REDEFINING PROSTHETIC DEVICES: AESTHETIC CONSIDERATIONS IN USER-CENTERED DESIGN FOR LOWER LIMB PHYSICAL DISABILITIES

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ABSTRACT

Prosthetic devices for individuals with lower limb physical disabilities have traditionally been designed with an emphasis on restoring function and facilitating mobility. However, emerging research highlights the growing importance of aesthetics in prosthetic design, particularly in relation to the psychological and emotional well-being of users. The appearance of assistive devices significantly influences an individual's self-perception, confidence, and social integration. As a result, contemporary prosthetic design is shifting toward the development of devices that are not only functional but also expressive, fashionable, and reflective of the user's identity. This study aims to contribute to the advancement of user-centered prosthetic solutions by exploring the lived experiences of individuals with congenital lower limb deformities. A 12-month prospective intervention study was conducted involving two participants with distinct physical conditions. Data collection included semi-structured interviews, video documentation of the participants' daily use of conventional prosthetic devices, and detailed physical assessments focusing on the structure and muscular composition of the lower limbs. These observations underscored the necessity for personalized prosthetic designs that account for both anatomical differences and individual preferences. In addition to functional needs, participants expressed a strong desire for improved comfort, compatibility with clothing, and visual appeal. These findings align with broader consumer insights, which emphasize the importance of incorporating aesthetic considerations into product development. A user-centered design approach characterized by direct user involvement, iterative feedback, and customizable features such as prosthetic covers is identified as essential in achieving high levels of user satisfaction and acceptance. Ultimately, this study affirms the critical role of aesthetic value in prosthetic design and advocates for ongoing user engagement to inform future innovations. By integrating functionality with aesthetics, prosthetic devices can better support the holistic well-being of individuals with lower limb disabilities, enhancing both their physical independence and psychological resilience.

Keywords: *Prosthetic device, aesthetic, user-centered, lower limb physical disabilities*

INTRODUCTION

Restoring function and promoting mobility have historically been the main goals of prosthetic devices for people with physical limitations of the lower limbs. However, new research shows how important aesthetics are in prosthetic design, especially when it comes to users' psychological and emotional health. The way assistive equipment look has a significant impact on how someone feels about themselves, how confident they are, and how well they integrate into society. The development of devices that are not only practical but also expressive, stylish, and representative of the user's identity is thereby becoming a trend in modern prosthetic design. In Malaysia, the prevalence of physical disabilities underscores the need for such holistic approaches. As of 2023, Department of Statistic Malaysia reported there were 736,607 registered persons with disabilities (PWD), accounting for 2.2% of the national population. Among these, physical disabilities were the most common, with 245,015 individuals affected. However, registration is not mandatory, and the National Health and Morbidity Survey (NHMS) 2019 estimates that 11.1% of Malaysians aged 18 and above have disabilities, with 1 in 4 adults experiencing functional difficulties in domains such as mobility. Furthermore, a study conducted at 13 Medical Rehabilitation Clinics in Malaysia revealed that approximately 70% of limb amputations were due to complications from diabetes mellitus, with a significant proportion being transtibial amputations. Despite the availability of prosthetic devices, only 58% of unilateral lower limb amputees utilized them, averaging 6.48 hours of use per day. (Karim, H. H. A., & Chern, P. M. (2020).

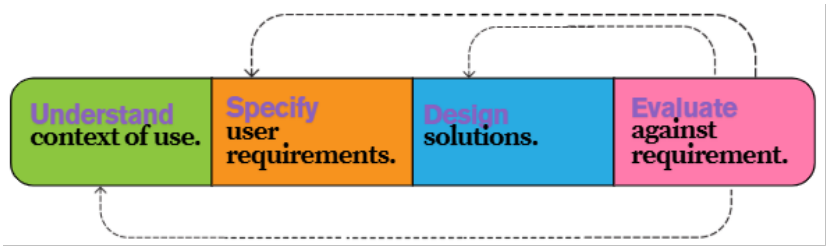
The integration of aesthetic considerations into prosthetic design has been shown to positively influence social perceptions and interactions. For instance, a study by Phelps, C., Hutchings, P. B., Stokes, T., Cooke, Z., Williams, M., & Jenkins, S. (2024) demonstrated that customized aesthetic leg covers led to higher ratings of agreeableness and extraversion in individuals with lower-limb amputations, compared to those with traditional prosthetics or no amputations. Such findings highlight the potential of aesthetically enhanced prosthetics to improve not only the psychological well-being of users but also their social integration. Given these insights, it is imperative to adopt a user-centered approach in prosthetic design that balances functionality with aesthetic appeal. Furthermore, the dearth of research on users' perceptions of how well the design now available on the market meets their needs and preferences raises concerns (Rana, M. R. I.., McBee-Black, K., & Swasan, I. S., 2024). To find the best strategy for involving consumers in the creation of the products, they advise conducting additional research. Such an approach can empower individuals with lower limb disabilities, fostering greater confidence and facilitating their reintegration into society.

LITERATURE REVIEW

The development of prosthetic devices for individuals with lower limb physical disabilities has historically prioritized function over form. Traditionally, the primary goal was to restore mobility and enable users to perform daily activities with minimal discomfort or limitation. However, recent studies suggest that this utilitarian approach may overlook critical aspects of user experience, particularly the psychosocial and emotional needs of prosthetic users (Smail et al., 2020). Aesthetic appeal has emerged as a significant consideration in prosthetic design, influencing not only user satisfaction but also confidence, identity, and social inclusion. According to Murray (2005), the prosthesis is not merely a tool but a part of the user's body image. When devices appear overly clinical or mechanical, users may feel stigmatized or alienated. Conversely, aesthetically pleasing and customizable prosthetics can foster a stronger sense of identity and acceptance, both personally and socially.

In Malaysia, the importance of addressing these user needs is underscored by demographic data. As of 2023, 736,607 individuals were registered as persons with disabilities (PWDs), with physical disabilities comprising the largest group at 245,015 cases (Department of Statistics Malaysia, 2023). Moreover, limb loss is predominantly attributed to diabetes-related complications, and only 58% of unilateral lower limb amputees reportedly use prosthetic limbs regularly. These statistics point to the critical need for prosthetic solutions that not only meet physical requirements but also resonate with users on a psychological and emotional level. This is where the principles of User-Centered Design (UCD) play a pivotal role. UCD is an approach that involves end-users throughout the design process to ensure that the final product aligns with their actual needs, preferences, and values (Norman & Draper, 1986). In the context of prosthetics, UCD facilitates the development of devices that are functional, comfortable, and aesthetically congruent with the user's lifestyle and identity. For example, research by Pousett et al. (2014) emphasizes that involving users in the design phase leads to increased satisfaction and improved device acceptance.

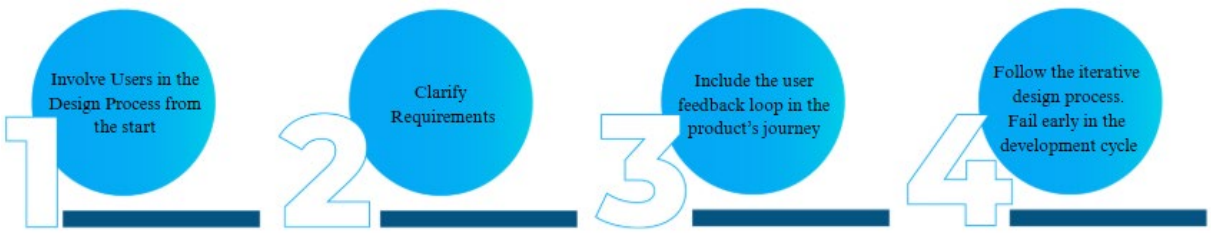
Figure 1: User Centered Design Principles



Source: Interaction Design Foundation - IxDF. (2016, June 5). *What is User Centered Design (UCD)?*

Aesthetics, in particular, has become a focal point within UCD frameworks. A study by Smail et al. (2020) found that participants perceived individuals wearing customized aesthetic leg covers as more agreeable and extroverted than those with conventional prosthetics. Such perceptions can positively affect social interactions and reduce the stigma often associated with disability. The integration of aesthetics and UCD principles also aligns with broader goals of inclusive design and social sustainability. By considering the emotional, cultural, and personal dimensions of prosthetic use, designers can create devices that are not only medically effective but also socially empowering. This shift reflects a redefinition of prosthetic success—not merely in terms of biomechanical performance, but also in terms of quality of life, user empowerment, and community inclusion.

Figure. 2: User Centered Design Principles

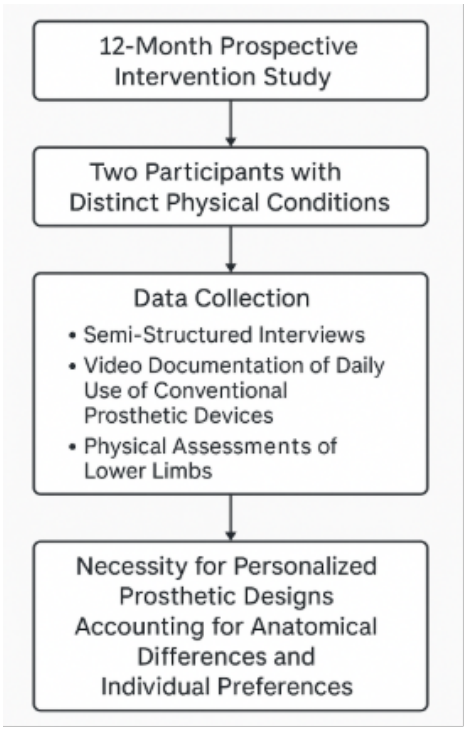


Source: The User Centered Design Principles. https://www.cuelogic.com/blog/user-centered-design

RESEARCH METHODOLOGY

This study employed a 12-month prospective intervention design aimed at exploring the influence of personalized prosthetic design on the functional and psychosocial experiences of individuals with lower limb physical disabilities (Diagram 1). The study involved two participants, each presenting with distinct physical conditions that affected the structure and muscular composition of their lower limbs. These case study sampling strategies allowed for in-depth investigation into the unique needs and responses associated with varying anatomical profiles.

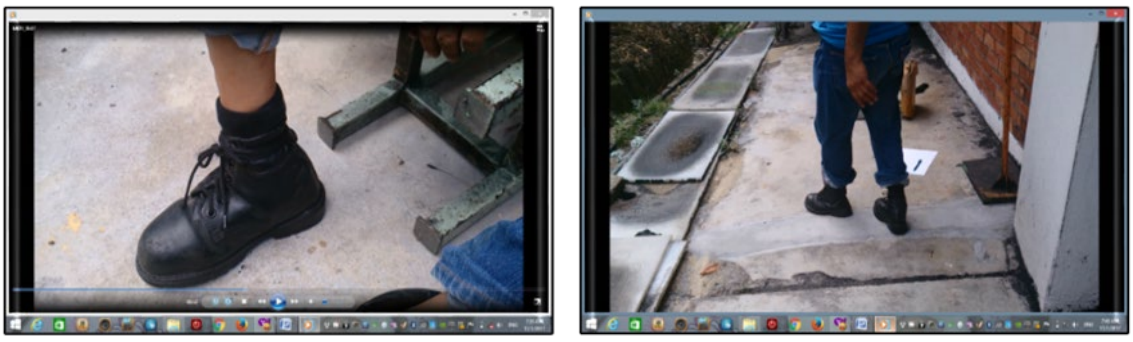
Diagram 1: Research Framework



Data collection was conducted through a triangulation of qualitative and observational methods to ensure comprehensive and holistic insights. First, semi-structured interviews were administered at multiple stages throughout the intervention period. These interviews were designed to elicit detailed narratives regarding participants' daily experiences, perceptions, emotional responses, and expectations related to their prosthetic devices. The use of open-ended questions facilitated the emergence of participant-driven themes and allowed for greater contextual depth.

Second, video documentation (Figure 3) was carried out to observe the participants' daily usage of their conventional prosthetic devices in naturalistic settings. This method enabled the capture of nuanced behavioral patterns, mobility challenges, and adaptation strategies employed by the participants in real time. The visual data also served to validate the verbal accounts provided during interviews and provided critical insights into movement mechanics, comfort, and body-prosthesis alignment.

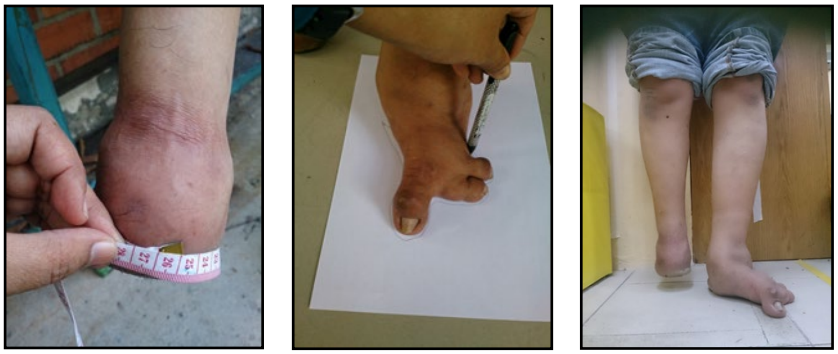
Figure 3: Video Documentation



Source: Authors, (2019)

Third, physical assessments (Figure 4). These assessments included measurements of residual limb shape, volume, muscle tone, and range of motion. These evaluations were essential in identifying physical discrepancies and anatomical considerations that would inform the design of a more personalized prosthetic solution.

Figure 4: Physical Assessment



Source: Authors, (2019)

The integration of these three data sources provided a rich, multi-dimensional understanding of the participants' needs and experiences. The findings from the interviews, video observations, and physical assessments collectively highlighted the limitations of standardized prosthetic devices and underscored the critical need for individualized design approaches.

FINDINGS

Both case study subjects were not wearing a proper footwear, prosthetic or assistive devices although the working environment and the job specification required them to do various movements such as walking, standing, and sitting for a long time. Here is the primary investigation about subjects working footwear.

Case Study A

Congenital foot abnormalities include this one (Table 1). Every leg has a unique set of deformities. It has many abnormalities, including talipes valgus and reduced toe length. Medical dictionaries define talipes valgus as a chronic eversion of the foot, where only the inner side of the sole rests on the ground. This condition is typically accompanied with a breakdown of the plantar arch (left foot). Talipes is any of a number of foot abnormalities, particularly those that are congenital. A non-traumatic foot deviation toward one or two of the four lines of movement could potentially be the cause.

Table 1: Foot deformities of Case Study A

View	Front	Side (Inside)	Side (Outside)	Rear
Right Foot				
Left Foot				

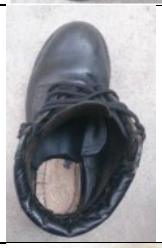
Source: Authors, (2019)

The current safety footwear of the case study is presented in Table 2 below. The right shoe was fine in its design but the left shoe's quarter side (which is the part of the shoe which is recognized to be opened to insert the foot) was widely opened with one of the shoelaces out of proper bondage. The cause was that the wearer feels uncomfortable due to the ankle of the leg being enlarged and deformed. Because the right leg conditions, during working and sitting, only the quarter part was used, so the right shoe slant forward. The shoe's outsole displays the various heel sizes and levels of wear, which suggests a heavy or excessive load and can result in additional foot issues. According to the findings of the Frey et al. (1993) study, poorly fitting shoes were prevalent and linked to foot pain and forefoot illness. The patient additionally installed the elevated insole device for the stump for stability when wearing the shoe. To achieve the desired leg height, 18 pieces of cellulose board with a thickness of 2.5 mm were adhered

together. (Figure 5). However, Active Health Management states that these shoe changes are only taken into consideration to make up for minor limitations and foot abnormalities or leg shortening of less than 1.5 inches.

Figure 5: Cellulose board insole

Table 2: The shape and the condition of the shoe

Shoe part		
Right side		
Left side		
Outsole		
Insole		

Sources: Nor Rofizah Johari, & Khatijah Md Saad. (2019). DESIGN INVESTIGATION ON FOOT DEFORMITIES WORKING FOOTWEAR. *JOURNAL INFORMATION AND TECHNOLOGY MANAGEMENT (JISTM)*, *4*(15), 41–47. Retrieved from https://gaexcellence.com/jistm/article/view/1093

Case Study B

Another case study, Subject B, is depicted in Figure 6 below. Because of his abnormalities, Subject B decided to wear a boot that was calf length. Because the feet stay apart in the shoe while he walks, Subject B stated that the calf length boot was the best fit for him. Additionally, the zippered boot facilitates opening and wearing the shoes. He still requires assistance to stand and walk correctly, though

Figure 6: Foot deformities of Case Study B

Table 3 below shows how the case study findings can be aligned with the UCD principles.

Table 3: Alignment of Case Study Findings with User-Centered Design Principles

Case Study	User Feedback / Observation	Design Implication	Aligned UCD Principle
Case A	Left shoe had to be wide open and improperly fastened due to ankle deformity	Need for adjustable or expandable shoe openings tailored to limb shape	Understanding user's physical context and limitations
	Right shoe slanted due to uneven use during walking/sitting	Indicates need for custom weight distribution support	Designing for real-world use and functional diversity
	Heavy outsole wear on heel due to load imbalance	Custom outsole design and support to accommodate gait asymmetry	Iterative testing with user input for durability and function
	Use of 18-layer cellulose insole to balance limb height	Indicates need for personalized height-adjustment inserts	Co-design with user to ensure biomechanical alignment
	General discomfort due to congenital deformities (talipes valgus, fewer toes)	Custom anatomical fit and soft inner materials	Accommodating anatomical variation in design
Case B	Prefers calf-length boots with zippers for better fit and ease of use	Prioritize ease of donning/doffing and secure fit in future designs	Designing for usability and accessibility
	Reports that feet remain detached from shoe while walking	Need for enhanced interior foot stabilization	Emphasis on functional feedback during design
	Still unable to walk or stand properly without assistance	May require integration of supportive orthotic or external aid	Incorporate assistive feedback into performance testing

Application of User-Centered Design Principles

The findings from Case Studies A and B underscore the critical importance of User-Centered Design (UCD) in the development of prosthetic and orthotic footwear for individuals with lower limb physical disabilities. UCD is an iterative and participatory design approach that focuses on the end-users' specific needs, preferences, and limitations throughout all stages of the design and development cycle (ISO 9241-210:2010; Norman & Draper, 1986). By centering design decisions around the actual lived experiences of users, UCD aims to enhance usability, functionality, comfort, and psychological well-being. Case Study A illustrates the challenges faced by an individual with congenital, multi-directional foot deformities—namely, *talipes valgus* and toe deficiencies in both feet. The participant's feedback reveals a clear mismatch between standard footwear design and their unique anatomical structure. For instance, the left shoe, which required an unusually wide opening due to ankle deformity and swelling, lacked proper fastening, thereby compromising stability and comfort. Similarly, the asymmetric outsole wear on the right shoe suggests abnormal gait cycles and disproportionate weight distribution, both of which are common among individuals with musculoskeletal abnormalities and can lead to secondary injuries (Frey et al., 1993).

From a UCD perspective, these issues highlight a failure to accommodate biomechanical variability and user-specific comfort needs. The participant's creative adaptation by using 18 layers of 2.5 mm cellulose board to build an insole, demonstrates an unmet need for customizable prosthetic design features. Incorporating this user feedback into design could inform more effective and safer solutions, such as adjustable insoles, adaptive arch support, or contoured ankle collars. As Pousett, Gallant, & Moser (2014) emphasize, user involvement in early-stage prototyping significantly enhances product relevance and long-term satisfaction. Case Study B involves a participant who chose to wear calf-length boots with zipper enclosures due to difficulties in foot containment within conventional footwear. Although the boot improved the perceived sense of containment, the participant still could not walk or stand unaided. This highlights another dimension of UCD: the significance of psychological assurance, proprioception, and the perception of safety. Aesthetic and structural features that enhance confidence and independence such as extended ankle support, simplified fastening systems, and interior stabilizers—play a vital role in user acceptance (Smail et al., 2020; Murray, 2005).

Beyond mechanical function, both case studies highlight the psychosocial and emotional dimensions of assistive device design. Individuals desire not only mobility but also dignity, identity, and independence. The aesthetic aspect of prosthetic and orthotic footwear, often overlooked in clinical design, plays a crucial role in how users perceive themselves and how they are perceived by others (Smail et al., 2020). As Murray (2005) notes, the social meanings associated with prosthesis use influence self-esteem, social interactions, and overall quality of life. Aesthetic customization through color, texture, or form can therefore foster stronger emotional attachment and higher rates of device use. Research by Frey et al. (1993) also confirms that ill-fitting footwear is strongly associated with foot pain and the development of forefoot disease, reinforcing the need to involve users in design decisions that affect fit, comfort, and daily usage. UCD practices prioritize contextual inquiry, which considers not only physical anatomy but also the user's lifestyle, mobility goals, and social environment.

The lived experiences of participants A and B demonstrate how prosthetic and orthotic footwear design can greatly benefit from UCD methodologies. Their stories advocate for the development of assistive devices that are not only biomechanically sound but also emotionally and contextually appropriate. Future design initiatives should prioritize continuous dialogue with users, real-world functional trials, and modular design frameworks that allow for personalization and iterative refinement, all essential components of a truly user-centered approach.

CONCLUSION

Through detailed case analyses of two individuals with distinct congenital lower limb physical disabilities, it is evident that improperly fitted or generic prosthetic and orthotic devices can exacerbate pain, reduce mobility, and contribute to further biomechanical complications. As no two fingerprints are identical, each foot deformity presents unique anatomical and functional characteristics. Hence, personalized design must consider a combination of factors, including skeletal and muscular structure, limb asymmetry, body size, type and severity of deformity, and the user's financial constraints. In line with the User-Centered Design (UCD) framework, the involvement of users in the design process ensures that assistive devices are functionally suitable, emotionally resonant, and contextually appropriate (Norman & Draper, 1986). Recent studies find that aesthetics play a significant role in improving patient satisfaction, self-esteem, and acceptance of prosthetic devices. This indicates that prosthetic devices serve as both personal identity and assistance (Lee, Mitchell, Repayo & Tillitt et al., 2022); Vlachaki, Paterson, Porter & Bibb (2020); Holt & Murray (2020); Taylor (2020). Beyond biomechanical function, aesthetic design plays a significant role in user satisfaction and psychosocial well-being. Prosthetic and orthotic devices that are visually pleasing, stylish, or expressive contribute positively to the user's self-image, confidence, and social acceptance (Smail et al., 2020). Many users view their assistive devices not just as medical equipment but as extensions of their identity. Therefore, future designs should incorporate both functional and aesthetic considerations, allowing users to feel empowered and dignified in their daily lives. However, the current study's limitations impact the scope and significance of its outcomes in numerous ways. To begin with, the study's sample size of two participants is too small to represent the broader population with lower limb deformities. Moreover, while user input is fundamental in the UCD approach, reliance on subjective self-reports without standardized tools may compromise some level of objectivity. Furthermore, the scope of collaboration with qualified prosthetists and orthotists was encouraged but not fully pursued, which inhibited the technical rigor of the design outcomes. Finally, although the study claimed that user identity and identity satisfaction were crucial, the study did not assess the psychological and emotional impact of visual design elements. Overall, these limitations highlight the need to focus on sample size, collaboration, technology, and structured analysis in future research studies.

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