Avoiding Product Abandonment through User Centered Design: A Case Study involving the Development of a 3D Printed Customized Upper Limb Prosthesis

Amanda Figliolia[1,*], Fausto Medola[1], Frode Sandnes[2] and Luis Carlos Paschoarelli[1]

[1] Department of Design, São Paulo State University (UNESP),
Av. Eng. Luiz Edmundo C. Coube 14-01, Bauru, 17033-360, Brazil
[1] amanda.figliolia@gmail.com, {fausto.medola, luis.paschoarelli}@unesp.br
[2] Oslo Metropolitan University (OsloMet),
P.O Box 4 St. Olavs plass, 0130 Oslo, Norway
frodes@oslomet.no

Abstract. This study reports on experiences with a user centered design approach for the development of a customized mechanical transradial prosthesis for a patient who were unable to adapt to a standard prosthesis. The development process explored the needs, preferences and expectations of the user, as well as physical and functional aspects. The production process was based on 3D printing technologies, with emphasis on originality and customization. During the design process, the user participated in the design and evaluation phases through practical handling tests. The results indicated that the participation of the user in the design process using a user-centered design approach lead to a customized product that matched the user's preferences. This acceptance and satisfaction with the product help minimize the risk of product abandonment.

Keywords: Prosthesis · Upper limb · Collaborative Design · Assistive Technologies · 3D Printing.

1 Introduction

Upper limb amputation requires a drastic adaptation from the amputee in order to perform daily manual tasks. The functional difficulties are more intense in activities that require synergic actions from both hands (bimanual tasks), which is the case of many situations of daily life such as opening a bottle, washing dishes, cutting a piece of meat or slice of bread, driving a car, etc. Thus, the immediate impact of the amputation of an upper limb expo subject to a situation of limitation and dependence in many activities of daily routine.

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[*] Please note that the LNCS Editorial assumes that all authors have used the western naming convention, with given names preceding surnames (first name then last name). This determines the structure of the names in the running heads and the author index. No academic titles or descriptions of academic positions should be included in the addresses. The affiliations should consist of the author's institution, town, and country.

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In contrast to lower limb prosthesis, upper limb prosthetic devices usually do not allow the same level of function recovery compared to those of the lower limbs. This is due to the complexity of hand function for both micro and macro motor movements, which is allowed by the highly developed sensory-motor function of these body parts. In practice, upper limb prostheses tend to be difficult to operate and do not allow satisfactory performance during its usage. Indeed, Kejlaa et al. [1] found that users of upper limb prostheses face problems with the independence in daily activities even after years of training.

Many users of upper limb prostheses end up adapting to do manual tasks with just a single hand, leading to device abandonment. Biddiss and Chau [2] found that the mean rejection rates were 45% and 26% in pediatric and adult users, respectively. Pain, low comfort and a lack of functionality are frequently reported as the causes of prosthesis rejection (see for instance McFarland et al. [3]). In addition to functional difficulties, upper limb prostheses also have a symbolic load that may further contribute to rejection. The significance of the assistive device for the user, and stigma associated with disability and the use of assistive devices have been addressed [4-6]. Still, the design of upper limb prosthesis is a challenge for designers, engineers and manufacturers. Innovative solutions that optimize function and minimize technology abandonment are required.

This paper documents experiences with the development of a personalized upper limb prosthesis based on the interdisciplinary collaboration between the product designers, rehabilitation experts and 3D printing technologists. The project described is part of a Brazil-Norway collaboration on education, research and development on collaborative design, rapid prototyping and Assistive Technologies [7]. Recently, a playful approach to the design of an upper limb prosthesis for a child was reported [8]. The project has also addressed the design and evaluation of assistive devices from an interdisciplinary perspective [9-11].

2 Methods

2.1 Informational Project

This is report of a case study conducted at SORRI BAURU Specialized Rehabilitation Center, with a 16 year old person who had to amputate the left arm and leg four years ago after a train accident. As part of his rehabilitation process, both an upper and a lower limb mechanical prosthesis was provided by the Brazilian public health system. The adaptation of the lower limb prosthesis was successful and the user recovered the walking ability to a satisfactory level. However, the adaptation of the transradial upper limb prosthesis was unsuccessful (Fig. 1) because of its weight, size, aesthetics and difficulty of use. Thus, the device was eventually abandoned by the user.

Fig. 1. The user and his conventional upper limb prosthesis.

This abandonment of the technology revealed the demand for a customized mechanical prosthesis designed to meet the user's needs and preferences. This customized prosthesis would also be a mechanical prosthesis, but with different operation characteristics and materials. A design briefing highlighted the most desirable features, namely low weight, easy to operate (to activate and deactivate hand grasping), and aesthetically pleasing.

The user was interviewed to explore the user's perceptions about the prosthesis and thereby better understand the reasons for the abandonment and uncover the user's needs and preferences. Prior to the interview, the user and his mother agreed by signing an Informed Consent Form (ICF) and the Informed Assent for Children/Minors. Next, the user completed a questionnaire with Likert scale questions to measure practical and perceived features of his prosthetic device.

The questionnaire results suggest that size, weight and difficulty of use mostly contributed to the difficulty of adaptation to the prosthesis and consequently abandonment of the device (see Fig. 2).

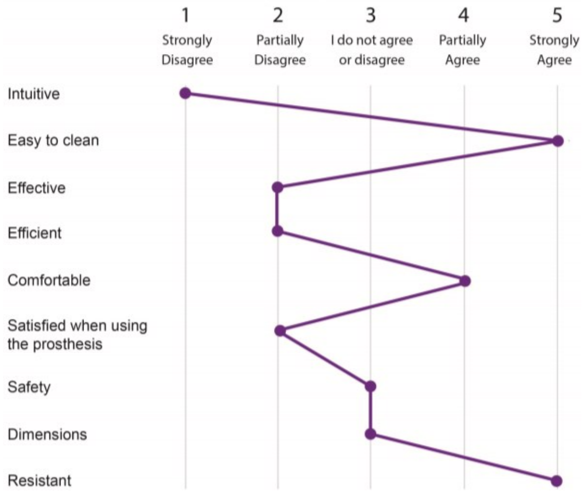

Fig. 2. User's prosthesis evaluation.

The information gathered from the interview was crucial for the development. The user's aesthetics preferences uncovered during the interview, complemented information about practical issues revealed by the questionnaire. Additionally, some examples of 3D printed prostheses were presented to the user, allowing him to visualize the product and actively participate in key design decisions: the colors would be inspired by Marvel's Captain America, the hand would be coloured in red and should contain a logo of a sport brand of his preference. Also, the prosthesis would carry the user's name.

Using a collaborative approach, the user was presented to a series of design proposals and could indicate changes and improvements according to his preferences. Changes in the position and colours of the logos, as well as the inclusion of the logo of his favorite football club are examples of changes resulting from this interactive process.

2.2 3D Scanning, Modelling and Printing

Three-dimensional scanning, modeling and printing were considered ideal for the development of a customized prosthesis that could fit properly to his limb, allow good functionality of holding and moving objects with the hand, and be aesthetically pleasant. It was decided to start the process from the existing model available open source UnLimbited Arm v2.1 - Alfie Edition available at Thingiverse website (https://www.thingiverse.com/thing:1672381/#files), where the Customizer app was used to modify the prosthesis dimensions. This open source prosthesis was chosen after reviewing several similar options.

In order to acquire a 3D representation of the user's left upper limb, a plaster mold was used to obtain an exact model of the arm, which was then three-dimensionally scanned using the 3D GOM ATOS I 2M optical scanner and the ATOS Professional V 7.5 SR1 software Ad available at the Advanced Product Development Center (CADEP-

UNESP). The output of the 3D scanning process is a file with the 3D model that can be edited in 3D modelling software (see Fig. 3).

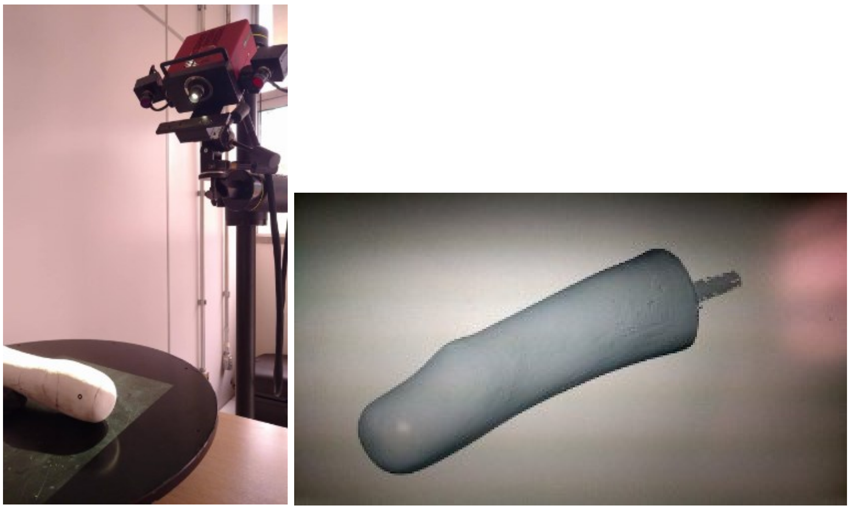

Fig. 3. Three-dimensional optical scanning and the virtual plaster cast.

The 3D modeling phase started after completing the briefing and the measurements. The first step was to create a digital 3D model. In addition to measures taken from the plaster mold, it was necessary to take measurements of the biceps circumference of the amputated arm, the length of the right (unaffected) forearm and hand. These data were used in the Customizer app, available at the Thingiverse using the UnLimbited Arm v2.1 model, which then applies the measures to create a 3D model that can be downloaded.

The 3D modelling process was carried out using the Rhinoceros modelling software along with some changes in the geometry of the palm through the Magics software. The other files used Rhinoceros for the customizations, and Magics, at the end of the modeling process, to check for flaws and resizing adjustment needs. Changes in the position of the logos and openings for the velcro tapes were made in the modelling process. Another this customization the user's name was printed on the cuff. A font similar to that of the original Captain America brand was used. After a series of reviews by the user, the final design of the prosthesis pieces was obtained (see Fig. 4).

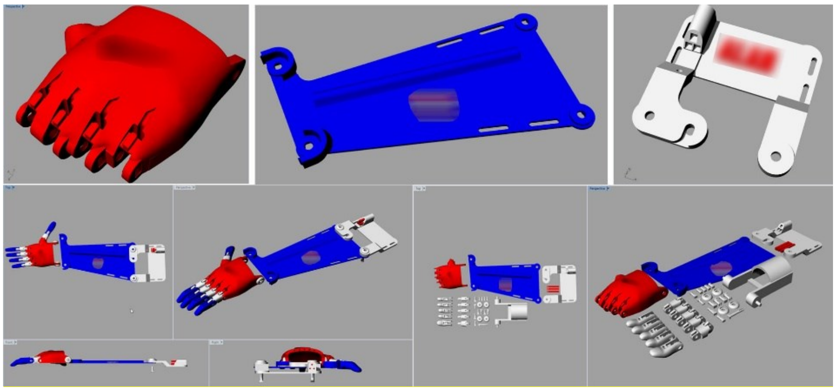

Fig. 4. 3D models ready for 3D printing.

The pieces were produced with fused filament fabrication (FFF) technology using the Mousta Mega 2 printer (Mousta, Brazil) at CADEP-UNESP with Polylatic Acid (PLA) thermoplastic material.

A first version of the prosthesis was prototyped to test the dimensions and usability. Other materials were used the assembly of the prosthesis, namely medium ¼” and medium 5/16” dental elastics for the finger movements; 0,6 mm diameter nylon string for the prosthesis tension; hot glue to fix the sting strongly, 6 mm screws and Velcro tape, and stickers for the user to indicate the size and location of the printed logos. The forearm and cuff were formed in hot water, using the printed support and the plaster cast to get the correct arm curvature.

2.3 Evaluation by the user

For the evaluation of the user-prosthetic interface, handling tasks were carried out with common objects that varied in size, shape, weight and material. Members of the SORRI rehabilitation team were presented during this evaluation, and the results reported here are based on observations.

3 Results

The first version of the prosthesis (without painting) printed with the measurements adjusted to properly fit the patient’s left limb is presented in Fig. 5.

Fig. 5. First prosthesis prototype.

To have a first evaluation of the potential of successful use as well as the need for adjustments in the design, we asked the user to manipulate a series of objects of different shapes, sizes, weight and material with the prosthetic limb (see Fig. 6). Surprisingly, the user showed good performance with the prosthesis, although having some with smaller objects. In order to improve gripping effectiveness, a transparent rubber cover was added to the distal phalanges of the thumb and second finger. As a result, the user was able to grab a full 500 ml plastic water bottle.

This preliminary test with the patient allowed the identification of minor changes needed to improve comfort and usability. Most of these changed related to the position of the Velcro stripes and the height of the arm. The post-processing involving manually painting the details approved by the user. The base parts could only be 3D printed without any finishing process. Finally, the user had to approve the prototype, including proper addressing of the usability issues revealed by the tests the final aesthetic of the prosthesis.

Fig. 6. Usability tests.

4 Conclusion

This paper documents the interdisciplinary collaborative development of a customized upper limb prosthesis involving both design, rehabilitation and 3D engineering. The participation of the user in the phases of design and testing benefited the process. By incorporating the user's input and decisions lead to a design that meet his needs and preferences better than the standard issue device. Furthermore, the 3D technologies were valuable tools for the design of this customized product, particularly when there are specific features to consider related to the shape of the interface, as is for an amputated limb. The preliminary results demonstrate that, although one may consider collaborative projects with users and members of different domains too complex and challenging in terms of time and decision-making process, the chances of obtaining a better result is higher. Yet, there is potential for more systematic collaborative design process approaches for of assistive technologies involving users and professionals from different area.

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