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Preliminary Clinical Evaluation of the X-Limb Hand: A 3D Printed Soft Robotic Hand Prosthesis

Alireza Mohammadi, Jim Lavranos, Ying Tan, Peter Choong, and Denny Oetomo

Abstract This paper presents the initial clinical assessment of the X-Limb hand, a 3D printed myoelectric hand prosthesis with fully soft/compliant structure. The design also takes into account the practical requirements including light-weight, multi-grasping capability, ease of manufacture and intrinsic actuation. The X-Limb hand is tested with one person with unilateral congenital below-the-elbow deficiency who never used any type of hand prosthesis. He performed two prosthetic functionality benchmark measures: Jebsen-Taylor Hand Function Test (JHFT) and Box and Block (BB) test. The results of the X-Limb hand are compared with the DEKA arm (the most advanced upper-limb prosthesis) and SoftHand Pro (a clinically assessed flexible myoelectric hand) using the z-score method as there was only one subject in our study. The results showed comparative performance of the subject using the X-Limb hand to the performance of the DEKA Arm and SoftHand Pro in other two studies. The promising performance of the first time prosthetic hand user demonstrates the capability of the X-Limb hand in performing wide range of tasks and shows its potential to significantly reduce the difficulty in learning to operate a myoelectric hand prosthesis.

Keywords Prosthetic hand · Soft robotics · Myoelectric hand prosthesis · 3D printing

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1 Introduction

Soft robotics is an emerging field which has shown great potential in addressing issues with current hand prostheses, i.e., non-compliant structure, heavy weight and complex system. The inherent material compliance in the soft robotic systems provides safer, cheaper, and simpler mechanisms (and consequently simpler control structures) compared to the traditional rigid robotic systems [1].

Current soft hand prostheses such as Hannes Hand [2], SoftHand Pro [3] and RBO Hand 2 [4] are not satisfying the practicality requirements including the weight (less than human biological hand), ease of manufacturing and personalisation. In [5], we addressed the practical requirements in the X-Limb hand with the consideration of the trade-off between practicality and performance and demonstrated its capability in performing grasping tasks required for activities of daily living (ADLs). The X-limb had a weight of 253 g, three grasps types (with capability of individual finger movement), power-grip force of 21.5 N and hand closing speed of 1.3 s.

X-Limb represents a simplified solution to the prosthetic hand design not only in the physical design but also in the interface to its functionality. More specifically, the design focuses only on two main grasps (pinch and power), produced with the synergy of fingers. This allows a very basic simple operation of the hand while retaining the ability to perform the required tasks of the benchmark tests in this paper.

Although the functionality of the X-Limb has been tested on different grasping tasks, it has not been tested on any individual with upper-limb amputation yet. Therefore, the objective of this study is to evaluate the performance of one subject with unilateral transradial limb difference who is fitted with the X-Limb hand and compare the performance results with two state-of-the-art myoelectric hand prostheses.

2 Method

The experiments were conducted with one subject (male, 22-years-old) with congenital transradial (below-the-elbow) limb deficiency in the left side (non-dominant side) who never used any types of hand prosthesis. The subject read the plain language statement and signed the consent form approved by the Ethics Committee of the University of Melbourne (Ethics ID 1852363.1).

A custom prosthetic socket build for the participant using 3D scanning of his residual and 3D printing with the same flexible material of the X-Limb hand and then secured on the residual limb by an adjustable elbow strap. A single EMG electrode is used for flexion and extension of the X-Limb. In order to reduce the complexity of the experiment for the naive subject, a single tactile button on the X-Limb arm is used to switch between grasp types. Other forms of switching can be used. The experimental results in [6] demonstrated that first time subjects were more effective in performing the task of selecting the right grasp using the buttons than through the attempt of producing the right EMG signals (as seen in some commercial devices).

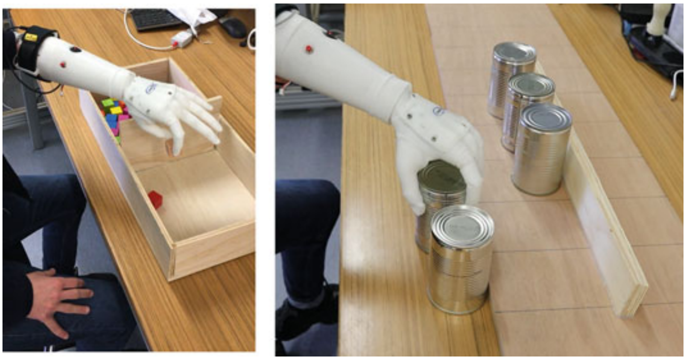

Fig. 1 Participant performing prosthetic hand assessment tasks: Box and Block test (left) and carrying heavy cans as one of the tasks of the Jebsen-Taylor Hand Function Test (right)

Two grasp types are used in the experiments: pinch and power. In power grasp, the thumb will move from the natural open hand position towards the center of the palm in coordination with other fingers. When the thumb is in adduction position, the actuation of the index finger will produce the pinch grasp [5]. The participant received one hour of training to use EMG signals for opening and closing of the X-Limb hand in two grasp types.

As shown in Fig. 1, two prosthetic functionality benchmark tests are used: (1) The Box and Blocks (BB) test (number of 1-in. blocks moved from one side of a box to another in 60 s) to measure the gross manual dexterity and speed. The results are compared with SoftHand Pro [3]; (2) Jebsen-Taylor Hand Function Test (JHFT) which is a measure of dexterity and simulated ADLs. The modified version used in this study which caps maximum time for each task at 120 s and scores the number of items completed per second. The results are compared with DEKA Arm [7].

In order to compare the performance of one subject with results of the group of participants in the other studies, we exploit the z-score test [8]. The z-score measures how many standard deviations above or below the mean a data point is and defined as z-score = $(x - \mu)/\sigma$ where x is the single data point (the score of one subject in our study), μ and σ are the mean and standard deviation of the group (the performance of the group of the participants in using SoftHand Pro and DEKA Arm as reported in [3, 7]). Then, in order to know how well the subject performed compared to the participants in the other groups, we use the z-table (standard normal distribution table). The table determines the percentage of the groups participants who obtained higher and lower scores then single subject.

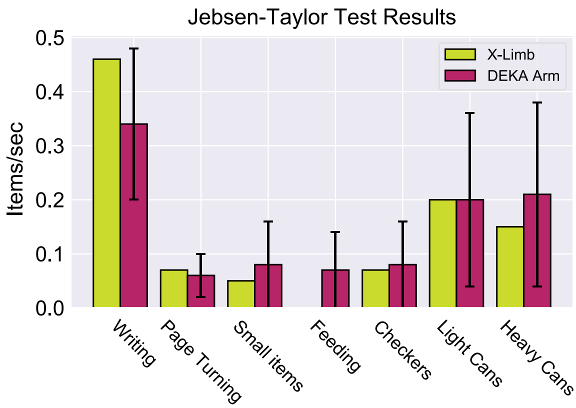

Fig. 2 Jebsen-Taylor hand function test results and comparison with the results of DEKA arm. Higher values show better performance (performing task quicker)

3 Results and Discussion

The average of three trials of the subject using X-Limb in performing BB test is 8 blocks in one minute. The reported results of 9 participants in [3] using the SoftHand Pro after 6–8 h of training showed the mean and standard deviation of $\mu = 9.5$ and $\sigma = 4$, respectively. Therefore, the z-score = −0.38 shows that the X-Limb hand user performed better than 34% of the SoftHand Pro users.

The results of the subject in performing JHFT tasks and the reported results of 23 participants in [7] using DEKA Arm at the end of the initial training sessions are shown in Fig. 2. The subject performed the tasks once and then we recorded the scores. The z-scores of X-Limb hand user for the 7 tasks of the JHFT (writing, page turning, small items, feeding, checkers, light cans, heavy cans) in comparison to DEKA Arm users are (0.85, 0.25, −0.37, −1, −0.12, 0, −0.35) which shows that the performance of the X-Limb hand user in better than (80%, 60%, 35%, 15%, 45%, 50%, 36%) of the DEKA Arm users, respectively. Excluding the feeding task, the performance of the X-Limb hand user was comparable to the DEKA Arm users. In the feeding task, due to small size of the teaspoon, the X-Limb was not able to grasp it.

4 Conclusions

The results of this study demonstrated the capability of a first time myoelectric hand user in using the X-Limb hand and showed comparable results to the state-of-the-art myoelectric hand prostheses. The future work will focus on testing the X-Limb hand with more subjects including children (using the paediatric version of the X-Limb [9]) and providing bone conduction vibrotactile feedback [10].

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