COMPARISON OF FUNCTIONALITY AND COMPENSATION WITH AND WITHOUT POWERED PARTIAL HAND MULTI-ARTICULATING PROSTHESES

Andrea B Wanamaker[1], MS, Lynsay R Whelan[2], MS, OTR/L, Jeremy Farley[2], CPO/L,

and Ajit MW Chaudhari[1], PhD, FACSM

[1]The Ohio State University, [2]Touch Bionics by Össur, Columbus, OH, USA

ABSTRACT

This study aimed to evaluate differences between Southampton Hand Assessment Procedure (SHAP) outcome measure scores and kinematic movements during functional tasks for individuals with partial hand limb loss with and without a myoelectric prosthesis. The results presented here indicate that an externally powered hand prosthesis restores function to individuals with partial-hand limb loss, as demonstrated by improved SHAP scores and changes in upper limb kinematics. The kinematic analysis of three functional tasks resulted in the prosthesis condition having decreased upper limb joint range of motion (ROM) compared to the non-prosthesis condition.

INTRODUCTION

The function of the human hand is essential for communication, independence in self-care, and maintenance of a good quality of life. According to the American Medical Association guidelines, amputation of the 4 fingers and the thumb, leaving the palm intact, can result in an impairment rating of 54% of the whole person, while amputation of the entire leg at the level of the hip results in an impairment rating of only 40% [1]. Of the 20,000 new cases of upper limb loss each year, 90% occur at or distal to the level of the wrist [2]. In those individuals with upper limb loss, 50% report overuse problems in their unaffected limbs [3]. Risk factors associated with overuse injury include repetitive motions, awkward joint posture, prolonged unnatural posture, and high gripping force [4]. Use of an upper limb prosthesis may reduce the compensatory mechanisms, particularly awkward and prolonged joint postures, which individuals with upper limb loss use in their activities of daily living.

The Southampton Hand Assessment Procedure (SHAP) is a standardized assessment that measures hand function utilizing both abstract objects and activities of daily living [5]; and has been used in several studies of prosthesis performance. The SHAP results in six general assessment scores out of 100 for the six specific grip styles (spherical, tripod, power, lateral, tip, and extension) and one overall function score (Index).

The objective of this research was to examine differences in SHAP scores and compensatory motions at the wrist, elbow, and shoulder used by individuals with partial hand amputations in completing food preparation tasks both with and without their prosthesis. We hypothesized that there would be significant differences in kinematics between conditions, with the prosthesis condition resulting in reduced joint motion, and joint motion more similar to healthy controls than without the prosthesis. For the SHAP analysis, we hypothesized that the individuals with partial hand amputation would score higher, indicating better function, during the prosthesis condition compared to non-prosthesis.

METHODS

Subjects

Participants were recruited from the Touch Bionics' facility during a week-long training program they attended with their treating prosthetist from facilities across the United States. With the permission of the treating prosthetist, the client was given information on the study and completed testing after providing IRB approved informed consent. Potential participants in the limb loss group had to have an acquired partial-hand amputation (4-digit loss with intact thumb or 5-digit loss), be over 18 years of age, have a minimum of 10 hours of occupational therapy, have good skin integrity, strength, and control of the residual limb (minimum 40º wrist range of flexion/extension, minimum 60º forearm range of supination/pronation, and minimum lateral thumb pinch strength of 10 pounds, if applicable).

Healthy two-handed participants were recruited from the local community. Healthy controls had to be over the age of 18 years and were disqualified if they had previously had surgery on their upper extremities or experienced a severe upper extremity injury, such as a torn muscle, ligament or tendon, or a displaced fracture.

Data Collection

Data collection involved 3D motion capture (Vicon) while participants performed various tasks of daily living focusing on upper limb movement as well as the SHAP which requires the participants to complete the tasks as quickly and accurately as possible while self-timing [5]. The prosthesis users performed the testing protocol twice: once with their prosthesis and once without. The two-handed participants also performed the protocol twice: once with their dominant hand and once with their non-dominant. Condition order was randomized with a fifteen-minute break between conditions to minimize possible learning and fatigue effects. Two trials were collected for each task within each condition, with the best used for analysis

Data presented here reflect the SHAP outcomes and kinematics from the following three food preparation tasks: slicing a tomato, peeling a cucumber, and cutting a piece of meat. To complete the tomato task, participants used a paring knife with a cutting board to slice a tomato four times. The tomato was sliced in half with the flat side on the cutting board to minimize stability issues. To complete the cucumber task, participants use an ergonomically designed vegetable peeler and were instructed to make approximately 4-7 smooth peeling strokes on the cucumber. To compete the meat cutting tasks, participants were given a dinner plate with a ¼ inch piece of cooked breakfast ham. Using a butter knife and dinner fork, they were instructed to cut four bite size pieces. During the prosthesis condition, the users were instructed to use the knives and peeler with their prosthesis and use their contralateral hand solely for support (e.g., situating knife in prosthesis, holding cucumber). For the non-prosthesis condition, the 4-digit users were instructed to try to use the tools with their residual palm and thumb, while the 5-digit users performed the tasks using their contralateral side with the residual limb for support. Healthy controls used the tools in both hands dependent upon condition.

Data Analysis

Upper limb kinematics were calculated using custom Visual3D code. Marker data were filtered using a fourth order low-pass Butterworth filter at 6 Hz. Peak and ROM joint angles for the shoulder, elbow, and wrist were found for each participant for each condition. SHAP function scores were calculated from the timing results, where a score less than the normal 95-100 indicates a functional deficit [6]. Kinematic analysis was limited to when the participant and tools were in contact with the food. Only the movement strokes used to slice the tomato, peel the cucumber, and cut the meat were examined. Statistical comparison between conditions was completed using a mixed-effect model with a between-subjects (individuals with limb loss vs. two-handed healthy) and a within-subject (prosthesis vs no prosthesis; dominant vs non-dominant) design with a significance level of 0.05.

RESULTS

Twelve male individuals participated in the study with the following demographic data (Table 1):

Table 1: Demographic data
* indicates significant difference between groups ($p<0.05$)

	Individuals with Limb Loss		**Two-handed Controls**
Number of participants	4 digit n=3	5 digit n=3	n=6
Age	27.7±8.1 yrs	43.7±18.6 yrs *	25.5±3.9 yrs *
Height	177.8±9.2 cm	173.5±6.4 cm	182.9±5.8 cm
Weight	76.2±.4 kg	97.2±25.3 kg	83.0±13.3kg
Dominant-Side Amputation	3	1	No amputation, all RHD

SHAP Results

As a group, the prosthetic users demonstrated no significant differences in the SHAP scores. The 4-digit subgroup also demonstrated no significant differences (Table 2). The 5-digit subgroup had significantly different scores in four of the six categories, as well as the overall Index score, and trended towards differences in the last two ($p<0.10$) (Table 2). The healthy cohort demonstrated significantly different scores between dominant and non-dominant conditions, and compared to those with amputations, the two-handed participants scored significantly higher on all scores, regardless of condition for either group.

Table 2: SHAP scores for 4-digit and 5-digit groups
Results presented as group mean (SD)
* indicates $p<0.05$ between conditions

	4-Digit (n=3)		***5-Digit (n=3)***	
Category	**Prosthesis**	**Non-Prosthesis**	**Prosthesis**	**Non-Prosthesis**
Spherical	87.0 (5.3)	91.7 (1.5)	**77.7 (2.3) ***	**37.0 (2.6) ***
Tripod	80.7 (9.3)	82.3 (8.5)	53.3 (18.0)	14.7 (10.7)
Power	90.7 (8.7)	87.7 (6.5)	**67.7 (12.7) ***	**14.7 (4.0) ***
Lateral	91.0 (7.8)	93.3 (2.1)	**70.7 (18.1) ***	**11.7 (0.6) ***
Tip	77.0 (10.4)	60.7 (28.1)	46.0 (26.5)	10.0 (6.1)
Extension	94.0 (4.4)	96.7 (0.6)	**77.0 (10.4) ***	**31.7 (19.4) ***
Index	90.7 (5.9)	89.7 (5.7)	**71.7 (13.7) ***	**25.3 (5.9) ***

Kinematic Results

Analysis of shoulder, elbow, and wrist range of motion (ROM) resulted in various significant differences within subjects (prosthesis vs non-prosthesis; dominant vs non-dominant) and between subjects (limb loss vs healthy) for all three food preparation tasks (Table 3). One 4-digit participant was unable to complete the tomato slicing and meat cutting tasks using his residual limb and instead had to use the intact contralateral side. Thus, there were four prosthetic users who were compared to their intact hand for the tomato slicing and meat cutting.

Table 3: Kinematic results for tomato slicing, cucumber peeling, and meat cutting. Presented as group mean (SD). Units are in degrees. The following key is used to indicate significant findings ($p<0.05$): [a] between prosthesis conditions, [h] between healthy conditions, * between dominant and prosthetic user conditions, and ^ between non-dominant and prosthetic user conditions.

Tomato Slicing		Prosthesis	Non-Prosthesis	Dominant	Non-Dominant
Shoulder ROM	Flexion/Extension	20.6 (8.8)	15.4 (4.7)	17.0 (3.5)	19.4 (4.9)
	Adduction/Abduction	13.7 (8.7)	15.7 (3.9)	11.2 (3.1)	12.3 (3.4)
	Int/Ext Rotation	22.0 (8.7) *^	27.2 (10.7) *^	12.7 (1.9) *	12.2 (2.5) ^
Elbow ROM	Flexion/Extension	24.9 (9.1)	41.3 (20.5) *^	20.8 (5.1) *	21.9 (4.5) ^
	Adduction/Abduction	9.8 (5.8) [a]	14.1 (6.8) [a]*^	7.7 (2.2) *	7.0 (2.1) ^
	Pronation/Supination	35.1 (27.1) *^	31.6 (5.0) *^	10.1 (1.9) *	9.5 (2.7) ^
Wrist ROM	Flexion/Extension	13.2 (7.2)	16.7 (4.4)	14.0 (3.7)	16.8 (3.3)
	Adduction/Abduction	6.0 (7.2)	8.0 (3.6)	4.5 (1.5) [h]	7.1 (2.4) [h]
	Hand Rotation	2.4 (0.9) [a]^	5.8 (1.2) [a]*	2.9 (1.1) [h]*	5.4 (1.3) [h] ^

Cucumber Peeling		Prosthesis	Non-Prosthesis	Dominant	Non-Dominant
Shoulder ROM	Flexion/Extension	13.7 (4.1) [a]	18.9 (2.7) [a]	16.7 (4.0)	17.5 (4.3)
	Adduction/Abduction	10.5 (4.3)	13.9 (2.7) *^	9.8 (2.7) *	10.1 (2.6) ^
	Int/Ext Rotation	23.8 (6.0)	31.7 (7.8) *^	19.2 (5.1) *	19.7 (8.1) ^
Elbow ROM	Flexion/Extension	27.2 (5.8) [a]	39.5 (7.7) [a]*^	26.7 (6.1) *	28.9 (3.0) ^
	Adduction/Abduction	15.5 (14.2)	22.2 (15.6) ^	8.4 (1.1)	7.0 (1.5) ^
	Pronation/Supination	33.0 (6.8)	49.6 (25.1) *	22.1 (11.1) *	22.5 (19.1)
Wrist ROM	Flexion/Extension	11.4 (5.9) ^	21.4 (11.3)	15.3 (5.6)	19.5 (6.0) ^
	Adduction/Abduction	5.5 (1.2) [a]^	11.3 (3.0) [a]	9.0 (4.1) [h]	9.3 (3.9) [h]^
	Hand Rotation	2.5 (1.3) [a]^	5.2 (3.1) [a]	2.6 (1.3) [h]	9.3 (5.2) [h]^

Meat Cutting		Prosthesis	Non-Prosthesis	Dominant	Non-Dominant
Shoulder ROM	Flexion/Extension	29.9 (21.9)	17.4 (3.9)	15.6 (4.0)	21.0 (5.1)
	Adduction/Abduction	17.1 (7.5)	14.3 (5.1)	14.5 (2.8)	14.6 (3.0)
	Int/Ext Rotation	33.8 (22.6)	29.5 (13.7) *	16.3 (2.4) [h]*	23.5 (7.0) [h]
Elbow ROM	Flexion/Extension	21.8 (10.7)	29.6 (10.7) *	16.8 (1.9) [h]*	21.2 (2.5) [h]
	Adduction/Abduction	7.4 (2.8) [a]	18.4 (13.1) [a]*^	6.2 (1.2) *	6.7 (1.2) ^
	Pronation/Supination	41.3 (18.9) *^	44.3 (13.7) *^	14.3 (4.5) *	17.6 (6.8) ^
Wrist ROM	Flexion/Extension	14.0 (10.5) [a]	26.7 (10.1) [a]*^	12.6 (2.8) [h]*	15.7 (2.8) [h]^
	Adduction/Abduction	8.2 (3.5) [a]	11.6 (2.2) [a]*	7.5 (2.6) [h]*	9.4 (3.4) [h]
	Hand Rotation	3.9 (3.1) ^	7.7 (2.9) *	3.1 (1.3) [h]*	8.4 (2.1) [h]^

DISCUSSION

The results presented here indicate that use of an externally powered hand prosthesis restores function for individuals with partial hand limb loss. The SHAP outcomes show that the prosthesis improves functional capabilities, particularly for the individuals with 5-digit loss. It should be noted that five of the six individuals with partial hand limb loss demonstrated improved scores with the prosthesis. Only one user with 4-digit loss scored higher without the prosthesis. This individual had exceptional thumb dexterity and his scores without the prosthesis actually fell within the normal range of the SHAP with an intact hand. While the individuals with amputations had improved function with the prosthesis, they still demonstrated significantly lower scores than the healthy cohort. The prosthesis users must consciously open, close, and position the fingers throughout the task, whereas the healthy controls do not have this delay in movement. Thus, while the scores are improved with the prosthesis, the inherent time delay may be why they were not comparable to the healthy cohort results.

The kinematic analysis of various food preparation tasks gives insight to movement strategies with and without the prosthesis. The prosthetic user group had decreased hand rotation, decreased elbow adduction/abduction, and, while not significantly different, had increased shoulder flexion/extension (p=0.16) while slicing a tomato. The prosthesis design included a laminated outer frame and silicone inner socket. The trim lines of the socket typically were at or slightly proximal to the wrist, which may have limited wrist motion to some extent. Decreased elbow motion indicates a stiffening of the joint, possibly to improve stability of the knife and wrist during the task. The same strategy of stiffening the elbow and wrist for stability is also seen in the cucumber task, with decreased elbow flexion/extension, wrist adduction/abduction (ulnar/radial deviation), and hand rotation. In the cucumber task, the shoulder also demonstrated reduced flexion/extension. This may be due to how the individual completed the task with their prosthesis, as they tended to use very short strokes to peel the cucumber. Finally, the meat cutting task also indicated reduced wrist and elbow motion compared to the non-prosthesis condition.

Comparison of healthy dominant to healthy non-dominant resulted in multiple differences, particularly with wrist motion for all three tasks. The motion with the dominant wrist appeared more stable and smoother, while the non-dominant side demonstrated a possible lack of control and instability during the cutting tasks, as the non-dominant wrist had increased motion. Comparing the individuals with amputations to the healthy group, there were a high number of differences for each task. The use of the prosthesis did result in motion more similar to healthy dominant than the non-prosthesis condition. The prosthesis condition had seven significant differences with the non-dominant condition across the three tasks. However, five of the seven variables were not statistically different from the dominant condition, indicating that the prosthesis performed more similar to dominant motion than the non-dominant motion. Finally, the non-prosthesis condition was significantly different from both dominant and non-dominant conditions across all three food preparation tasks and had the highest ROMs of all four conditions.

CONCLUSION

The results presented here indicate that an externally powered hand prosthesis restores function to individuals with partial-hand loss, as demonstrated by improved SHAP scores and changes in upper limb kinematics. The kinematic analysis of three functional food preparation tasks resulted in the prosthesis condition having lower joint ROMs compared to the non-prosthesis condition. Comparing to healthy dominant and non-dominant movement, the prosthesis condition was more similar to the dominant condition and the non-prosthesis condition had the highest joint ROMs of all four conditions.

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