my artificial knee, even though it is not actually part of my body's flesh, it is still mine even though it's a piece of plastic and metal. (ibid., p. 970).

In the interviews examined in Murray (2004) we can see that users may feel the prosthetic limb to be an extension or to be felt as part of their body. Both these terms are present several times in Merleau-Ponty's work, e.g. for extension (Merleau-Ponty, 2012, p. 232), and for incorporation (Merleau-Ponty, 2012, p. 93), and their use is meaningful in different aspects. If a prosthesis is seen as an instrument, then it is an extension, while if it is felt incorporated, then it can be felt as part of their own body. In the case of incorporation, Merleau-Ponty elaborates that the actions combined with the used artifacts: "shows that the actions in which I habitually engage incorporate their instruments and make them participate in the original structure of my own body" (Merleau-Ponty, 2012, p. 93).

While users can conceive prostheses as extensions or incorporate them into their body, when and if they get accustomed to them, it has been researched that sensorimotor feedback eases the integration in the body image of prostheses' users (Marasco, Kim, Colgate, Peshkin, & Kuiken, 2011). As the authors argue, providing the limbs with "tactile feedback is essential to intuitive control of a prosthetic limb and it is now clear that the sense of body self-identification is also linked to cutaneous touch" (ibid., p. 747). Frederick Mills (2013) moves one step further and aims to find conditions for which an incorporation in the body schema occurs by performing a phenomenological analysis. Using the argumentation of Merleau-Ponty, Mills (ibid.) identifies three different conditions necessary in order to achieve the embodiment of prosthetic limbs. First is the corporeal understanding, the "know how" of bodily movements (ibid.), e.g. the knowledge of how to type a text without contemplating the letters' position on the keyboard. Second,

transparency or, as Mills names it (ibid.), the absence-presence relations with external objects and my body. This is illustrated in the aforementioned example of the user of a prosthetic limb gradually forgetting that she is wearing one, in which case the prosthesis has become transparent and unnoticeable. But as Murray (2004) also notes a prosthetic limb, besides the mechanical maintenance of the limb, the user should forego a careful diet in order to avoid "overloading" the prosthesis (ibid., p. 970), in which case the prosthesis becomes *present*. However, in the same study conducted by Murray, not all users see prostheses as part of their body, rather as a useful instrument or a tool that extends their body. The third condition is sensorimotor feedback both in phenomenal and physiological terms: in the perception of the body schema and the way that brain responds to the change (ibid.). On the phenomenal level, which is Mill's interest, our sensorimotor skills are fundamental in navigating in the world, moving the devices to transparency, and improve the corporeal understanding of the users.

The idea that prosthetic limbs can be incorporated into the body schema is supported also by scientific studies. Using behavioral methods to trick the brain and evaluating the results with subjective reports by the participants, researchers were repeatedly able to assert the 'rubber hand illusion', i.e. that stroking a rubber hand (one that does not provide any kind of tactile sensation feedback to the user), can create a sense of feeling the hand as own by the participates (Botvinick & Cohen, 1998; Ehrsson et al., 2008; Tsakiris & Haggard, 2005). The point of these studies is that experiencing sensations is not the only factor necessary to feel non-corporeal artifacts as one's own, rather that the body image and schema can be a matter of perceptual change and brain adaptations. In a different manner of gathering scientific evidence, scientists studied users with prostheses and their relation with them; as Giummarra et al. specify:

> "prosthesis use relies on the same cortical areas as those involved in the movement of an intact limb. Prosthesis use may reinforce the preservation of the innate representation of the missing limb in the body schema, possibly through use of the same motor schemas that are used for regular bodily motion, as well as the conscious incorporation of the prosthesis into the body image, and thus may prevent cortical reorganization and, accordingly, reduce the intensity of phantom pain." (Giummarra, Gibson, Georgiou-Karistianis, & Bradshaw, 2008, p. 154).

This section has featured three key insights vis-à-vis prostheses and cognitive embodiment. The first of these came in the form of users' habituation on the technology or restrictions that come with the technology, such as maintenance, diet, or exercise required of the user. In addition, Mills articulated three different conditions which when satisfied cognitive embodiment can be achieved. The phenomenological analyses of Murray (2004) and Mills (2013) are supported by different scientific studies which show that prostheses users use the same cortical areas that are used by users with an intact limb. The highlighting of

basic preconditions regarding cognitive embodiment and, also, having the scientific evidence to support them, is useful in order to understand the meaning that prostheses may have for the user. For instance, female prostheses users may feel differently if the prosthetic limb is modeled from a male hand (Murray, 2008). Thus, for prostheses, we need not only comprehend the specific complexities in technological devices but also the complex meanings and uses that individuals attribute to them or may feel about them. The insights derived in this section thus provide a supplement to the ideas explained in the first chapter regarding the different social and cultural meanings, and their relevance to a huge role in the creation of specific technologies, but also on the varied interpretation of these technologies. In the next section, I will focus on bionic limbs and how they can be analyzed using the framework provided from Merleau-Ponty.

3.3 Examination of bionic limbs from a Merleau-Pontean view

The remaining of this chapter will examine bionic limbs under a Merleau-Pontean analysis. I will show how his concepts regarding the unity of the *corps vécu* stand, after which three criticisms on his analysis will feature, arguing that it falls short in accounting for bionic limbs. Merleau-Ponty transcended from the initial thinking of subject as the sole preceptor to a concept that the subject is embodied and that its movement in the world is fundamental in conceptualizing the world. When compared to the other objects that Merleau-Ponty examines, bionic limbs offer more than what the rest of the worldly objects can offer. Their sensorimotor feedback and myoelectric control are active means through which the user can know the world and shape perception. In other words, bionic limbs contribute perceptually and are displaying the users' motor skills. Yet, when compared to artifacts examined by Merleau-Ponty e.g., a blind's man cane or a typist with her typewriter, which respectively contributes perceptually and displays motor skills, we can see that there is a difference. Regarding their perceptual contribution, bionics' difference with the blind's man cane is that the later passively intervenes between the floor and the user's hand e.g., through its solid structure the user can feel the differences in different surfaces, whereas bionic limbs play an active role in decoding and shaping the surroundings.

The user of a bionic limb does not feel the pressure change on her skin, which is what happens with the cane, rather she perceives through the active role of artificial sensations the differences on surfaces or objects. The active role of a bionic limb comes forth because the experience of the sensations is decoded by the mechanisms of the bionic limb. This comes in contrast with traditional prosthetic limbs of which mechanisms do not decode the environment rather they offer a passive way of communicating with the world. For example, the blind's man cane only informs the user about the surroundings and their distance while in contrast the bionic limb with artificial sensation actively decodes the structure, texture, or even

temperature of each object. Regarding the display of motor skills, with a bionic limb the user can not only have control over the technology by commanding its targeting, but can also extend the abilities that existed prior to the use of the bionic prosthesis. Mills (2013) considers sensorimotor feedback important for incorporating the technology as it is crucial for getting accustomed to the users' corporeal understanding, as well as for the transparency of the object. Combined with the two reasons which distinguish bionic limbs from other technologies that cannot offer sensorimotor feedback or myoelectric control over their objects, bionic limbs may offer improved potential in being incorporated when compared to other artifacts. Returning to Merleau-Ponty, and using Mills study (2013) as a stepping stone, we can see that the characteristics a bionic limb have sufficient mechanisms to be incorporated and consequently be part of the *lived body* or the "own body or proper body" as distinct from all the other objects (Moran, 2000, p. 423).

However, bionic limbs remain objects of the world as they reside in-between the world and the users. On the one hand, they contribute to the lived experience, or, as Merleau-Ponty would say, to the embodied cognition of the own *lived body* and, thus, philosophically, they can be conceived of as body parts from some users. As seen in the section regarding the cognitive embodiment of prostheses users can get the sensation that a device with which they perceive the world is in fact a part of their own body. On the other hand, when the agentic nature of the bionic limbs emerges e.g. that the bionic reclaims its position in the objective world through maintenance or other disruptions, the user would have to detach a part of her body. While a prosthesis may be incorporated at the same time it has the meaning of being an object of the outside world making it never completely theirs. A bionic limb alludes to the nature of being just an instrument as e.g., a blind's man cane, and is transferred to the realm of shaping and mediating experiences, in a similar way as my natural hand contributes to my experiences. Nevertheless, at the same time, the device fails to merge completely to the users' subjectivity as it remains an artifact of the world; a breakable device which needs repairs or upgrades, other actors' having a say on the processes or on the artifact itself, and so on. Users of bionic prostheses have a distinct way of perceiving the world and conceptualizing their body, a body that can be subject to change, not peripherally as happens with an instrument, but in the manner that because artificial sensations contribute to a user's perceptions, the changes can affect an incorporated artifact and hence the very essence of what Merleau-Ponty called *corps vécu*. Forming an odd handshake between the world and the user, bionic limbs offer to the user sensations with which she can interact with and perceive the world while at the same time they remain instruments fleshed out from the world carrying specific meanings.

Bionic limbs may become incorporated artifacts of which disturbances remind the user of its worldly origins are in contrast to the rest of the body which has always been there. A relation which shows not only the relation of the user with the prosthesis but also the relation of the world to the prosthesis which

is instantiated when the disturbances occur. The prosthesis is the locus of the experience between the user's roaming and habituating the world with the prosthesis and the way in which the world contributes to the lived experience of the user. Placing Merleau-Ponty's analysis in the center of the attention once more, the user may incorporate not only the artifact, but additionally the agentic nature of the bionic limbs, transforming the corps vécu, not only perceptually, but additionally in terms of the own body. These blurred boundaries show the difference between the own corporeal body, the natural body, and the own non-corporeal body, the bionic limbs. After all, the corps vécu is enriched with an artifact, the bionic limb, which can contribute in more manners than just in perception through the artificial senses because with bionic limbs their agentic nature is incorporated as well.

Overall, the Merleau-Pontean analysis can help us to crystallize where the bionic limb resides considering the body. It can certainly contribute to how the body schema is altered. The important difference with other artifacts, and using Murray (2004; 2008) and Mills (2013), we can see that bionic limbs can shape certain beliefs regarding the artifact and how deeply it may connect with the body, i.e. the body image. In this sense, the incorporation to the *lived body* that may occur, due to the mechanisms that a bionic limb may offer, show how a bionic limb can be a part of the body in the same way as the own body is perceived. In the level of the own body (*corps propre*), which is the *lived body* as distinguished from the other objects of the world, the user experiences the issue of incorporating an artifact which, in its agency but not in matters of 'ownness', is distinct from the other objects.

3.4 Criticizing Merleau-Ponty

Three main criticisms will be introduced in this section. The first is developed through original argumentation in this thesis and two are derived from existing literature. Together they support the case that a Merleau-Pontean framework is insufficient when analyzing the complex nature of bionic limbs. The three criticisms that will be presented here are summarized to a) my argument that, by using Merleau-Ponty's framework, we end up in an ontological ambiguity regarding the status of bionic limbs, i.e., if they belong to the *lived body* or are objects of the world; b) an argument found in the literature (De Preester & Tsakiris, 2009; De Preester, 2011) that Merleau-Ponty used the term 'extension' and 'incorporation' interchangeably; c) that Merleau-Ponty's framework cannot examine the agentic nature of bionic limbs because in Merleau-Ponty's interest the agency was of humans and not of artifacts (Merleau-Ponty, 2012). However, the agentic nature of objects has been argued by plenty scholars since then, e.g., Latour, 1993;

Ihde, 2002. These criticisms are instrumental for the purpose of this thesis and its main research question and will be discussed extensively in the next chapter.

a) Ontological ambiguity.

First, the issue of an ontological ambiguity regarding the status of bionic limbs when contrasted with the natural body will be analyzed. In the case of the natural body, we can understand that if it is part of the *lived body* then it can also be part of the *own body*, except some medical cases like BIID. The very fact that the lived experience of Merleau-Ponty's framework is inextricably connected with sensations — sensations that can be offered in a bionic limb — is making the Merleau-Ponty analysis problematic, as the bionic limb resides in the *lived body* but, at the same time and due to its agentic nature, also in the world. The bionic limb can neither be part completely of the world nor solely part of the *lived body*. This difference, when compared with other artifacts, gives a substantially distinct meaning to bionic limbs. For example, the objects examined by Merleau-Ponty are part of the experience of the user, contributing perceptually or in the motor skills field, but had no active role on encoding or decoding the movements. In other words, a bionic limb contributes actively in the lived experience by structuring the senses that distinguish an experience received from the world in contrast to experiences that are perceived by my body.

In these terms, since the lived experience that Merleau-Ponty argues for is conceptually connected with sensations and sensorimotor feedback, it creates an ambiguity regarding the ontological categorization of bionic limbs. Because, if the artifact can have sensorimotor feedback in the same way that a corporeal hand has, then it should be categorized as a part of the *lived body*. However, the worldly disruptions, and the agency of the bionic limbs, obstruct this feeling and facilitate a temporality to the experience of bionic limbs being a part of the *lived body*. This temporality breaks the continuum that the *lived body* has had, both the corporeal and the non-corporeal, and reminds the user that the bionic limb is not solely a part of her *lived body*. Further, different actors, who contribute to the shaping of this experience of bionic limbs, e.g. insurers and manufacturers, provide to a bionic limb different meanings and requirements. For instance, for these agents the bionic limb is conceptualized as an instrument and the meanings they embed on bionic limbs are crucial for the acquirement of the desired prosthesis. Due to these reasons, while a bionic limb can be part of the *lived body*, the disruptions and constructed meanings make the bionic limb a *more* worldly object than other parts of the *lived body*, e.g., a corporeal hand. In other words, the ontological ambiguity is met when we solely use Merleau-Ponty's framework to understand the *lived body* and bionic limbs. The ambiguity regards whether the bionic limbs belong to the *lived body* or if they are worldly objects and to what extent a categorization on both cases can be applied.

b) Interchangeability of the terms 'extension' and 'incorporation'.

The second problem is that, as De Preester (De Preester & Tsakiris, 2009; De Preester, 2011) argued, Merleau-Ponty uses the terms *extension* and *incorporation*, even for the same example as is the blind man's cane, interchangeably. Thus, the fact that artifacts can be extensions or be incorporated is not analyzed in the depth that a contemporary analysis of the current technologies would require and especially for one type that can contribute both perceptually and to the motricity of the body. The distinction between incorporation and extension is significant in the case of bionic limbs because if the artifact is a mere extension, then the sensorimotor feedback and all the unique experiences that bionic limbs may offer to the user, would be different categorizations of instruments, of objects that work as an extension, in the same way that a blind's man cane extends the abilities of its user. Nevertheless, if the artifact is incorporated, then, philosophically, the user should perceive the artifact as part of their body. This distinction is crucial on how to proceed in analyzing bionic limbs. Despite the fact that some users may conceive of bionic limbs as belonging to either category, the issue in this section is not whether users conceive of the technology as part of their body or not, but whether the bionic limb can be thought to belong in both categories at the same time; both as an extension and as incorporated. This ambiguity between the two terms creates an uncertainty on how bionic limbs should be analyzed, as incorporated or as extensions, and is frequent in Merleau-Ponty's work.

c) The agentic nature of bionic limbs.

A third issue with Merleau-Ponty's approach is that in the artifacts he analyzes the agency that they may carry is not examined. Instead, throughout phenomenology of perception the only agency that is examined is the agency that the subjects may have towards objects. In his reasoning, artifacts are viewed solely as objects of which the important fact is the manner through which they shape the perception of users or users' motor understanding. It is the human agency that he often examines and how this agency interacts with the world where objects and artifacts are included. The conceptualizations that Merleau-Ponty offers are important for the understanding on how they can alter our perception of our body, but fail to produce an insightful approach regarding the artifacts' agency. Canes may vary from a wooden stick to an artistically designed cane, can be expensive or can be even built by a company of the most advanced canes for blind people, however, since the experience they offer is limited in recognizing just the distance of different objects, their contribution to the users' life is limited to recognizing the distance between the user and the world. On the contrary, a bionic limb not only has multiple actors that assess each situation but additionally their decisions contribute in a more in-depth way to the users lived experience. For instance, the manufacturer's decision on whether a product series should be discontinued, upgraded, or downgraded, reflects on how the user of a bionic limb may feel about prostheses she owns belonging in the same product

series. Thus, the agency of a bionic limb can be from different actors that can shape the artifact and the users' experience, but also, the agency can be found in the artifact as of how the artifact is built.

In summary, in this section, Merleau-Ponty's argumentation was used to analyze bionic limbs. In this effort, I analyzed bionic limbs as contributing to the lived experience in a deeper way than other artifacts may do, and I also included the worldly side of the artifact. As a result of this analysis, three different issues emerged. First, that since bionic limbs are at the same time active contributors to the lived experience and simultaneously an object prone to disruptions from the world, the ontological categorization of bionic limbs regarding whether they belong to the *lived body* or to the world creates an ambiguity. Second, taken from the argumentation of De Preester, Merleau-Ponty uses the terms extension and incorporation interchangeably a fact that results in further ambiguity regarding how bionic limbs should be conceptualized. Third, even though Merleau-Ponty does not focus specifically on technologies, his analysis regarding instruments and artifacts fails to see the complex and multidimensional agency that contemporary artifacts can have, either as extensions and plain products or as incorporated body parts.

3.5 Conclusion

The purpose of this chapter was to discuss the manner in which Merleau-Ponty's work can help us analyze artifacts and prostheses regarding body perception and cognitive embodiment, and what criticisms can be made when his analysis is applied to bionic limbs. This chapter's research question was : *how can Maurice Merleau-Ponty's work help us analyze prostheses regarding body perception and cognitive embodiment, and what criticisms can be made regarding his analysis when applied to the topic of bionic limbs?* In order to answer this question, I gave an overview of some of the related ideas of Merleau-Ponty to body and prostheses. Then I proceeded to associate prostheses in general with cognitive embodiment and showed from two empirical sides the way that some users perceive prosthetic limbs and how bionic limbs may have better results in achieving cognitive embodiment. I did so using studies from the literature such as a phenomenological interpretation of qualitative findings and with an approach based on scientific findings. The users' experience regarding the cognitive embodiment of prostheses offers the scientific validity with which the analysis and discussion of this thesis are meaningful and scientifically relevant. Then, I started focusing on how, using Merleau-Ponty's framework, we could analyze bionic limbs, which resulted in three main criticisms to his work. These three criticisms are summarized to: first, my argument that there is an ontological ambiguity regarding whether the bionic limb is part of the *lived body* or not. Second, an argument from De Preester & Tsakiris (2009) that Merleau-Ponty used the terms 'incorporation' and

‘extension’ interchangeably. Third, that Merleau-Ponty’s framework does not suffice to examine the agentic nature of bionic limbs. The question in this chapter is responded by having a thorough understanding of Merleau-Ponty’s analyses and the way that they can reach an approach regarding bionic limbs.

Chapter 4 - Postphenomenology, Hybrid body ownership, and bionic limbs

In this chapter, I will further examine the ways with which an analysis can surpass the criticisms posed here by using arguments from the literature with the overarching purpose to focus with more clarity on the matter of body ownership and how new implications may emerge. The first and second chapters had two different purposes: first, to examine the historical development of prostheses accompanied with an analysis regarding the different actors and agencies that are responsible for the development of bionic limbs. Second, to examine, from a phenomenological point of view, how bionic limbs contribute to the experience of the user supported with relevant to phenomenology scientific analysis. Additionally, to claim why Merleau-Ponty's analysis is insufficiently equipped to examine the phenomenon of bionic limbs. In this chapter, I will use the analytical framework as outlined in the previous pages and will examine, from a Postphenomenological point of view, how the issues mentioned previously can be solved with a different framework. In order to analyze the hybrid agency of bionic limbs and their users' experience with this technology, answering the following two questions will be the leading aim of this chapter*: how does the philosophical embodiment of bionic limbs connect with body ownership, and how do bionics question established concepts regarding body ownership?* The word 'philosophical' in the philosophical embodiment clause comes to distinguish the cognitive embodiment presented in the previous chapter with the embodiment as developed by Ihde (1990; 2002). While both terms have a common starting point, that is, embodying an artifact or a cultural concept, cognitive embodiment, as elaborated by Murray (2004; 2008) and Mills (2013), refers to the cognitive processes regarding the said artifact or culture. Murray and Mills examine as scientists the way a prosthetic limb can be embodied and empirical research to support their claims. Don Ihde (1990; 2002) examines the embodiment conceptually in terms of what meanings can have such an embodiment.

In order to answer the research questions for this chapter, the text is divided in the following sections: in section 4.2, I will use arguments from postphenomenology to address the criticism for Merleau-Ponty. Specifically, I will first examine the agentic nature of bionic limbs and use the argument by Ihde (2002) that the relation of a user with an object may involve different degrees of symmetry followed by an examination of how the agency of bionic limbs is expressed. Then, in section 4.2.2, I will examine the *decisive role of ownership* to in understand the difference of the terms 'extension' and 'incorporation'. In section 4.3.3, I will respond to what I claim to be an ontological ambiguity regarding the status of bionic limbs in relation to the conceptualization of the *lived body*, by using arguments about the cyborg intentionality from Verbeek (2008). At the end of section 4.2, a conclusion will be offered regarding the

conceptualizations that have been presented to that point, and how these can aid in deepening the understanding of the *lived body* when related to the bionic limbs. At the second part of this chapter which starts at 4.3, I will use terms related to the *technological body* by Ihde (2002), which is the crossing of the *lived body* with the cultural body when related to bionic limbs. Every section of this chapter paves the way towards introducing the term: 'hybrid body ownership' which will be presented at the end of this chapter, address this chapter's research question and is linked to the core with the main research question of this thesis.

4.1 Using Postphenomenology to resolve the criticisms to Merleau-Ponty

Postphenomenology can provide a fruitful argumentation to clarify the ambiguities argued earlier and can also help us move one step further with this analysis. Postphenomenology has a detailed approach towards technology — a focus that is lacking in phenomenology. Specifically, in phenomenology as developed by Merleau-Ponty, the focus is on how the body interacts with the world in which there are objects and artifacts. Hence, the focus is not on the artifacts but rather on the body and the user as an agent in the world. Examples like a cane or a car are not examined as technological products but as factors of relating to the perception of a person. In every example that Merleau-Ponty uses his effort is to affirm his theory and make a general claim about the human and the world. Instead of producing a theoretical approach that would be applied to the world, in postphenomenology the focus moves to how specific objects may create certain meanings and the relation that a person may have with a specific technology. In this direction, postphenomenologists are using empirical research to affirm their arguments. To this extent, there has been work in prosthetic technologies by plenty scholars. Thus, while postphenomenology has direct links with phenomenology, the empirical approach allows us to study new directions and adapt the applicability of the theory.

This section, which is divided in three subsections, addresses the issues pointed in the previous chapter by using arguments from a postphenomenological point of view. Postphenomenology has the benefit over traditional phenomenology in that it enables a focus on the agentic nature of bionic limbs, which is the focus of the first sub-section. This supplements Don Ihde's arguments (2002) vis-à-vis the degrees of symmetrical relations between different objects and their users. The second section clarifies the ambiguities that emerged from the terminology used by Merleau-Ponty regarding the interchangeability of the terms 'extension' and 'incorporation' by using the contribution of De Preester et al. (De Preester & Tsakiris, 2009; De Preester, 2011). This argumentation sheds some light on our understanding of bionic limbs, but are also crucial in creating a link between the concept of ownership with prosthetic technologies,

and prosthetic limbs in general. Finally, the last part focuses on clarifying what I argue to be an ontological ambiguity regarding the bionic limbs and the *corps vécu* used in Merleau-Ponty's work. While, as has been argued by Latour (1993), the object and the subject are seen in phenomenological discourse as a relation of a dichotomy, in the work of Verbeek (2008) we can find a new understanding regarding the merging of a subject with a technology. This merging urges us to create new conceptualizations regarding how we see such a relation. While the merging that Verbeek argues for takes place in the physical dimension e.g. surgical implants, I argue that the merging that takes place in the case of bionic limbs regards the *ownness*, and how the subject relates to the object. At the end of this section, I will have used the postphenomenological framework as a means to overcome the initial issues presented by bionics limbs when analyzed from a strictly phenomenological point of view. Finally, this task paves the way to analyze how the new understanding of body and technology urges us towards a new conceptualization of this relation.

4.1.1 Degrees of symmetry and the agency of bionic limbs

One of the purposes of phenomenology was to overcome the rigid distinction between the subject and the object which meet on the common ground of a relationality of the objects and the subjects (Verbeek, 2005). However, as I argued in the previous chapter, with Merleau-Ponty's theoretical framework we could not analyze in depth the process under which bionic limbs reach the user; additionally, it does not reflect on the agency of the artifacts. This criticism was initially articulated by Bruno Latour (1993) and then discussed in the context of postphenomenology by Ihde (2002), and Verbeek (2005).

To overcome these shortcomings, a number of scholars have further developed the field into what is now called postphenomenology. Postphenomenology, in contrast to traditional phenomenology, is capable of addressing these issues, but additionally, it also introduces a new understanding in hermeneutics regarding the contribution of the technology on how they mediate our experience. Furthermore, postphenomenology focuses on the agency that artifacts create, but in a different manner than Actor-Network Theory (ANT) of Latour. For instance, Bruno Latour argued that carriers of agency can be not only human actors but also artifacts, as non-human actors, which contribute in a specific way (1993). In his line of reasoning, a speed bump will make the driver reduce the speed of his car thus it becomes an *actant*, an agent which acts in reducing the speed of the car. However, ANT does not focus on the experience of the user but examines the way that constructed networks play a role in how humans interact with the world. In a different vein, postphenomenology acknowledges the presence of these networks but also examines

the shaped experience of these relations (Verbeek, 2005). Thus, Latour's contribution in analyzing artifacts is not the only one which can be usefully applied in this context. The most prominent postphenomenologist, Don Ihde (2002), takes the argument from phenomenology that humans are related to the objects of the world but also includes in his analysis the agentic nature of non-human actors. However, and contrary to Latour, Ihde focuses on the way that different objects, as non-human actors, can mediate the experiences of users and, additionally, co-constitute subject and object respectively. Nonetheless, while in Latour's reasoning the relationality of objects is symmetrical, in Ihde's thinking the symmetry has different degrees.

As elaborated in Bodies in Technologies (2002), there are degrees of symmetry between humans and different artifacts (ibid., p. 96), degrees of symmetry which other scholars, who examine relations with objects, do not take into account their complexity (ibid., pp. 88-100). In elaborating his concept, Ihde gives the example of a pen which offers to the user a different relation than that of a pair of eyeglasses, not only because their purpose is fundamentally different but also because their contribution in experiencing is different. In these terms, postphenomenology provides additional insights, furthering our understanding from the points that Merleau-Ponty has raised. In Merleau-Ponty's terms, the examination of artifacts is examined in terms of perception and hermeneutics, meaning how they change the experience and the perception of the user, but he does not delve into the different levels of such an experience. Thus, the different symmetries that Ihde argues for can provide us a different categorization among different artifacts, as for example between a traditional prosthetic limb and a bionic limb. Having thoroughly examined in the first chapter the complex process behind the acquisition of a bionic limb and also the different technologies and their outcomes regarding the user, we can see that both the process and the technology can be quite complicated.

In elaborating the different degrees of symmetry between the humans and nonhumans actors, Ihde (2002) uses the example of a pen. In the different relations formed, he explains how the user, through the pen, writes the letters in the paper and the pen "modifies the bodily action undertaken" (Ihde, 2002, p. 96). Though symmetrically, the pen is also modified by the user meaning that the pen is worn out after consecutive use, the ink gets depleted, and so on. The relation between the user and the pen constitutes both the user, e.g. the writer modifying her bodily position, and the pen, e.g. the pen wears out. He then compares the symmetrical relation between the human and a pair of eyeglasses. In this case, the pair of eyeglasses modifies the users' seeing but it is not obvious how the user modifies the pair of eyeglasses. In his thought, humans interact with the pair of eyeglasses in a larger context at the stage of design or manufacturing. In this context, Ihde argues that there are different degrees of symmetry among different objects as not all objects and humans interact with the same symmetrical relation rather in different degrees of symmetry.

Moving on to the case study of prosthetic limbs a similar correlation can be detected. In the case of a traditional prosthesis, there are different levels of agency compared to bionic limbs. In both cases, the agency of the artifacts modifies the bodily movements of the user where the user has to adapt and make movements that occur because of the prosthesis, for example walking. Also, the prosthesis may be worn out so that the user affects the artifact. However, the agency of bionic limbs transcends in more than those two levels. The case where a bionic limb mechanically adapts its mechanisms when the user makes a certain movement, e.g. climbing the stairs, results in a different change to the bodily movements of the user. Moreover, as elaborated in the second chapter with the cognitive embodiment and the study of Mills (2013) on the importance of movement for users of a prosthesis to incorporate it, certain functions of a bionic limb intervene with the understanding of the user's *body image* or what she *feels* to be her body. In the case of a bionic limb, a user does not only use the artifact as an instrument but may feel accustomed to it in a deeper relation than with other instruments, and especially with those which do not have, say, artificial skin or sensorimotor feedback. The concept of bionic limbs having different degrees of symmetry compared to traditional prosthetic limbs allow us to argue that more degrees of symmetry, when compared to other artifacts e.g., a pen or a traditional prosthetic limb, may result in a deeper symmetrical relation with the artifact. In this deeper symmetrical relation, which has more degrees of symmetry, the relation between the bionic limb and its user has more degrees of interaction. Thus, the agency of bionic limbs not only occurs on the levels regarding the materiality of the artifact, e.g. climbing the stairs, when compared to traditional prosthetic limbs, but also the manner in which the users conceptualize in a different way their body.

In this section, how postphenomenology allows for a deeper analysis than Merleau-Ponty's approach, regarding the agentic nature of bionic limbs. In this direction, postphenomenology allows us to explore the multidimensional agency that is embedded in the bionic limbs. Using Ihde's arguments on the different degrees of symmetry, we can see that a bionic limbs' agency carries different degrees of symmetry when compared with a traditional prosthetic limb, such as the different mechanisms that a bionic limb may incorporate whereas a traditional prosthetic limb is lacking. However, the agency of bionic limbs does not limit itself in the mechanisms which result in different bodily movements and adaptations, rather in the terms of the richness of such experiences. In this sense, the symmetrical relation with a bionic limb goes onto different levels than when compared to a traditional prosthetic limb, since the first artifact may be easier to cognitively embody than the latter one.

4.1.2 The decisive role of ownership in the discussion about extension vs incorporation

In order to clarify the complex agentic nature of bionic limbs and the involved meanings, this section will explore the interchangeability of terms by Merleau-Ponty and will highlight the importance of ownership in this conceptualization. At the end of the second chapter, I pointed out that Merleau-Ponty used the terms 'extension' and 'incorporation' interchangeably. This point was initially made by Helena De Preester and Manos Tsakiris (2009) and elaborated further by De Preester (2011). While it has been argued that with a careful textual analysis a clarification can be achieved (Besmer, 2015), the distinction becomes important in order to understand the difference in prostheses use and the significance of body ownership in this process, in this sense the clarification remains relevant and significant to this thesis. In the paper by De Preester and Tsakiris (2009), the authors examine in empirical terms the differences between extension and incorporation. Pointing to the ambiguity that exists generally in the literature and specifically in Merleau-Ponty's influential work and the overall difficulties in defining such a thin line, they provide scientific evidence in which incorporation and extension are phenomena which apply to body ownership. Their contribution to the literature is not the only one which examines the case of body ownership. Other scholars (e.g., Vignemont, 2007; Tsakiris, 2010; Gallagher, 2001) have argued for different conditions that such an experience may take place. However, the comparison of different theories regarding body ownership would fall outside of the scope of this thesis and would move towards an epistemological analysis of how we can have safe conclusions about such experiences. Thus, by using the paper of De Preester and Tsakiris (2009) as a tool and not as a universal rule, we can clarify the conceptual difference between the two terms as developed in this thesis and understand whether a non-corporeal artifact should be seen as a tool, i.e. an extension, or as a body part, i.e., being incorporated.

As De Preester and Tsakiris argue (2009), there is evidence that tool use results in neuron re-organization in the brain e.g., the user of a tool perceives changes in what her body can reach or perform. However, this extension of the user's capabilities does not result in an alteration of their sense of body ownership. In other words, the tool extension does not result in conceiving this tool as a body part in the same manner that the use of a fork does not result in perceiving the fork as a body part (Botvinick, 2004). Additionally, incorporation of non-corporeal artifacts does not result necessarily in their inclusion in the users' sense of their body ownership. As they argue (De Preester & Tsakiris, 2009), the sense of ownership of incorporated artifacts only occurs if the artifact responds or replaces a body part which belongs to a *body-model*. They define "*body-model*" as the abstract concept which

> "contain a reference description of the visual, anatomical and postural properties of one's own body (Costantini & Haggard, 2007; Tsakiris & Haggard, 2005), that are maintained through time, in contrast to the body schema model, which is continuously updated as the body moves (Wolpert et al. 1998)" (De Preester & Tsakiris, 2009, p. 313.).

In other words, the *body-model* offers a link to what is perceived to be anatomical, visually, and posturally as a body. In this sense, a dog's leg will not apply in this concept of *body-model* since it does not resemble a human's body in either of the three conditions mentioned above. On the contrary, an artifact that may resemble a body part —visually, anatomically, posturally— can be perceived as part of the *body-model*. Hence if an object can be seen as relevant to the *body-model*, the sense of ownership can be extended to include the non-corporeal object. Oddly, this change in body ownership based on pre-existing body modes occurs not only in amputees, who used to have a limb that can now be replaced but additionally to users who have a congenital limb absence in which case they were born without a limb. A person born without a limb can feel as part of her own body a non-corporeal object because she perceives it as a reference to another body part, e.g. another limb. To clarify this fine distinction, De Preester elaborated in another paper (2011) that in general there should be a better understanding of different prostheses and what these may mean for the user. For instance, De Preester questions whether the body artist Stelarc will ever feel the third prosthetic hand, which was surgically implanted in his body, as part of his own body because the existence of a third hand does not replace or apply to a part of the *body-model* (ibid., p. 126). To sum up, the decisive parameter whether a non-corporeal artifact is seen as a tool or as incorporated body part lies in the sense of ownership regarding that object. And for the body ownership to be achieved, there are certain limitations, one of which, as De Preester and Tsakiris argue (2009), can be the *body-model*. This limitation outlines the variety and number of objects that can be conceived as body parts. In this sense, while a prosthetic limb may be incorporated to the corporeal body, body ownership regarding the said artifact can be absent if it does not apply to the *body-model*.

Returning to the criticism that was made in the second chapter regarding the use of the terms extension and incorporation, the difference is a crucial one. De Preester's contribution remains important, since it urges us to classify different conceptualizations about objects in general and prostheses specifically. In other words, incorporating an artifact does not necessarily occur for every prosthesis user as there are different conditions that may occur which may prevent the user from feeling the prosthesis as own. To my knowledge, there are no studies regarding the examination from a postphenomenological framework of the experience of artifacts perceived as own. While postphenomenology focuses on the experiences of artifacts, for example, what do they mediate and of what nature is their hybrid intentionality, there is no analysis on what it means for the experience of the users of objects that are conceived to be part of the own body and what they can mediate as for example in the case study of prostheses and bionic limbs.

Postphenomenological analyses for prostheses can be found in the work of Don Ihde (2002), or Kirk Besmer (2012; 2015), and, of more relevance to my thesis, Lucie Dalibert (2014), who, among other technologies, focused on prosthetic limbs and discussed De Preester's articles (p. 209), but the

aforementioned scholars do not focus on how different the experience of a non-corporeal object may be if the object feels as a part of the body. Overall, by combining the works of Murray (2004; 2008), Mills (2013), and De Preester neuroscientific and (post) phenomenological oriented investigations (De Preester & Tsakiris, 2009; De Preester, 2011), we have gained an insight of the experiences of prostheses. An example of this can be found in Murray's work, in that prosthesis use is more complex than a plain instrument, and while it may be perceived by some users as an instrument, it is not the same for every user, e.g. they may feel the object as incorporated. By using the work of Mills from the second chapter, we can see that bionic limbs' characteristics may suffice to conceive these objects as body parts. Finally using De Preester's work we can see that by understanding the difference between incorporation, extension, and how incorporation does not lead necessarily to body ownership, we can start approaching postphenomenologically the matter of ownership of a prosthesis, in this case of a bionic limb. In the next section, I will engage with the ontological ambiguity presented in Merleau-Ponty's work by connecting the concept of ownership with postphenomenology.

4.1.3 Responding to the ontological ambiguity by connecting ownership with postphenomenology

The last criticism of Merleau-Ponty was that using the phenomenological framework of his work to analyze bionic limbs results in an ontological ambiguity regarding the status of bionic limbs. The reason for this ambiguity is that in phenomenology, and specifically in Merleau-Ponty's theory, both subjects and objects are two different poles which connect and relate with each other. While Merleau-Ponty tries to provide an understanding of how objects shape our perceptions and experiences, the fact remains that his theory does not avoid falling into the trap of a subject-object dichotomy. This dichotomy was pointed by Bruno Latour (1993) and acknowledged from a postphenomenological point of view by Verbeek (2005). The ontological ambiguity then boils down to the concept that due to the nature of bionic limbs technology and the dynamic that sensorimotor mechanisms, neuromuscular control, and artificial skin may offer, bionic limbs could be categorized as part of the *lived body*. However, due to the disruptions that may occur among the user, the technology, and the different actors, the technology could not be ontologically categorized solely as part of the *lived body*, i.e. as a body-part that can be felt as one's own as can happen with other body parts of the *lived body*.

Postphenomenology offers a way out of this ontological ambiguity by overcoming the distinction between subjects and objects and focusing on the co-constitution of both subject and object. Both the user

and the bionic limb are constituted in their mutual relation. This co-constitution is crucial because in phenomenology's understanding the *lived body* is a point of departure, a pure concept that intervenes and relates with objects, but in postphenomenology, the *lived body* ceases to be the center of attention. After acknowledging the phenomenological relationality, postphenomenology examines the constitution of both subject and object and how this relation forms the experience of the user. In the following of this section, I will elaborate on these concepts of postphenomenology and will conclude on how it can respond and clarify the new relation.

Don Ihde argues that in human-technology relations technology mediates our various experiences. In the mediation theory of Ihde, there are four different kinds of relations between the Human, the Technology, and the World (1990). These interactions could be schematized through different variations of the human, the technology, and the world:

Human – Technology – The World

For the purpose of this thesis, I will not explain in great detail the different categories of Ihde's mediation theory as the embodiment relation, one out of four, is the most useful for elaborating the approach of this thesis. In the embodiment relations, the user of a technology, say of a pair of eyeglasses, experiences the world through them. This relation shapes the manner in which the user perceives the world. The pair of eyeglasses, on the premise that they do provide a better eyesight, withdraws from the user's attention and mediate the world to the user. Then the mediated relation of embodiment is schematized in

(I-technology) → world

This schema means that the user of a bionic limb, if and when it becomes transparent or withdraws from our attention, experiences the world through the technology. This experience is shown in the scheme by the arrow which is the intentional relation towards the world. While Don Ihde opposed (2002; 2012) that a prosthesis could withdraw from the user's attention meaning that it can never become fully transparent, studies like Murray's (2004); Mills' (2013); and De Preester's (2011) indicate that a different understanding is in order.

Ihde (2012), in a response he wrote to De Preester (2011), argued that with a prosthetic limb the user cannot feel the warm sand, rather that the user only feels the pressure on her skin from stepping on different surfaces. In this manner, the prosthesis cannot completely withdraw from the perception of the user as the lack of experiencing the warmness of the sand distances the user from the object and the world. However, the way that current technology is developed, this lack of transparency due to the *inexperiencing* of the warm sand, does not occur anymore as a user can have an artificial skin with which she may perceive

the world, i.e. the warmness of the sand. Furthermore, the hypothesis of de Prester suggests that if there are met certain conditions, then a sense of ownership occurs over the prosthesis in which case the transparency can be better indicated. However, the embodiment relation as proposed by Ihde still does not clarify the ontological ambiguity, since the relation remains more complex than just for the bionic limb to become transparent or not. While users experience this transparency and feel a non-corporeal artifact as part of the own body, the relation with the technology cannot be examined from a simple embodiment relation.

Verbeek's theoretical contribution (2008) moves one step further from plain embodiment relations and allows us to solve the ontological ambiguity in Merleau-Ponty's work. The reason for resolving the ambiguity is that it allows us for an understanding for the user to be merged with the technology. Due to the merging of technologies with the user, the use of certain technologies may result in a deeper relation than just an embodiment relation. Examples that Verbeek provides are cochlear implants, artificial heart valves, pacemakers, or even antidepressants, which form a new entity: the cyborg. The difference between the embodiment relation of Ihde's work and the cyborg conceptualization of Verbeek is that the human is merged with the technology and through this merging they intentionally look at the world. This is what Verbeek calls *hybrid intentionality*, an intentionality that transcends the human intentionality. In cyborg intentionality, the technology ceases to simply mediate the world and the experience, as happens in embodiment relations which offer a mediated intentionality, but instead the constitution of both subject and object takes place in a merged relation. In this hybrid intentionality, the initial schema among Human, Technology, World transforms to:

(Human/Technology) → World

The new relation suggests that because human and technology are merged, their intentionality directs towards the world, not each from a separate point of view, but merged into one entity. Both the human and the technology interpret and experience the world and its experience is perceived in a mutual and merged relation.

Coming back to bionic limbs and to the ontological ambiguity presented on Merleau-Ponty's work and the embodiment theory of Ihde, which insufficiently addresses bionic limbs, the cyborg intentionality could offer us a way through this philosophical issue. While an astute reader would point out that in bionic limbs that have been presented here, there is mostly no surgical *merging* with the technology, in the argumentation given by De Preester (De Preester & Tsakiris, 2008; De Preester, 2011), we can see that despite the absence of physical merging there is a useful conceptualization regarding the incorporation of the artifact. Accepting her approach about the *body-model*s, which is one of the different ways for conceptualizing body ownership, we can see that the merging that Verbeek argues for does not occur in a

physical dimension but rather at a conceptual level: on how the user conceives a non-corporeal artifact as one's own. In that sense, since the prosthesis is felt as a body part, the ontological ambiguity regarding whether the bionic limb should be categorized as part of the world or as part of the *corps vécu* becomes obsolete, as from the merging of a non-corporeal artifact and its conceptualization as own in the cyborg relation of the hybrid intentionality, the artifact can be thought of as own despite having the worldly disruptions, despite being a non-corporeal artifact which may carry its own agency. The user feels as own an object that comes from the world and its procedures, and she continues in having this relation in which the sense of her body ownership is shaped.

To sum up, the ontological ambiguity is dissolved when we start thinking of the user of a bionic limb as a cyborg. While at this point this may seem self-evident, self-evidenct is problematized when we conceptualize the users as cyborgs based not on a sense of physical merging rather on the concept of ownership they have towards the bionic limb. Though this cyborg relation does not occur necessarily due to a physical merging, but through the conceptual extension of the body ownership. Building on De Preester's work, it points us in a direction where the sense of ownership applies in non-corporeal artifacts, like bionic limbs. Thus, the use of bionic limbs may not only mediate and shape the experiences towards the world, but also, have the potential to transform the user's sense of ownership.

4.1.4 Interim conclusion

In section 4.1, I responded to the three criticisms made in the second chapter. To be precise, I argued that bionic limbs have an agency not only in the mechanical relation with the user but also regarding the sense of ownership that may occur due to the mechanical features they have. This two-folded type of agency not only complicates the approach that should be used regarding bionic limbs, but also illustrates how bionic limbs and their mechanical features can have different degrees of symmetry when compared to traditional prostheses. These degrees of symmetry place the analysis of bionic limbs in a distinct position as they may result in a different co-constitution of the object and the user. The second criticism, regarding the interchangeability of the terms extension and incorporation, was addressed by using De Preester's argument and the decisive role that ownership plays in this distinction. By using the concept of *body-model*, we can have a justified picture of what may be felt as one's own. This is crucial as it is a building block towards arguing how the use of a prosthetic limb may result in a sense of ownership. The third criticism, regarding the ontological ambiguity between the use of bionic limbs and the *lived body*, was addressed by using the hybrid intentionality that Verbeek argues for. However, in the case of bionic limbs, the merging does not

occur on a physical level but on a conceptual one. Thus, the sense of ownership is extended towards a non-corporeal artifact, in this case a bionic limb. To summarize the philosophical findings thus far, bionic limbs have a unique position in the relation between the user and the world. The different degrees of symmetry differentiate bionic limbs from other artifacts of similar purpose. Additionally, since a bionic limb can be felt as own in a more fruitful way than in other prosthetic limbs, different degrees of the user and the bionic limb symmetrical relation are exhibited. Finally, while there is no physical merging with the artifact, the merging relation results in a relation of an extended body ownership. All the examined issues of this section were focused on the relation with the *lived body* having as a starting point the criticism to Merleau-Ponty.

4.2 The technological body and the implications regarding bionic limbs: introducing hybrid body ownership

In this section, I elaborate on how the argumentation from the *lived body* presented throughout the section 4.1., combined with the argumentation regarding the cultural body, give a new dimension to the agency of the bionic limbs. Section 4.1 was significant not only for responding to the points of critique raised in the second chapter but also because it helps to conceptualize the novel approaches that bionic limbs invite us to develop. Having seen how the agentic bionic limbs become a non-corporeal body-part, we can introduce the concept of *technological body*, first used by Don Ihde (2002). Don Ihde argued that what Husserl named as Leib, or corps vécu by Merleau-Ponty, was one aspect of the human body. Renaming the Leib as *body one*, he means the experienced body. He then introduces the concept *body two*, which for him is the experience of the cultural body. The cultural body is based on a "Foucauldian framework" (ibid., p.17) and is the instantiation of how culture reflects on a person's body and how she experiences these cultural reflections. To exemplify this, he gives the example of female bodies, where certain views of the female body are seen as more erotic or attractive than in other cultures, e.g. the neck vs the ankle. The *body two* is the body on which are written all the different political, social, cultural aspects of each society. The crossing of these different *bodies* (the physical body or *Koerper*, the *lived body*, and the cultural body) is epitomized in what Ihde calls the "technological body". The technological body is the combination of these different concepts regarding the body in which the cultural and political reflections are essential in the relation that our bodies have with the technology. This multi-dimensional analysis is useful to include the social aspect regarding bionic limbs.

As seen in the first chapter, prosthetic artifacts have different meanings over the course of their historical development. In their historicity, prosthetic limbs, besides the basic functions that provide better

stability to the user, have additional meanings and are the outcome of different social interactions and dynamics. For example, in the case of the Egyptian Toe, the purpose was not only to provide basic stability, but additionally to provide a certain service post mortem, the opportunity to continue in the after-life. In the case of Goetz von Berlich, the German knight from the 15th century, his prosthetic hand allowed him to handle his sword and in this way maintain an aspect of his social role. During the American Civil War, amputees with a prosthesis were once again useful to give their bodily services to the war front. In this sense, bionic limbs are certainly an outcome of this society, with their multidimensional agency from prosthetists, insurers, manufacturers, not only they provide better mechanical functions and offer a hybrid way of conceptualizing the body, but additionally they provide a new understanding of how body ownership could be conceptualized.

4.2.1 The meeting point of different levels of body: Technological body and bionic limbs

The remaining of this chapter will focus on introducing, explaining, and justifying the term *hybrid body ownership* by examining the different levels of body, as elaborated by Ihde (2002), regarding bionic limbs. The concept hybrid body ownership is the outcome of the analysis presented throughout this text and pushes us towards new understandings regarding the implication of such delicate artifacts, as bionic limbs are, for the users' body understanding. Contrary to prostheses of different historical eras, the fact that bionic limbs are a field of such complex meanings should urge us to push our boundaries in comprehending the implication of their use in every aspect of their use, as for example the feeling of body ownership, and not only on how the users' experience of the world is shaped, as is explained in the embodiment theory of Don Ihde. This section will focus on prostheses and bionic limbs and will analyze their implications for *body one*, and *body two* and their anchors in the real world regarding bionic limbs. It will conclude on how the crossing of these meanings is founded in the technological body, and how this crossing establishes the concept of hybrid body ownership.

a) Body one.

Moving on to the *body one* of Ihde, the bionic limb belongs to the body image which means the system of beliefs and attitudes that the user has towards the bionic limb. In experiencing the *body one* of Ihde, a bionic limb does not only mediate the experience of the world or the co-constituted experience by the common relation as in cyborg intentionality. It also mediates the sense of body ownership of the user regarding the prosthesis. Experiencing the body and the bionic limb as an own body, the user is faced with the paradox

that when compared to a bionic limb, a corporeal body part, e.g., a natural hand, has a different origin, structure, capabilities, texture, and so on, yet both feel as part of the own body. Contrary to the *Koerper*, where the user *has a body*, in the *lived body* the user *is the body*. In that sense, besides the hybrid intentionality towards the world, the user experiences a hybrid intentionality towards her body. In this hybrid intentionality towards her body and towards her body ownership, the user experiences the differences between a corporeal hand with body ownership and that of a non-corporeal hand with body ownership. It is useful to clarify this paradox with the comparison of a hand transplantation and of a bionic limb. In a hand transplantation, however strange a natural hand may be (Slatman, 2009), the user does not experience the internal conflict of whom does the hand belong to. Since in current hand transplantations the hands are from cadaveric donors (Errico, Metcalfe & Platt, 2012), the user experiences the donated hand as an object on which, besides any medical restrictions, she has the sole power over. Of course, the recipient may have problems incorporating the artifact (Slatman & Widdershoven, 2010), but nonetheless she can do whatever she wants with the donated hand, e.g., play beach volley, which may be damaging to the hand but there is no warranty that if the hand is mistreated then it would not be justified by the insurer or the prosthetist. There was no other agency experienced besides the fact there were some medical rules that should be followed e.g., taking the immunosuppressant drugs (ibid.).

However, in bionic limbs the agency is much more complicated and is not always restricted to the case of what is medically best for the user. For instance, what may be classified as improper use by the user can be a matter of socio-economic understanding about what is economically and technologically justified and may bear little relation to the user's medical condition. In the case where the user's desires over a body-part felt as own come in conflict with the regulations regarding the artifact, then the conflict is not on medical requirements but on socio-technical rules. Then the conflict comes in how body ownership is experienced, how the regulations are applied in a part felt as bodily owned. Similar to Jean Luc-Nancy's analysis on the Intruder, a chapter found in his book Corpus (2008), whose heart condition made him question what can mean the ownership of his failing heart was: how can you own something that fails you (ibid., p. 162). Nancy experienced both his failing heart and the transplanted heart as foreign objects. However, the strangeness of a bionic limb is not experienced due to the *strangeness* of an organic object, but due to the social and cultural agency from external factors. Nancy's feelings towards his own failing heart reveal to us a crucial point regarding of how the ownership of body parts can be experienced. In the case of the failing heart, he started questioning the relation he could have with such an object, an object whose purpose ceased to be how to keep him alive. As with Nancy's case, bionic limbs' users may identify themselves with objects, corporeal or not, for which they have a sense of ownness. In this sense, the *lived body* and the ownership they have towards it escape these two conceptualizations and transcend towards issues regarding, how can I identify with an object that despite being own has a *strange* agency in it.

To sum up, bionic limbs and the user meet on many different levels of the experience that result in their relation. In the context of the lived experience, the external factors that present themselves in the relation between the user and the bionic limb not only break the continuity of experiencing the world but additionally hinder the way that the body ownership is experienced. The experience of Nancy becomes relevant in the case of bionic limbs as well, where the agentic nature of the bionic limbs may disrupt the sense of ownership a user may have developed in the relation she has with the bionic limb.

b) Body two.

Moving on to the concept of *body two*, the body as how the cultural and social norms are being reflected upon, bionic limbs reflect social norms. In this sense, bionic limbs do not only reflect the understanding of how the user perceives the prostheses, but additionally the way that different social actors comprehend and conceptualize bionic limbs, and how this discrepancy is incorporated into the idea of one's own body. Due to the complex process with which bionic limbs are acquired by the user, the agency of bionic limbs escapes the materiality of the artifact and extends to the regulations and rules that are accompanied with the process. This complex process, meaning that prescribed bionic limbs have to be ISO-certified, to have specific guidelines for use, as well as the influence of the agency of the prosthetists, insurers, doctors, and manufacturers, is shaping the outcome which is instantiated in the bionic limbs. The actors' different agencies accompany the user even after the purchase where the user's use of the bionic limb — an object potentially cognitively embodied and with a sense of ownness — shape the user's experience and conceptualization about a body part. For instance, we saw in the first chapter that the acquired prosthesis should be appropriate for the activity that is dedicated meaning that the user, even though technically able, should not proceed in sports activities because if so, the artifact might not endure the pressure of the physical activity. Thus, the user comes to a point where she cognitively embodies an artifact where the agency of other actors plays an important role on how she approaches and uses the technology and how she conceptualizes her body image.

There are different legal cases where a prosthesis or an assistive device are not seen as a crucial artifact for the well-being of the user, let alone, to be bodily owned (Lichtenstein, 2015). Rather, prostheses, as well as other assistive devices (MacDonald Glenn, 2012), are seen as instruments; artifacts like all the others that may be an assistance for the user to which the user has the rights of a customer, as for example it would happen with buying a car, and not someone who acquires an object that can be conceived as a body part. For instance, Ottobock, a leading company in bionic limbs, in their general warranty for their products state that:

> "This warranty applies, subject to normal wear and tear, when the products are used as intended, without unapproved modifications, following all Ottobock instructions and requirements; and when they are fitted by or under the direct supervision of certified/licensed practitioners who meet all Ottobock product-specific training requirements as needed for given products" (Limited Warranty, n.d.)

and a few lines bellow:

> "This limited warranty does not cover test sockets and/or test orthoses, or damage due to accidents, *neglect, misuse or operation beyond capacity* [emphasis added], parts damaged by improper installation, *substitution of parts not approved by Ottobock, any alteration or repair by others that, in Ottobock's judgment, materially or adversely affects the product, part or service.* [emphasis added]." (Limited Warranty, n.d.)

In both excerpts, we can see how a leading manufacturer of bionic limbs as Ottobock conceptualizes their products as objects for which have to be followed specific regulations. In addition, "certified/licensed practitioners", who have specific training requirements, also intervene in this process. The agency of external actors does not stop only in the manufacturer; court decisions play an important role on how settlements are applied. For example, we read in an article written by Lichtenstein (2015), a lawyer urging for understanding the relation with prostheses users and technology, that in the USA, from where most of the examples examined in this thesis are drawn, have been cases where prostheses have been seen as "inanimate things":

> "In National Union Fire Insurance Company of Pittsburgh, Pennsylvania v. Janes, the breaking of a metal plate used to repair a femur did not qualify for Workers' Compensation in Texas since the metal plate was a 'static, inanimate thing.'" (Lichtenstein, 2015).

Clearly, the conceptualization that prostheses are inanimate objects was crucial for the economic compensation of a user whose prosthesis broke while in his job. There are plenty other cases and examples that can be given, in which assistive devices are seen as plain instruments instead of been seen as body extensions (e.g., MacDonald Glenn, 2012) or non-corporeal body parts (Goldberg, 2015). For this reason, users have to endure a long and often complex process in which insurers or conflicting parties might object paying for coverage of an expensive mechanical prosthesis, as for example a C-Leg, where users may be caught in the turbulences of different state and insurance policies that are applied (Goldberg, 2015). As a result, Goldberg, a C-leg user, wrote: "It became increasingly difficult to juggle medical school curriculum when I had a significant part of my body declining." (ibid.)

In all the above-mentioned cases, what is dominant is the narrative that prostheses, assistive devices, and bionic limbs, are viewed by different actors as instruments in the same way that private property is seen. Combining this narrative with the socially and culturally construction of *body two*, bionic limbs, and prostheses in general, are a matter of interpretation of social norms and constructions. These interpretations can be medically justified but can also be constructed due to the social understanding of the artifacts. The fact remains that different actors shape the experience of a body-part. These interpretations are transferred in how the user may modify, alter, or be a subject of external factors and confusions about an object which can be perceived as an owned body part. This discrepancy in social meanings is not common for other body parts in the western world, e.g. a corporeal natural limb, but is of the same nature as for example the way that bodies are seen in countries where the civil rights prevail when compared with countries in deeply religious states. Hence, for the bionic limbs and prostheses, the user may feel as own an artifact that its meanings and technology are socially constructed. The significance of this is that while different actors may acknowledge the importance of someone having full control over the decision process regarding corporeal body-parts, this control is not acknowledged when the user may have a body part that can be technologically developed. In other words, the understanding regarding what can one do with her own body becomes ambiguous when the body relates to such complex technologies, like with bionic limbs.

4.2.2 The technological body and hybrid body ownership

The intersection of the physical body, body-one, and body-two gives us the conceptualization of the technological body. Having established conceptually and scientifically that bionic limbs can be felt as part of the own body and at the same time acknowledging the discrepancies and disruptions of the different actors, we can see that there are various dimensions of relationality regarding how the body ownership of a bionic limb is conceptualized a) by users and b) by different actors. When thinking of a natural corporeal hand, a citizen of the western world has gained the civil right to perform as thinks best, meaning that she has the right to modify, alter, *repair*, or even remove certain body parts on her own will. Of course, there are certain limitations to what one can do with her own body. For example, there are conflicting views on if a person should be legally allowed to sell body parts like kidneys, and it may be prohibited (Have & Welie, 1998). Furthermore, scientists, psychologists, and philosophers are puzzled on how to treat a reversed case, where body parts are not felt as own and hence their users want them to be amputated as for example in the BIID case (Slatman & Widdershoven, 2009). However, the case of bionic limbs is quite different from these cases of body ownership. The reason is that while the user may acquire it as a property,

the growing relation that she may have with it is not taken into consideration. This discrepancy of meanings leads to not having a common understanding of what type of ownership there is regarding bionic limbs.

At a first level, bionic limbs mediate the experiences from the world. As mentioned previously, the fact that bionic limbs can have features with which the user can experience the warm sand is something that adds up in mediating the experience of the world. In this sense, bionic limbs do mediate the user's experiences, like it happens with other artifacts when examined under the embodiment theory. However, at a second level, bionic limbs also mediate the experience of how the own body, i.e. the bionic limb included, is perceived. Since the user conceptualizes the bionic limb as an own non-corporeal body part and at the same time she experiences the aforementioned discrepancies in the *body two*, the bionic limb mediates these discrepancies regarding the body ownership. In a third level, the experiencing of having different degrees of ownership from bionic limbs to the natural hand is experienced in the external decisions regarding the "declining body" of the C-Leg user when compared to the natural body. This discrepancy, between having a dominant agency of what one does to her natural body versus the lack of dominant agency of what one does to a bionic limb, mediates a different sense of body ownership: the *hybrid body ownership*.

The reason that the body ownership of bionic limbs results in a hybrid sense of body ownership is that there are different meanings and processes involved. First, there is the natural corporal body which can be felt as own. Second, there is the argument from De Preester that if a bionic limb fits the *body-model*, for which multisensory stimuli and body representations have to apply, then it can be felt as own in the same manner that ownness is felt for the corporeal body. The difference lies in the very nature of bionic limbs, that are man-made artifacts which have a certain agency involved. In every different level of the body, as developed by Ihde (2002), bionic limbs offer a distinct understanding of their relation to the user than when compared to the natural body. The hybrid body ownership summarizes the differences among the different levels of the body and includes the discrepancies from the different agents. To this extent, the word 'hybrid' differentiates the relation from the plain body ownership as it involves the different conceptualizations about the feeling of body ownership. Hybrid body ownership combines the term of body ownership as elaborated by De Preester but at the same time also involves the different conceptualizations from different actors. The hybridness of the body ownership can be seen in the experience of the C-Leg user (Goldberg, 2015) in which case the power he has over his technological body is questioned by different actors.

In the hybrid intentionality of Verbeek (2008), the user merges with the technology and this results in a hybrid orientation towards the world. However, the intentionality does not only direct to the world, but to the body and consequently to the sense of body ownership as well. While the user may experience the conceptual merging with the technology, she also experiences the different levels of experiencing her body. However, in the merging that occurs, the sense of ownership is not examined. The concept of hybrid body

ownership urges us to understand, distinguish, and examine the incorporation of these discrepancies in regard to how the user may feel a non-corporeal artifact produced in the world as own. Additionally, such a clarification between the concept of body ownership and the difference it has with a hybrid body ownership as a result of the use of an agentic artifact as the bionic limbs becomes important when we think the differences among a person without prosthetic limbs, a person with traditional prosthetic limbs, and a person with bionic limbs. The cyborg relations that emerge and the hybridness of the body ownership among the different users or no-users can challenge conceptualizations regarding not only the body ownership, but additionally to the identity of the users or non-users of the examined technologies. Because if the term of hybrid body ownership succeeds in explaining the discrepancies and meanings attributed to bionic limbs related to the users, then the question that may emerge is how can one's body ownership connect with her identity and how does the hybrid body ownership challenge her understanding towards her body, the technology she uses, and the world. Ultimately, the term hybrid body ownership, in the context of this thesis, does not answer all the issues among the different levels of the body and the cases presented here, but comes to question if the different actors' approach towards bionic limbs, the users and their sense of ownership, is sufficient to examine the complex relations that emerge.

4.3 Conclusion

This chapter is divided in to two main sections related to the core of this chapter's research question: *How does the embodiment of bionic limbs connect with body ownership, and how do bionic limbs question established concepts regarding body ownership*. In the section 4.1, I address the three main criticisms towards Merleau-Ponty. The first criticism answered includes the introducing of a manner in which the agentic nature of bionic limbs can be explained and additionally, I use an argument by Ihde (2002) that the bionic limbs may have different degrees of symmetry when they are compared with other artifacts such as traditional prosthetic limbs. Second, I examine the interchaneability of the terms 'extension' and 'incorporation' by using De Preester's argument (De Preester & Tsakiris, 2009; De Preester, 2011) who notes the importance of the body ownership on how to approach the different terms. The concept of ownership is crucial for the argument of this thesis because De Preester's argumentation is used as a stepping stone to approach bionic limbs. The third criticism answered involved the argumentation about the ontological ambiguity regarding the status of a bionic limb, which was elaborated by using the argument from Verbeek (2008). Specifically, I use his argument, that in the cyborg relations there is a merging that occurs between technology and humans which results in hybrid intentionality, to argue that in the case of

bionic limbs use the merging does not occur necessarily in a physical level rather in a conceptual level, i.e. how the user may feel the bionic limb as own body, supported by arguments presented in this thesis.

In the section 4.2, I explored the implications of this response by directing towards the concept of the technological body as developed by Ihde (2002). Specifically, I examined the body-one under the scope of the technological body by examining not only how the mediation of the experience of the world may occur, but additionally how the sense of body ownership with a bionic limb may be conceptualized. Then, I examined the body-two and explored how the agentic nature of bionic limbs is additionally a culturally oriented process that is deeply related with the sense of ownness over the bionic limb. In the second part of this section, I introduced the term Hybrid body ownership as a conceptualization which summarizes all the discrepancies in meanings, the lived experience by the user, and the cultural processes that are instantiated in the bionic limbs. The term hybrid body ownership was introduced not so much as a solution to the problems presented here, but as a building block on how to question the established meanings of body ownership when bionic limbs are examined and the users' relation towards them. In this sense, the examined case of bionic limbs urges us to re-conceptualize what the body, and related to the body concepts like body ownership, may mean for the relation that different actors may have towards the technology.

Chapter 5 - Thesis' conclusion and reflection

5.1 Bionic limbs and body ownership: a summary

The purpose of this thesis was to explore how bionic limbs may urge us to conceptualize under a new light the variety of relations that may emerge. By understanding how bionic limbs can challenge different aspects of our approach towards them, our understanding moved one step further. This thesis main research question was: *Q Considering discussions from the phenomenological tradition and postphenomenology theoretical framework regarding body perception, how do bionic limbs urge us towards new understandings regarding body ownership?* In the previous pages, this question has been answered in three different levels. First, by considering the differences of traditional prosthetic limbs to bionic limbs, we saw that bionic limbs may offer more complexities. Second, by exploring the relevance of phenomenology to prosthetic limbs and how a Merleau-Pontean framework would analyze bionic limbs, we saw the insufficiencies of the said framework when bionic limbs are examined. This task resulted in the third point, where I made three criticisms with which I responded to Merleau-Ponty. Additionally, having paved the way with these criticisms, I continued in how bionic limbs should urge us towards new conceptualizations about the body. With the overall course of this thesis, I managed to distinguish how traditional prosthetic limbs are distinct from bionic limbs and how the distinct nature of bionic limbs may lead us in understanding differently the concept of body ownership, for the purpose of which I introduced the term Hybrid body ownership.

More specifically, the first chapter's purpose was to respond to the question: *What is the historical and technological development of prostheses, and how do bionic prosthetic limbs differ from traditional prosthetic limbs.* This two-folded question was answered first by clarifying the historicity of prosthetic limbs, in general, and how the bionic limbs are a product of the current society. As the outcome of this society, bionic limbs incorporate the agency of different actors who are instrumental in the process with which the user acquires such a technology. In this process, bionic limbs have to be ISO-certified and they carry decisions by the manufacturers, insurers, prosthetists, all of which may continue shaping the life of the user of a bionic limb long after the purchase. At the very end, I showed how bionic limbs, which have strong economic and medical estimates, can be conceived and analyzed by the aforementioned actors as mere instruments; this instrumentality of bionic limbs is the outcome of conceptualizations occurred for traditional prostheses and result in a discrepancy among the users and the different actors.

In the second chapter, I responded to the question*: how can Maurice Merleau-Ponty's work help us analyze prostheses regarding body perception and cognitive embodiment, and what criticisms can be*

made regarding his analysis when applied to the topic of bionic limbs? To respond to this question, I first had to establish a good basis for why Merleau-Ponty is a relevant philosopher and why his contribution could be helpful in understanding bionic limbs. After I showed the relevance of Merleau-Ponty's philosophy for prosthetic technology and the *lived body*, I continued on how bionic limbs may achieve a deeper cognitive embodiment when compared to traditional prosthetic limbs. From that point on, I tried to analyze bionic limbs using a Merleau-Pontean theoretical framework. This task lead me to three criticisms regarding Merleau-Ponty's theory when it approaches bionic limbs. The first criticism regards an ontological ambiguity about the ontological status of bionic limbs. Namely, while bionic limbs may provide all the necessary features that would allow the technology to be categorized as part of the *lived body*, worldly disruptions may obscure this lived experience for the user. The second criticism was found in the literature and has to do with Merleau-Ponty's practice to use the terms 'extension' and 'incorporation' interchangeably. A final criticism of the second chapter was that in Merleau-Ponty's theory the agency of the artifacts, and specifically, of bionic limbs could not be examined in depth as it involves meanings developed in a later era.

In the third chapter the purpose was to respond to the question: *How does the embodiment of bionic limbs connect with body ownership, and how do bionic limbs question established concepts regarding body ownership.* To respond to this question, I started off with the criticisms for what could be a Merleau-Pontean approach towards bionic limbs. First, I examined how a postphenomenologist like Don Ihde would explain the agency of bionic limbs and I argued that bionic limbs offer greater symmetrical relation with the user, a relation that may translate to deeper incorporation, when compared to a traditional prosthetic limb. Second, I elaborated on the concept of using the terms 'extension' and 'incorporation' by using De Preester's arguments. In that chain of thought, the concept of body ownership and how this may occur play a decisive role in clarifying the differences between the two terms. Third, I responded to the ontological ambiguity by using the hybrid intentionality as argued by Verbeek (2008). However, in the case of bionic limbs, the hybridness occurs at a conceptual level, i.e. how the user may feel a non-corporeal artifact as a body part. Having responded to the three criticisms of the third chapter, I moved to the second aspect of my argumentation in which I explored how the technological body can help us analyze bionic limbs regarding the body ownership. After examining how the lived experience of a bionic limb associates with the aspects of the cultural body and the bionic limbs, I concluded that the term 'hybrid body ownership' can describe the discrepancies that may be experienced by the user and other involved actors when there is a body ownness regarding the bionic limbs.

Overall, with each respective question, I showed how bionic limbs not only differ from traditional prosthetic limbs, not only how we should use one more modern approach in comprehending top-notch

technologies, but additionally, how with questioning different implications of the relation someone may have with a technology, we should orient towards conceptualizing new terms, namely, the concept of hybrid body ownership. The term hybrid body ownership questions how a users' relation with a technology can be approached, regarding not only the experiences that this technology may mediate or shape but to show the manner in which certain technologies can question concepts such as the body ownership. By including the social agency of bionic limbs, I showed how the concept of body ownership can be explored in the dynamic relation when is compared with a complex technology such as the bionic limbs.

5.2 Reflections and remarks

The fact that bionic limbs may question established concepts regarding body ownership bring us in front of new challenges and responsibilities that may emerge. In this last section of this text, I will make three reflective remarks on where we may stand from now on.

The first one has a philosophical-ethical aspect and is focused on if and how to embed morals to non-corporeal body parts. It is acknowledged by different scholars that artifacts, besides any technical functions they may serve and have certain levels of agency that may be incorporated in the artifact, they also may carry the morals of the designers of the technology. A technology, as is the product of every society, not only has certain agencies incorporated, but may make strong moral statements in the form of actions, which often may go unnoticed by members of the society. For what I am concerned is: how, why, and if, to embed morals in bodily owned but non-corporeal artifacts, and if so, how the concept of hybrid body ownership can emerge more conflicting compared to plain body ownership. What may mean for a user to have a bodily owned part which may have a different moral agent than the body owner. This topic connects deeply with the issue of identity, which has not been the focus of this limited text, and the continuity of the self as a moral agent. In other words, the embedding of morals in non-corporeal body parts is a new field worth exploring.

The second remark, which is also a reflection, regards the epistemological aspect of the theories examined here and used in discussions about the body. In other words, the epistemological validity of terms such as cyborg, body ownership and ownness in general, body-model as used by De Preester, and, of course, hybrid body ownership are issues that remain to be examined, not only on their scientific premises, but additionally, how to have philosophically and epistemologically valid conclusions about such topics. In a descriptive thesis, such as this one, I had neither the time nor the intention to go into a thorough examination of how these conclusions can be safely made. The purpose was indeed to describe all the issues presented

here and how these issues may urge us to conceptualize new directions for our analyses. Nonetheless, an epistemological validity of the premises and conclusions drawn here is necessary to examine the depth of how far conclusions like these can get us. Connecting the epistemological aspect with the reflection presented in the previous paragraph, can be examined how to approach ethical issues regarding the embedding of morals in non-corporeal body parts.

The third remark is of a broader ethical scope, something that was not examined in this thesis at all because its purpose was not to provide a normative conclusion. However, if the arguments claimed here have basis, then our society should take them into deep consideration. It certainly seems that in the next years, cyborgs and those who will relate deeper to technology than other humans may claim a more dominant place in this society. In this sense, understanding the implications that these new relations may create, is crucial for the stability of the society and the general well-being. One of this implication that has been shown throughout this text is how to conceptualize and regulate these relations and understandings among the involved actors on the premise that the users' feelings about her body and the technology that is involved should be taken into consideration.

Last, while this thesis paved the way towards new conceptualizations, the ideas elaborated here are nothing but a departure point towards new questions and answers regarding relation humans can have with the technology and, in the case of this thesis, with non-corporeal body-parts. As technology advances, we should remain clear-minded and vigilant so as our criticism towards the new technologies would not have turn to the appreciation of passed utopias, where technologies were better, but towards technologies with which relations, meanings, and conceptualizations will be crystal clear to avoid any conflict among society's actors.

References

Avramov, E. (2015, January 2). Experience: I chose to amputate my leg. *The Guardian*. Retrieved from http://www.theguardian.com/lifeandstyle/2015/jan/02/i-chose-to-amputate-own-leg-erez-avramov

Balaraman, V., & Singh, Y. P. (1995). Enumeration of human knee prostheses--an overview. *Biomedical Science Instrumentation*, *31*, 263-268. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/7654975

Bassett, M. H. (1980). *The fate of earthly things : Aztec gods and god-bodies*. Austin, TX: University of Texas Press.

Besmer, K. (2012). Embodying a Translation Technology: The Cochlear Implant and Cyborg Intentionality. *Techné: Research in Philosophy and Technology*, *16*(3), 296-316. doi:10.5840/techne201216319

Besmer, K. (2015) What Robotic Re-embodiment Reveals about Virtual Re-embodiment. In R. Rosensberger, & P.P. Verbeek (Eds.), *Postphenomenological Investigations* (pp. 55-71). Lanham, MD: Lexington Books.

Biddiss, E. A., & Chau, T. T. (2007). Upper limb prosthesis use and abandonment: A survey of the last 25 years. *Prosthetics and Orthotics International*, *31*(3), 236-257. doi:10.1080/03093640600994581

Blough, D. K., Hubbard, S., McFarland, L. V., Smith, D. G., Gambel, J. M., & Reiber, G. E. (2010). Prosthetic cost projections for servicemembers with major limb loss from Vietnam and OIF/OEF. *Journal of Rehabilitation Research & Development*, *47*(4), 387-402. doi:10.1682/JRRD.2009.04.0037

Botvinick, M. (2004). Probing the neural basis of body ownership. *Science*, *305*(5685), 782–783. doi:10.1126/science.1101836

Botvinick, M., & Cohen, J. (1998). Rubber hands ‘feel’ touch that eyes see. *Nature*, *391*(6669), 756-756. doi:10.1038/35784

Brey, P. (2000). 'Technology and Embodiment in Ihde and Merleau-Ponty.' In C. Mitcham (Ed.) *Metaphysics, Epistemology, and Technology. Research in Philosophy and Technology*,*19*. London: Elsevier/JAI Press.

Brodtkorb, T.-H., Henriksson, M., Johannesen-Munk, K., & Thidell, F. (2008). Cost-Effectiveness of C-Leg Compared With Non–Microprocessor-Controlled Knees: A Modeling Approach. Archives of Physical Medicine & Rehabilitation, *89*(1), 24-30. doi:10.1016/j.apmr.2007.07.049

Brueggemann, B., & Lupo, M. (Eds.). (2008). *Disability and/in prose*. London: Routledge**.**

Carman, T. (1999). The body in Husserl and Merleau-Ponty. *Philosophical Topics, 27*(2), 205-226. doi:10.1177/0959354399091005

Costantini, M., & Haggard, P. (2007). The rubber hand illusion: sensitivity and reference frame for body ownership. *Consciousness and cognition*, *16*(2), 229-240. doi:10.1016/j.concog.2007.01.001

Dalibert, L. (2014). *Posthumanism and somatechnologies: exploring the intimate relations between humans and technologies* (No. 14-303). University of Twente, the Netherlands. doi:10.3990/1.9789036536516

Dehghani, A. (2010). Intelligent Prosthesis–a Biomechatronics Approach. In D. Bradley & D. W. Russell (Eds.), *Mechatronics in Action* (pp. 173-195). London: Springer. doi: 10.1007/978-1-84996-080-9_11

Dyer, B. T., Noroozi, S., Redwood, S., & Sewell, P. (2010). The design of lower-limb sports prostheses: fair inclusion in disability sport. *Disability & Society, 25*(5), 593-602. doi: 10.1080/09687599.2010.489309

Ehrsson, H. H., Rosén, B., Stockselius, A., Ragnö, C., Köhler, P., & Lundborg, G. (2008). Upper limb amputees can be induced to experience a rubber hand as their own. *Brain, 131*(12), 3443-3452. doi:10.1093/brain/awn297

Errico, M., Metcalfe, N. H., & Platt, A. (2012). History and ethics of hand transplants. *Journal of the Royal Society of Medicine Short Reports*, *3*(10), 74. doi:10.1258/shorts.2012.011178

Finch, J. (2011). The ancient origins of prosthetic medicine. *The Lancet, 377*(9765), 548-549. doi:10.1016/S0140-6736(11)60190-6

Finch, J. L., Heath, H. G., David, A. R., & Kulkari, J. (2012). Biomechanical Assessment of Two Artificial Big Toe Restorations From Ancient Egypt and Their Significance to the History of Prosthetics. *Journal of Prosthetics and Orthotics*, *24*(4), 181 - 191. doi:10.1097/JPO.0b013e31826f4652

Fortington, L. V., Rommers, G. M., Postema, K., van Netten, J. J., Geertzen, J. H., & Dijkstra, P. U. (2013). Lower limb amputation in Northern Netherlands: unchanged incidence from 1991-1992 to 2003-2004. *Prosthetics & Orthotics International, 37*(4), 305-310. doi:10.1177/0309364612469385

Gallagher, S. (2001). Dimensions of embodiment: Body image and body schema in medical contexts. In *Handbook of phenomenology and* medicine. (pp. 147-175). Springer Netherlands. doi:10.1007/978-94-010-0536-4_8

Garber, M. (2013, November 21). The Perfect, 3,000-Year-Old Toe: A Brief History of Prosthetic Limbs. *The Atlantic*. Retrieved from http://www.theatlantic.com/technology/archive/2013/11/the-perfect-3-000-year-old-toe-a-brief-history-of-prosthetic-limbs/281653/

Giummarra, M. J., Gibson, S. J., Georgiou-Karistianis, N., & Bradshaw, J. L. (2008). Mechanisms underlying embodiment, disembodiment and loss of embodiment. *Neuroscience & Biobehavioral Review, 32*(1), 143-160. doi:10.1016/j.neubiorev.2007.07.001

Goldberg, D. (2015, May 13). How I fought my health insurance provider for a (prosthetic) leg to stand on. *Alternet:The Independent Media Institute*. Retrieved from: http://www.alternet.org/the-independent-media-institute

Have, H. A. ten, & Welie, J. (Eds.). (1998). *Ownership of the human body: philosophical considerations on the use of the human body and its parts in healthcare* (Vol. 59). Dodrecht: Springer Science & Business Media.

Hussain, S. (2010). Empowering marginalised children in developing countries through participatory design processes. *CoDesign*, *6*(2), 99-117. doi: 10.1080/15710882.2010.499467

Ihde, D. (1990). *Technology and the Lifeworld*. The Indiana series in the philosophy of Technology. Bloomington, IN: Indiana University Press.

Ihde, D. (2002). *Bodies in Technologies*. In K. Hayles, M. Poster, & S. Weber (Eds.). Minneapolis, MN: University Minnesota Press.

Ihde, D. (2012). Postphenomenological re-embodiment. *Foundations of Science, 17*(4), 373-377. doi:10.1007/s10699-011-9244-9

International Diabetes Federation. (2015). *IDF Diabetes Atlas.* Retrieved from http://www.diabetesatlas.org/resources/2015-atlas.html

ISO/TC -Prosthetics and Orthotics. (n.d.). Retrieved from http://www.iso.org/iso/home/store/catalogue_tc/catalogue_tc_browse.htm?commid=53630&published=on

Jacobsen, S. C., & Jerard, R. B. (1974, January 1*). Computational requirements for control of the utah arm*. Paper presented at ACM National Conference: Proceedings of the 1974 annual conference, New York. NY, USA. doi:10.1145/800182.810395

Jain, A., & Robinson, D. (2008). *Upper Limb Amputation: Synopsis of Causation*. Ministry of Defense, UK. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/384564/amputation_upper_limb.pdf

Jones, T. L. (2012, November 17). Under The knife. *The New York Times*. Retrieved from http://opinionator.blogs.nytimes.com/2012/11/17/under-the-knife/?_r=0

Kiss, J. (2015, April 9). What if a bionic leg is so good that someone chooses to amputate? *The Guardian*. Retrieved from https://www.theguardian.com/technology/2015/apr/09/disability-amputees-bionics-hugh-herr-super-prostheses

Kurichi, J., Bates, B., & Stineman, M. (2010). Amputation. In *International Encyclopedia of Rehabilitation*. Retrieved from http://cirrie.buffalo.edu/encyclopedia/en/article/251

Latour, B. (1993). *We have never been modern. (C. Porter. Trans.).* Cambridge, MA: Harvard University Press.

Leuthardt, E. C., Roland, J. L., & Ray, W. J. (2014, November 1). Neuroprosthetics. *The Scientist*, (November 2014 issue). Retrieved from http://www.the-scientist.com/?articles.view/articleNo/41324/title/Neuroprosthetics/

Licthenstein, J.D. (2015, March 25). Rights of Cyborgs: Is damage to prosthetic a personal injury? *New York Law Journal 253*(56). Retrieved from http://www.rightsofcyborgs.com/the-legal-rights-of-cyborgs-should-damage-to-a-prosthetic-be-considered-property-damage-or-personal-injury/

Limited Warranty. (n.d.). *Limited Warranty – Prosthetics and Orthotics.* Retrieved from Ottobock, https://professionals.ottobockus.com/warranty

MacDonald Glenn, L. (2012). Case Study: Ethical and Legal Issues in Human Machine Mergers (Or the Cyborgs Cometh). *Annals of Health Law, 21*(1). Retrieved from: http://lawecommons.luc.edu/annals/vol21/iss1/16

Manring, M. M., Hawk, A., Calhoun, J. H., & Andersen, R. C. (2009). Treatment of War Wounds: A Historical Review. *Clinical Orthopaedics and Related Research*, *467*(8), 2168-2191. doi:10.1007/s11999-009-0738-5

Marasco, P.D. Kim, K., Colgate, J.E., Peshkin, M.A., & Kuiken, T,A. (2011). Robotic touch shifts perception of embodiment to a prosthesis in targeted reinnervation amputees. *Brain 134*(3), 747-758. doi:10.1093/brain/awq361

McGimpsey, G., & Bradford, T. (2010). *Limb Prosthetics Services and Devices Critical Unmet Need: Market Analysis* [White paper]. Retrieved from Bioengineering Institute Center for Neuroprosthetics: http://www.nist.gov/tip/wp/pswp/upload/239_limb_prosthetics_services_devices.pdf

Merleau-Ponty, M. (2012). *Phenomenology of Perception. (D. A. Landes, Trans.)*. London: Routledge.

Mills, F. B. (2013). A phenomenological approach to psychoprosthetics. *Disability & Rehabilitation, 35*(9), 785-791. doi:10.3109/09638288.2012.708819

Moran, D. (2000). *Introduction to Phenomenology*. London: Routledge.

Muller, S. (2009). Body integrity identity disorder (BIID)--is the amputation of healthy limbs ethically justified? *The American Journal of Bioethics*, *9*(1), 36-43. doi:10.1080/15265160802588194

Murray, C.D. (2004) An interpretative phenomenological analysis of the embodiment of artificial limbs. *Disability and Rehabilitation*, *26*(16), 963-973. doi:10.1080/09638280410001696764

Murray, C. D. (2008). Embodiment and Prosthetics. In P. Gallagher, D. Desmond, & M. MacLachlan (Eds.), *Psychoprosthetics* (pp. 119-129). London: Springer London. doi:10.1007/978-1-84628-980-4_9

Nancy, J.L. (2008). *Corpus. (R. A. Rand, Trans.)*. New York: Fordham University Press.

Nerlich, A. G., Zink, A., Szeimies, U., & Hagerorn, H. G. (2000). Ancient Egyptian prosthesis of the big toe. *The Lancet*, *356*(9248), 2176 - 2179. doi:10.1016/S0140-6736(00)03507-8

Premera-Blue Cross. (2016). *Myoelectric Prosthetic Components for the Upper Limb*. (Medical Policy number: 1.04.502). Retrieved from: https://www.premera.com/medicalpolicies/1.04.502.pdf

Preester, H. de., & Tsakiris, M. (2009). Body-extension versus body-incorporation: Is there a need for a *body-model*? *Phenomenology and the Cognitive Sciences*, *8*(3), 307-319. doi:10.1007/s11097-009-9121-y

Preester, H. de. (2011). Technology and the body: the (im)possibilities of re-embodiment. *Foundations of Science*, *16*(2-3), 119-137. doi:10.1007/s10699-010-9188-5

Reznick, J. S. (2008). Beyond war and military medicine: social factors in the development of prosthetics. *Archives of Physical Medicine and Rehabilitation*, *89*(1), 188-193. doi:10.1016/j.apmr.2007.08.148

Robertsson, O., Mendenhall, S., Paxton, E. W., Inacio, M. C., & Graves, S. (2011). Challenges in prosthesis classification. *The Journal of Bone & Joint Surgery*, *93* (Suppl. 3), 72-75. doi:10.2106/jbjs.k.00990

Rommers, G. M., Vos, L. D., Groothoff, J. W., Schuiling, C. H., & Eisma, W. H. (1997). Epidemiology of lower limb amputees in the north of The Netherlands: aetiology, discharge destination and prosthetic use. *Prosthetics and Orthotics International*, *21*(2), 92-99. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/9285952

Saenko, M., & Todorovic, M. (2015). *Automating the Road to Recovery – How the Rehabilitation Robotics Market Is Changing the Future of Health Care*. Retrieved from http://www.luxresearchinc.com/news-and-events/press-releases/read/prosthetic-and-therapeutic-robotics-grow-36-billion-market-2025

Schmuch, M. (1998, March/April). Consumer Guide for Amputees: A guide to Lower Limb Prosthetics. *In Motion*, *8*(2). Retrieved from http://www.amputee-coalition.org/inmotion/mar_apr_98/pros_primer/page1.html

Sellegren, K. R. (1982). An Early History of Lower Limb Amputations and Prostheses. *The Iowa Orthopaedic Journal*, *2*, 13-27. Retrieved from http://europepmc.org/articles/pmc2328816

Slatman, J. (2009). A strange hand: On self-recognition and recognition of another. *Phenomenology and the Cognitive Sciences*, *8*(3), 321-342. doi:10.1007/s11097-009-9127-5

Slatman, J., & Widdershoven, G. (2009). Being whole after amputation. *The American journal of bioethics*, *9*(1), 48-49. doi:10.1080/15265160802626994

Slatman, J., & Widdershoven, G. (2010). Hand Transplants and Bodily Integrity. *Body & Society*, *16*(3), 69-92. doi:10.1177/1357034x10373406

Smith, A.D. (2007). The Flesh of Perception. In Baldwin T. (ed.) *Reading Merleau-Ponty: on Phenomenology of perception*. London: New York: Routledge.

Stevens, C. D., Schriger, D. L., Raffetto, B., Davis, A. C., Zingmond, D., & Roby, D. H. (2014). Geographic clustering of diabetic lower extremity amputations in low income regions of California. *Health affairs (*Project Hope*), 33*(8), 1383-1390. doi:10.1377/hlthaff.2014.0148

Tamayo, T., Rosenbauer, J., Wild, S. H., Spijkerman, A. M., Baan, C., Forouhi, N. G., … Rathmann, W. (2014). Diabetes in Europe: an update. *Diabetes Research and Clinical Practice*, *103*(2), 206-217. doi:10.1016/j.diabres.2013.11.007

Tee, B. C.-K., Chortos, A., Berndt, A., Nguyen, A. K., Tom, A., McGuire, A., … Bao, Z. (2015). A skin-inspired organic digital mechanoreceptor. *Science*, *350*(6258), 313-316. doi:10.1126/science.aaa9306

Thurston, A. J. (2007). Pare and prosthetics: The early history of artificial limbs. *ANZ Journal of Surgery*, *77*(12), 1114-1119. doi:10.1111/j.1445-2197.2007.04330.x

Tsakiris, M., & Haggard, P. (2005). The rubber hand illusion revisited: visuotactile integration and self-attribution. *Journal of Experimental Psychology: Human Perception & Performance, 31*(1), 80-91. doi:10.1037/0096-1523.31.1.80

Tsakiris, M. (2010). My body in the brain: a neurocognitive model of body ownership. *Neuropsychologia*, *48*(3), 703-712. doi:10.1016/j.neuropsychologia.2009.09.03

Vanderwerker, E. E. (1976). A Brief Review of the History of Amputations and Prostheses. *Inter-Clinic Information Bulletin (ICIB)*, *15*(5), 15-16. Retrieved from http://www.acpoc.org/newsletters-and-journals/1976_05_015.asp

Verbeek, P. P. (2005). *What things do: Philosophical reflections on technology, agency, and design* (*R. P. Crease, Trans.*). University Park, PA: Pennsylvania State University Press.

Verbeek, P. P. (2008). Cyborg intentionality: Rethinking the phenomenology of human–technology relations. *Phenomenology and the Cognitive Sciences*, *7*(3), 387-395. doi:10.1007/s11097-008-9099-x

Verbeek, P.-P. (2011). *Moralizing Technology: Understanding and Designing the Morality of Things*. Chicago: University of Chicago Press.

Vignemont, F. de. (2007). Habeas corpus: The sense of ownership of one's own body. *Mind & Language*, *22*(4), 427-449. doi:10.1111/j.1468-0017.2007.00315.x

Wolpert, D. M., Goodbody, S. J., & Husain, M. (1998). Maintaining internal representations: the role of the human superior parietal lobe. *Nature neuroscience*, *1*(6), 529-533. doi:10.1038/2245

Ziegler-Graham, K., MacKenzie, E. J., Ephraim, P. L., Travison, T. G., & Brookmeyer, R. (2008). Estimating the prevalence of limb loss in the United States: 2005 to 2050. *Archives of Physical and Medicine Rehabilitation*, *89*(3), 422-429. doi:10.1016/j.apmr.2007.11.005