Prosthesis Embodiment's Relationship to Society and Phenomenology

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Prosthetic Embodiment

Modern advancements in medicine and technology today offer a multitude of opportunities to society that were previously unfathomable. More specifically, these advancements have had a profound impact on the prosthetic industry with its origins dating back to ancient civilizations of Egypt, Greece, and Rome. The 2023 Volume 18, Issue 2, NIH MedlinePlus Magazine titled: Prosthetics through the Ages, importantly notes the reasoning supporting developing the first prosthetics for appearance or function as rehabilitation aids is unknown because of varying cultural ideals on personal identity. Today's advancement in robotics, 3D printing, artificial intelligence, virtual reality, motion-sensing technology, electrodes, myoprocessors, materials, etc. offer better solutions for amputees but complexities regarding what makes a person feel whole still exist. Ambroise Pare, a French surgeon in the 1500s started developing more biomechanically functional prostheses to counteract an overwhelming majority of amputee patients, mostly soldiers, that would rather take their own lives than live in society in such a way (P. Hernigou, 2013, pp.1195-1196). This is important to note as society's view of prosthetics and amputation became more developed throughout history along with technology. Evidently, throughout history exists a common desire for reaching wholeness through prosthetics, even if the technology or resources were not yet available in that time period.

As a whole, advancements in technology, extensive research and continuing promising developments continue all around us. There are many types of prosthetics and even prosthetics for a given specific task and the number of people who need them is only growing. A study showed the importance of focusing on the growing industry, "The U.S. prosthetics and orthotics market size was valued at USD 1.82 billion in 2022 and is estimated to reach around USD 2.93 billion by 2032, growing at a CAGR of 4.90% from 2023 to 2032." (Precedence Research,

2017). This paper will discuss the factors relating to the patient's acceptance of the prosthetic as oneself or prosthetic embodiment. Utilizing phenomenology to analyze prosthetic embodiment will illuminate the current divide between engineering design and societal approval, establishing the groundwork for a future where prosthetics are able to encapsulate technological advancement but are also intricately interwoven with societal factors that is better fit to an individual's identity.

Breakthroughs in materials, biomechanics, and biotechnology have facilitated unprecedented levels of functionality and customization. A prosthetic device is designed to improve the quality of life for amputees through functionality and independence. Around 1.7-1.9 million people in the United States alone use a prosthetic limb (Pro Med East, 2023). This number is projected and expected to grow as rates of diseases like diabetes that can limit blood circulation (dysvascularity) increase and life expectancy grows. Around 35-40 million people globally require prosthetics or orthotics and that number is expected to reach 2 billion by 2050 (Mduzana, L., Tiwari, R., Lieketseng, N., & Chikte, U., 2020). The growth of the industry highlights the need to focus on issues relating to prosthetic acceptance and embodiment.

Beyond their rudimentary origins, prosthetics are evolving into extension of the human body, blurring the boundaries between man and machine (Bates, T. J., Fergason, J. R., & Pierrie, S. N. 2020, pp. 485-493). Even with centuries of prosthetic development, prosthetic abandonment still plagues the industry due to personal embodiment of their prosthetic. In 2023, the Volume 84 Journal of Plastic, Reconstructive & Aesthetic Surgery stated:

> The success of a prosthesis can be measured by a plethora of different metrics, such as its ability to restore function or mimic limb anatomy. However, one critical aspect of prosthetic success, termed embodiment, is much more difficult to measure. Embodiment describes how effectively a prosthesis replaces a user's missing limb and has been a central theme within prosthetics research. From a physiologic standpoint, embodiment is the brain's assimilation of a prosthetic into a pre-existing neural structure to represent the lost limb. The higher the level of embodiment achieved, the higher the perception, action, and self-awareness a user develops with their prosthesis. (Eftekari, S. et al., pp. 469-486)

In order to increase prosthetic embodiment in patients, a refined definition of prosthetic embodiment that encompasses the complex relationships between society, technology, and its perception is necessary. Every person's interaction with a prosthetic device is different and individual, molded by personal, cultural, and societal elements. The objective of this paper is to unravel the complexities of prosthetic embodiment, bringing to light the varied perspectives that shape the assimilation of engineered limbs into users' daily experiences. The role of engineering design emerges as a crucial factor in shaping perceptions of prosthetic embodiment. These engineering design considerations are relevant in terms of prosthetic embodiment in addition to looking back into the history of prosthetics and prosthetic design in society as prosthetic embodiment evolves will offer a clearer look into prosthetic embodiment and how achieving a definition will help patients and researchers.

Patient approval of the prosthetic device and the factors that may increase approval have been studied. Studies have looked into comfort, functionality, weight, frequency of use, and prefered appearance (Baars et al., 2018) (Dillingham et al., 2001). Consequently, the uniqueness of each patient’s amputation is also a factor in patient acceptance (Resnik et al., 2020). Amputee patients often struggle with discomfort or irritation from the socket which is the attachment site of the prosthetic. This can prove difficult for design engineers given the patient experience is different for every individual and every patient perceives pain differently to some degree. A study from 2007 on upper-extremity prosthetic rejection showed:

> Mean rejection rates of 45% and 35% were observed in the literature for body-powered and electric prostheses respectively in pediatric populations. Significantly lower rates of rejection for both body-powered (26%) and electric (23%) devices were observed in adult populations while the average incidence of non-wear was similar for pediatric (16%) and adult (20%) populations. (Biddiss, E. A., & Chau, T. T., pp. 236-257)

This is important because amputee patients who are unsatisfied with their prostheses are more likely to favor a non amputated limb or abandon their prosthetic for something more suitable to their needs. Amputation is a very intense medical procedure which requires prolonged rest, rehabilitation, and features loss of mobility. Patients with diabetes or other conditions can be especially susceptible to unforeseen weight gain. Additionally, limb volume fluctuates after surgery and makes it harder to make the patient comfortable consistently but advanced custom imaging techniques, 3D printing, and materials more efficiently bridges the gap.

Interestingly, data shows that only 25% of patients wear their prosthetic all day, 50% most of them only when they need it for a particular activity, and around 25% abandon it after a time (Davidson, 2002). This highlights the idea that prosthetic embodiment is very complex and there are a multitude of factors that influence the patient's ability to use and accept their prosthetic device. Technological advances in prosthetics have been tasked with increasing function and comfort in order to ideally minimize the effect of the loss of a limb but there is still the sensorimotor aspect that is associated with prosthetic embodiment. Overall, the goal here is to craft prosthetics with the intent to stay with the user at all times and are accepted by them. In order to achieve that, it can be argued that prosthetic embodiment is required and will be further assisted by technological advancements.

Prosthetics today have been able to incorporate technology that gives sensory feedback and gives the patient motor control (Raspopovic et al., 2021). This is where the idea of prosthetic embodiment becomes even more complex due to the developing technology of neuroscience in prosthetics. Previous works have tasked themselves with analyzing the definition of prosthetic embodiment and the results of these studies have categorized prosthetic embodiment as a body representation or phenomenology. The future of prosthetics involves a world where the

prosthetics are functionally advanced, integrable into the lived experiences of users, and recognized by the patient as one self. It can be argued that this future will not be achievable until advancements in engineering are better equipped to the user's subjective experience.

The user's subjective experience is significantly impacted by their perceptions and also those of society. This is where another piece of the prosthetic embodiment puzzle comes into place. When a prosthetic wearer is placed in society, the patient is undoubtedly faced with challenges that will influence their ability to perceive their prosthetic device. Understanding the stereotypes that exist in society and the societal attitudes towards prosthetic users thus offers insight into creating a world where people with prosthetics are widely accepted and their prosthetics are viewed as extensions of themselves. One example of research discusses considering cyborg bodies through the lens of transmobility to change the negative narrative of disabled bodies as the people to take pity on or look towards for inspiration and in turn view these bodies as imaginative, playful, and mobile (Nelson, M. K., Shew, A., & Stevens, B. 2019). Here it should be obvious that to empower those with disabilities and prosthetics, we should challenge stigmas, preconceptions, and the attitudes of society in order to increase prosthetic embodiment. If inclusivity increases in society, prosthetic embodiment will increase among prosthetic wearers as societal integration of prosthetics encourages confidence among users. If the perception of society changes towards "cyborgs" and others with prosthetics and patients feel empowered to confidently sport their prosthetic. The current variability to test prosthetic embodiment and the lack of the agreed upon definition in society limits the ability to quantify prosthetic embodiment in patients. It can be argued that when trying to use prosthetic embodiment to express successfulness, the specific type of body representation must be clarified to establish an accurate and consistent course to achieve increased prosthetic embodiment.

Prosthetic embodiment should be analyzed utilizing phenomenology. Phenomenology being the study of phenomena or how people experience things (Spiegelberg, 2024). Through phenomenology, researchers can gain insights into the profound ways in which prosthetic technology reshapes the experiences of those who rely on it, providing a deeper understanding of the human-technology relationship. This allows researchers to better understand the lives and experiences of those who wear prosthetics without wearing one themselves. This is very important to consider for those developing prosthetics as it allows researchers to view a larger set of the factors influencing a user's decision regarding the success or failure of their prosthetic. When applied to the study of prosthetic embodiment, it seeks to understand the lived experiences of individuals using prosthetic devices, aiming to grasp how these devices become integrated into their sense of self and body image.

This approach involves examining the subjective experiences of users, focusing on how the prosthetic limb is not merely a tool or an external object but through prosthetic embodiment becoming a part of their body and lived experiences. Also, explores the transformation in perception, action, and identity that occurs as patients adapt to their prosthetic without leaving out how the device may influence user's engagement with the world. A previous study comprising 38 patient interviews used interpretive phenomenological analysis to understand more about what makes a prosthetic initially "successful" for patients. Murray's (2004) study found:

> This suggests the need to sufficiently motivate potential prosthesis users in the period between an experience of prosthesis use as unnatural and wieldy to one of pre-reflective, natural use. In addition, two broad forms of prosthesis experience were identified: one in which the prosthesis was experienced as a corporeal structure; and one in which it was viewed as a tool. While future work may be able to explore the psychosocial correlates of these experiences, it is nonetheless the case that persons with these differing experiences were able to enjoy the benefits imbued by prosthesis use. (Conclusion)

This method of analysis involves collecting information from those who wear prosthetics and their respective experience. Without incorporating a phenomenology approach into prosthetic research or development, ideas and changes presented may be found to lack a voice from users and limit prosthetic embodiment. This previous study highlights the fact that the user's relationship is not just with the technology and their experience can even be shaped by those around them who they view as successful prosthesis users. A 2022 study on the psychosocial impact of lower limb amputation on patients and caregivers helps encapsulate alternate issues regarding prosthetic success but this method is limited in its ability to establish connections between the technology and society that phenomenology includes (Alessa, M., et al., 2022). Notably, this research shows the need for additional work on psychosocial correlations to a user's experience accomplished through phenomenology's holistic approach. This brings forth the ability to form new ideas and have conversations through a new lens relating to prosthetic embodiment that may allow researchers to better fit a patient to a prosthetic. As new forms of prosthetics continue to emerge, this way of thinking and research can provide a framework for expedited patient prosthetic embodiment.

While prosthetic embodiment is a relatively new and developing term, there exists a growing interest in the field as more clinical papers on the topic are published. To do an analysis on prosthetic embodiment, the evidence collected consisted of a compilation of recently published works relating to prosthetic embodiment through a lens of phenomenology (Bekrater-Bodmann et al., 2020) (Zbinden et al., 2021)(Norlyk, A., Martinsen, B., Hall, E., & Haahr, A., 2016). These studies involve the grouping and recruitment of large samples of prosthetic users. My personal research conducted in the field consists of a smaller sample size but provides valuable insights into prosthetic embodiment. Notably, shadowing a prosthetic

company in the summer of 2023 offered the chance to personally question 3 prosthetic users utilizing the Prosthetic Embodiment Scale, Trinity Amputation and Prosthesis Experience Scales, and additional questions relating to the patient experience. This personal experience offered the ability to identify similarities between studies already conducted and additionally hear personal opinions and thoughts from patients. For example, a geriatric lower limb amputee identified issues regarding comfort that were attributed to continued weight loss and suction issues with the socket technology. Further discourse identified social issues troubling the patient as the success of the prosthetic limited the patient's ability to interact with friends in activities previously possible that further impacted mental health and body image. These issues created chaffing and discomfort for the patient but also highlight the intense customization and patient focused design necessary when creating and managing patients. The insights, specific choices, and conclusions made from supplementary published works further illustrate the importance of prosthetic embodiment in the future of prosthetic treatment.

To accomplish such a task, it proved important to comb through relevant clinical papers in an attempt to find the similarities and differences that presented themselves in the beginning or setup of the research and the conclusions drawn. The views and experiences expressed from personally interacting with prosthetic users helped guide this phenomenological analysis. This importantly permitted the analysis of alternative relevant papers in a way that honors the patient-user experience with a higher understanding of the topic and the biases that present from not being a prosthetic wearer. With that being said, the phenomenological analysis then allowed for a more structured interpretation of how participants perceive and integrate their prosthetic limbs into their identity and daily life. This process not only advances academic knowledge but

also has practical implications for the design and implementation of prosthetic devices, aiming to improve the quality of life for users.

By capturing a wide range of subjective experiences, the identification of diverse needs and preferences highlights the limit that quantitative research alone presents. Also, this lens allows for a better understanding of the embodiment process each prosthetic user experiences to improve the design interventions that facilitate a smoother adaptation to prosthetic use. Phenomenological research highlights areas in society where users might require additional support prosthetic developers have no control over like psychological adjustment or social integration to push society to make more empathetic and user-informed policies and practices (Norlyk, A., et al., 2016). This approach challenges and expands current notions of what it means to live with a prosthetic and the human-machine interaction. Engaging users in the research process as active participants whose experiences and insights are valued leads to higher levels of engagement and satisfaction with prosthetic solutions.

The inclusion of phenomenology in the analysis of the patient experience is necessary to reach an embodied future. Historical efforts to create more biomechanically functional prosthesis have lacked this inclusion. This is why embodiment and patient acceptance of their prosthetic has been an issue for thousands of years. Therefore, it can be said that future development of prosthetics and the analysis of their efficacy without phenomenology will continue to lack the necessary connections to the patient experience. Phenomenology which focuses on the holistic experience of the patient provides clarity and foresight into potential solutions for increasing the initial and continued efficacy of prosthetics.

Arguably, the societal impact of receiving an amputation and the mental issues presented can guide engineers and researchers towards technology that is more suited to each patient. If

included, the exponential growth of advancements and technology will trend towards embodiment in ways never before seen. This means that prosthetic development, surgical techniques, and patient care must all work to utilize phenomenology. For example, focusing on advancements in surgical techniques through the analysis of previous patient experiences offers the identification of problems following integration of prosthetic devices for patients. Techniques that bring forth reduced rehabilitation and recovery timeframes allow a patient to feel more empowered and further reduces the psychological impact that follows amputation.

A greater focus on addressing reducing phantom limb pain and the enhancement and refinement of patient care after surgery is also essential at moving towards an embodied future. Advanced surgical techniques and integration of technology into the body during surgery can give those an idea of what can be possible and further developed with phenomenology. An additional example of this would be refined techniques to reduce the timeframe that amputation volume fluctuates to allow for a more efficient transition toward an accepted prosthetic. In this way, researchers are able to identify commonalities presented in amputees and present advanced solutions more accordingly. The inclusion of the lived experience of patients provides additional design considerations for the advancement of existing and new technologies that are more equipped for integration into the complex interactions identified.

The development of new technology for the prosthetic industry is not only focused on the prosthetic itself. Phenomenology offers unique insights regarding the prosthetic experience as they pertain to society and the mental health of amputees. This means, the future of prosthetic care can include advanced preparation for amputee patients that more efficiently trend towards embodiment. Here the identification of gaps in the prosthetic industry and beyond are formed through phenomenology but it is argued that potential solutions will be established more

efficiently. For example, artificial reality can provide therapeutic techniques that better more efficiently prepare a patient for their new life without a limb. Additionally, counseling, group therapy, and education for amputees and members in close contact with patients will also smooth the transition. Also, further education and stigma reduction in society for those with and without amputees guided by phenomenology research will increase embodiment for patients. Phenomenology's ability to uncover the nuanced factors influencing prosthetic embodiment fosters acceptance and empowerment through the empathetic nature of the ideology.

The societal factors associated with prosthetic embodiment have taken an underlying backseat in traditional development but are crucial to the patient experience. The limitations in current prosthetic embodiment can be attributed to societies inability to work towards solutions that reduce stigmas and as a result hinder a patient's ability to accept this new life as their own. Therefore, these methods presented can be developed utilizing the phenomenology research that identifies issues in initial and continued acceptance for the diverse needs and preferences of amputee patients and their complex interactions within society.

Interestingly, personal discussion with prosthetic patients in some instances conflicted with initial ideas formed before these interactions. For example, at the prosthetic company it was identified that patients do not always care deeply about the aesthetics of the prosthetic as assumed. These differences are associated with economic factors pertaining to insurance coverage and the options available to patients. It is important to note that further phenomenological research on prosthetic development can aid in the production of more affordable customizable options for patients that allow patients to feel complete. This shows how the gaps in current technology, specifically more affordable options to make a patient embody their prosthetic exist but solutions can be identified through phenomenology. Also, this further

expresses the complex interactions between patients and society as economic factors. Without encapsulating the patient experience through phenomenology, future developments lack information regarding what is necessary to reach an embodied future. More research into the development of cheaper customizable options will benefit from phenomenological research as the focus shifts from functional success towards patient experience success as a whole.

The prosthetic experience is also ever changing with the patient. The pain experienced by each patient and their ability to tolerate such pain is not standard. It can be argued that phenomenological analysis of greater sample sizes can offer a more standardized approach to quantify what is better suited for each patient's custom needs and experiences. This methodology offers enhanced analysis of individual experience in such a way that can be translated to make more general conclusions regarding patient treatment. The prosthetic industry's inability to quantify these differences and encapsulate unique experiences of patients is evident from high rates of abandonment. This means that technologies that enhance comfort and allow for greater speed of production and development of prosthetics are necessary. Problems that arise from refitting sockets and the inability to provide the patient with a new socket in a timely fashion limit the patient's ability to experience embodiment. Here, phenomenology offers developers insights towards the factors that are necessary for embodiment as necessary timeframes for manageable development and refitting prosthetics are formed.

Other studies that focus on the psychosocial are limited in the insights that they offer as compared to a phenomenological approach (Alessa, M., et al., 2022). This is because phenomenology is able to include these psychosocial interactions and more as they pertain to the whole experience. Psychosocial analysis is still beneficial to the prosthetic industry but research utilizing phenomenology should be prioritized. Psychosocial analysis is limited in that the results

do not provide the holistic results necessary for the development of alternative solutions. It can be said that this technique can be utilized as only an identifier of the issues that present themselves mentally and socially for patients with prosthetics. When compared to a phenomenology approach it can be seen as potentially a waste of resources where phenomenology would be better suited and more insightful.

In conclusion, studying prosthetic embodiment through a lens of phenomenology offers the ability to capture the complex interactions between the patient experience and technologies. Without it, technical development and industry development beyond is limited. The inclusion of these factors can guide future development of more empathetic and patient centered technologies that the phenomenological lens provides. To create more successful solutions, researchers must acknowledge the bias from their viewpoints and continue refining their methods and techniques while utilizing phenomenology. Also importantly, the patient centered nature of phenomenology will require more intensive data collection and analysis because every personal experience is different. While result production can require more work, the information that phenomenological studies on prosthetics provides is much more robust. This trade off proves necessary for reaching a more embodied future in the field of prosthetics. The current systems and their complex interactions between the prosthetic industry and the patient experience can only benefit from a greater focus on utilizing phenomenology in the prosthetic industry. More research that utilizes this lens will develop a more refined definition of prosthetic embodiment that pushes society towards a necessary embodied future that sees increased inclusion and acceptance.

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