User Centered Design Study: Improvement for the 'Figure of 9' Harness

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Contextual review

About 1.7 million people are living with a limb loss in the United States (Braza & Martin, 2020). These individuals may be referred to as amputees and many choose to wear a prosthetic device(s) to assist with carrying out day-to-day functions. There are different types of prosthetic devices, one of which is described as a 'body-powered' device where movements of the user/body (force and excursion) are captured by the harness and transferred to the cable system to actuate the prosthetic's terminal device (Uellendahl, 2021). Many users choose to wear a body-powered prosthesis because the advantages include silent movement, lightweight, moderate cost, durability, and reliability to terminal device positioning, however, reports also show users are unhappy with the appearance and discomfort (overall dissatisfaction) of the prostheses system (Hashim et al., 2017; Huinink et al., 2016).

Referencing figure 1, the body-powered prostheses consist of four main parts: (A) harnessing system, (B) Bowden cable, (C) socket, and (D) terminal device (Gudfinnsdottir, 2013), with an optional metal ring (E) to join harness webbings. The 'Figure of 9' harness is the most commonly used harness (Gudfinnsdottir, 2013) for unilateral transradial prostheses. However, the 'Figure of 9' harness design has not substantially changed in about 70 years (Pursley, 1955). As a functional wearable product, the harnessing system needs the attention of apparel designers and researchers to develop and provide improved solutions that also meet consumers' aesthetic and expressive needs. Additionally, the clothing worn with the 'Figure of 9' harness also requires improved attention to meet users' expectations.

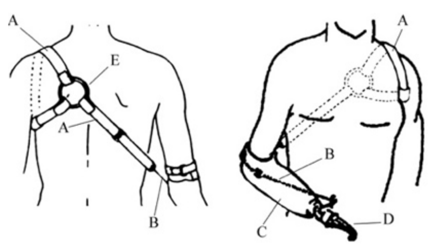

Figure 1. Schematic figure of a conventional body-powered prosthesis.

Therefore, the purpose of this study is (a) to outline functional, aesthetic, and expressive needs in harnessing system and related clothing; (b) to determine users' expectations in products associated with their prosthetic device(s); (c) to prototype a new harnessing system; (d) and design adaptive clothing compatible with the new harnessing system.

Method

In order to better understand the current 'Figure of 9' harness wearers needs, a qualitative case study approach that embodies the user-centered design (UCD) framework was employed. Currently, as women's fashion is more diverse than men's (Freeman & Pfeiffer, 2021), a female participant was recruited as the 'user' in this study. This study followed a user-centered design (UCD) framework originally developed by the International Origination for Standardization (1999) and further refined by Morris, et al. (2017). The UCD framework outlines five stages that guide the product development process: (1) Specify the context of use; (2) Specify the user goals for product success; (3) Create design solution (prototype); (4) Evaluate design solution, and (5) Assess for meeting requirements by the user. Specifically, within the second stage, the Functional, Expressive and Aesthetic (FEA) consumer needs model (Lamb and Kallal, 1992) was involved in understanding the needs of transradial prosthesis users and their dissatisfaction with existing transradial prosthesis harnessing system. A semi-structured interview was conducted via zoom informed by the FEA model. The interview was video recorded, transcribed verbatim, and content analysis was performed through inductive coding into themes using qualitative analysis software, NVivo (Creswell, 2007). Resulting themes informed ideation for new harnessing options. A harnessing system and adaptive clothing ensemble, intentionally designed to be worn together, were prototyped and evaluated.

Results

The case study participant was an adult woman who lost her arm in an accident approximately 36 years ago. She had experience with both body-powered and mechanical-powered prosthetic devices. However, she dislikes the use of prosthetic options due to the "uncomfortable and ugly design" of the 'Figure of 9' harness. The following sections briefly outline the results of this study as they align with each stage of the UCD framework.

Stage1: Specify the context of use. Alternative transradial harnessing system for body-powered prosthetic device users. Users wear the prosthetic-supporting harness on a daily basis to perform movements that activate the terminal device which simulates operations of a hand. Specifically, there are three primary biomechanical elements that should be 'captured' in harness design functionality: Glenohumeral Flexion, Bi-Lateral Scapular Abduction, and Elbow or forearm

Flexion. These three elements set minimum-requirement performance expectations of the prototype and also served as evaluation benchmarks.

Stage 2: Specify the user goals for product success. Based on the interview analysis, the main dissatisfactions of the 'Figure of 9' harness were themes of 'discomfort' and 'not attractive appearance.' According to the FEA model, 'discomfort' presents the user's functional needs, and the 'not attractive appearance' presents the user's expressive and aesthetic needs. Within the functional category, four themes emerged through content analysis: (1) Pulling Pressure, (2) Poor Fit, (3) Feeling Against Skin, and (4) Limited Clothing Choice. Within the Aesthetic and Expressive joint category, which represents the communicative and symbolic aspects of a worn item, the theme of 'Self-adjustability' was outlined, so that users may care and dress of themselves without relying on others. Additionally, an 'Attractive Desire' theme emerged connected to a sub-theme of 'Societal Perceptions' from public visibility of harness and prosthetic device.

Stage 3: Create design solution. The prototyped new harnessing system's structural design was based on body pressure results from the activation forces (Gudfinnsdottir, 2013). The new harnessing system consists of four straps, three of which are connected to a wide belt with boning, and the remaining one is connected to the prosthetic's actuating cable. Instead of nylon webbing, textiles and trims that contact the body were replaced with absorbent, soft knitted fabrics made from cotton and spandex fibers. A detachable formal dress can be worn with the new harnessing system or as a stand-alone ensemble.

Stage 4: Evaluate design solution. A comparative analysis was performed on the developed prototype with FEA points and interview themes. A rank-ordered list for how the prototype met users' expectations was outlined and recommendations for future prototype iterations on harnessing system with adaptive clothing were noted. The prototype was evaluated to ensure biomechanical benchmarks were met before advancing onto Stage 5.

Stage 5: Assess for meeting requirements by the user. The prototype was sent to the study's participant for functional, expressive, and aesthetic evaluation. Evaluation session was held via zoom and video recorded to further inform future design solutions.

Significance

This study successfully realized an updated harnessing system with coordinating adaptive clothing based on a user's FEA needs. In addition, this study provides valuable results for the research and development of new adaptive products for prostheses users.

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