PATTERN RECOGNITION CONTROL OF THE DEKA ARM IN TWO TRANSHUMERAL AMPUTEES WITH TARGETED MUSCLE REINNERVATION

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ABSTRACT

Background: Recent utilization of EMG pattern recognition (PR) as a control input for the DEKA Arm shows promise for decreasing cognitive burden by eliminating the foot controls. **Purpose:** To report outcomes and experiences of two subjects with transhumeral (TH) amputation who had undergone targeted muscle reinnervation and were fit with, and trained to use, a DEKA Arm, with 5 degrees of freedom (DOF) controlled by EMG PR. **Methods:** This study had 2 portions: in-laboratory training (Part A) and home use (Part B). Quantitative outcomes and qualitative data were collected at baseline, end of Part A and end of Part B. **Results:** Both subjects controlled a 5 DOF DEKA Arm using EMG PR and were generally satisfied with this control method. Quantitative outcomes were mixed. Subjects provided feedback on the DEKA Arm. **Conclusion:** PR control for the DEKA Arm was feasible in persons with transhumeral amputation who have undergone TMR surgery given adequate training.

INTRODUCTION

The DEKA Arm was designed to utilize unique "strap and go" controls including inertial measurement units (IMUs) worn on the feet and pneumatic pressure transducers. [1] To date, one or more IMUs were required to operate the DEKA Arm. Our prior study found that there was substantial cognitive load required for the complex task of pre-planning and sequentially controlling multiple joints/actuators using these controls. Recent commercial release of an EMG pattern recognition (PR) system, the Coapt System, and adaptation of that system for control of the DEKA Arm, holds promise for decreasing cognitive burden by eliminating the IMUs.

Substituting foot control with more intuitive PR control may lead to greater acceptance of, and better function with, the DEKA Arm. However, the benefits need to be examined empirically. This paper describes outcomes and experiences of 2 subjects with transhumeral (TH) amputation who had undergone targeted muscle reinnervation (TMR) who used a DEKA Arm with 5 degrees of freedom (DOF) controlled by EMG PR: hand open/close, wrist flexion/extension, pronation /supination, elbow flexion/extension, humeral internal/external rotation.

METHODS

Study Design

The study was approved by the Institutional Review Boards at participating sites. The study consisted of 2 portions: in-laboratory training (Part A) and home use (Part B). Subjects were tested with their personal prosthesis (if applicable) at baseline and with the DEKA Arm at the end Part A and at monthly intervals during Part B.

Subjects

Both subjects underwent TMR surgery approximately 5 years prior. Subject 1 had previously participated in the VA Study to Optimize the DEKA Arm and had been trained to use the DEKA Arm using IMU controls. At baseline, he was no longer using a prosthesis. Subject 2 was tested with his 3 DOF myoelectric prosthesis which he controlled using PR via standard Coapt controls.

Controls Set-up and Prosthetic Training

The Coapt system was configured to communicate directly with the DEKA Arm by way of bi-directional digital bus. Subjects were fit and trained to use the humeral configuration of the DEKA Arm using these controls. By the end of Part B, both controlled 5 DOFs (humeral rotation, elbow flexion/extension, pronation/supination, wrist flexion/extension and hand open/closed) with PR. Both controlled grip selection by using pressure transducer. During Part A Subject 1 had EMG PR control of humeral rotation however, it was controlled using the same pattern that he used for wrist flexion/extension pattern by switching from hand to arm mode using a pneumatic pressure transducer. His controls where updated requiring a unique muscular recruitment pattern for humeral rotation and eliminating the need for mode switching, when the new prototype became available at the beginning of Part B.

Subject 1, had 19 hours training with an early prototype of the Coapt controls, and 4 additional days of training with the new prototype. He then participated in approximately 12 weeks of home study. However, he decided not to wear the DEKA Arm after the 4th week of the home study (see results below for reasons why). Subject 2 had

approximately 34 hours of training with the new Coapt controls, and participated in 12 weeks of home study.

Data Collection

Both qualitative and quantitative data were collected. Qualitative data included recorded audio and video from in-laboratory and testing sessions, as well as data from open-ended surveys and transcripts from semi-guided interviews administered at the end of Parts A and B.

Self-report and performance based measures of function, and measures of quality of life (QOL), prosthesis satisfaction and community integration were collected at baseline (prior to training), at the end of Part A, and at the end of Part B. Self-report measures included a modified version of the Upper-Extremity Functional Scale (UEFS) [2, 3], Patient-Specific Functional Scale (PSFS) [4], the QuickDASH [5], Trinity Amputation and Prosthesis Experience Satisfaction Scale (TAPES) [6], QOL scale [7], and the Community Reintegration of Service Members Computer Adaptive Test (CRIS-CAT) [8]. Performance based measures included the modified Jebsen-Taylor Hand Function Test (JTHF) [3], the Activities Measure for Upper-Limb Amputees (AM-ULA) [9], and the University of New Brunswick Test of Prosthetic Function for Unilateral Amputees (UNB) [10]. Interpretation of measure scores is shown in Table 1.

Figure 1 Subjects wearing DEKA Arm

a. Subject 1 b: Subject 2

Data Analysis

We gathered key impressions about: PR control, DEKA Arm, and comparisons to the existing prosthesis (when applicable) to generate a detailed report of subjects' perspective. Highlights were selected to illustrate major findings. Descriptive analyses of outcomes were conducted.

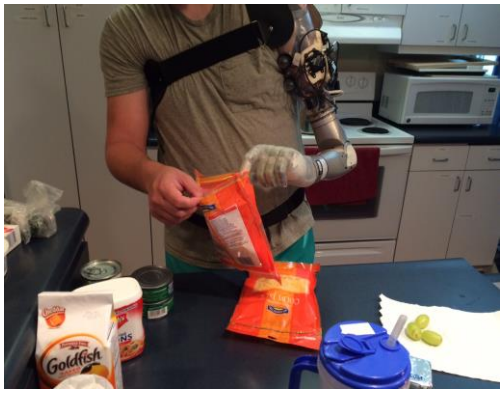

Figure 2: Subject 1 in training with check socket

Figure 3: Subject 2 using DEKA Arm

RESULTS

Subject 1

This subject was the first to utilize an updated version of the Coapt system to control the DEKA Arm. During the first few weeks at home, he experienced several technical problems related to the new Coapt controls configuration which required him to return the device for repair and also travel to the site to adjust the configuration and perform additional training with a new set-up which, as described above, required him to use a unique muscular pattern to control humeral rotation. The subject never fully acclimated to this change, and stated that this change, "made me not want to use the thing at all." The subject stated that the number of movements he needed to control was "extensive" and adding one additional movement "changed everything." That said, at the end of the study the subject indicated that he was "very happy" with the Coapt controls, but felt that he would have benefited from additional training.

He also compared PR control of the DEKA Arm to IMU control (which he had used previously) very favourably saying that it was, "so much more intuitive", and that "*it beat out the IMUs a billion to one"*. This subject reported that he disliked the weight of the DEKA Arm, which he called "excessively heavy."

This subject disliked the external battery which made donning and doffing more cumbersome and made wearing it "*so constricting*." He also complained about the bulk of the device and the excessive external wiring, which he reported made the device look "*horrible*." He also reported that if he was actively using the device and he was sweating he might have to doff and re-don it because he would lose function due to poor electrode contact. Finally, he felt that the battery life was insufficient and with the EMG PR system use , the battery was drained within a couple of hours.

Subject 1 rated his satisfaction with the DEKA Arm as 3.1, neither satisfied or dissatisfied), on a scale of 1-5 at the end of Part A (when he was using a wrist flexion/extension pattern to control humeral rotation) and as 1.9 (dissatisfied) at the end of Part B (when using a humeral rotation pattern to control humeral rotation). Self-reported difficulty performing activities, as measured by the PSFS was decreased at the end of Part B as compared to Baseline. Perceived difficulty with functioning (UEFS) was improved at the end of Part B, however perceived disability (QuickDASH) was unchanged from baseline. Community integration was improved at the end of Part B as compared to baseline and end of Part A. QOL was similar across time. (Table 1). Dexterity, as measured by the modified Jebsen Taylor Test, improved on 4 subtests at the end of Part B as compared to end of Part A. Activity performance, as graded by the AM-ULA, was improved. (Table 2).

Subject 2

Subject 2 rated satisfaction with the DEKA Arm similarly to the way he rated his own prosthesis at baseline (satisfied). His comments indicated that he found that the DEKA Arm was heavy and wished that the internal battery life was longer. Although he was an experienced PR user, he stated that there was "a steep learning curve" required to control the additional degrees of freedom of the DEKA Arm (humeral rotation and wrist flexion/extension). However, at the end of the study he felt that he had acclimated "*completely*" to the controls, and he rated his skill level as "good", although he commented that he found that the device was more "*mentally taxing*" than his own device. He participated in the study during hot summer months and reported that sweating impacted the precision of his controls, "*..small movements become real erratic and large, so I found like the Arm was moving unintentionally….. so I would constantly have to correct."* He reported that he experienced the same heat-related control issues with his personal prosthesis, and that he typically did not wear his myoelectric in summer months because it was too hot and he was very active. Subject 2 stated that it was easier to perform daily activities with the DEKA Arm given its wrist flexion and humeral rotation, which he said made the prosthesis "look and feel more natural." These additional degrees of freedom, he felt, allowed him to reduce compensatory movements, "*you don't have to turn your whole body.... you don't have to angle yourself because you have wrist flexion."*

Self-reported difficulty performing activities, as measured by the PSFS, the UEFS, and the QuickDASH, was improved at the end of Part B as compared to baseline. QOL and community integration was similar across time (Table 1). Dexterity, as measured by the JTHF, improved in 2 subtests at the end of Part B as compared to baseline, but was worse in 5 subtests. Activity performance (AM-ULA) decreased from baseline to end of B, but prosthetic skill and spontaneity (UNB) improved slightly (Table 2).

DISCUSSION

This case series describes the experiences and outcomes of two transhumeral amputees who had undergone TMR surgery 5 years prior. Both learned to control a 5 DOF prosthesis (the DEKA Arm) using EMG PR and were generally satisfied with this control method. Subject 1, who had used the DEKA Arm with IMU foot controls clearly preferred EMG PR to the foot controls.

We do not know how user perspectives on the EMG PR controls would have changed with additional training or home use time. Subject 1 was initially trained with an earlier prototype of EMG PR. Although he received additional training, when his control system was updated, he never fully acclimated to this change, and did not use the DEKA Arm regularly at home. Although Subject 2 felt that he had fully acclimated to the DEKA EMG PR controls, he reported that using them was more mentally taxing than using PR for his own, less complex device.

Given that Subject 1 was not a prosthesis user we were unable to compare performance outcomes of the DEKA Arm to his own prosthesis. While we did observe an improvement in his CRIS-CAT scores at the end of Part B, we attribute this to an improved living situation associated with a move. For Subject 2 there were clear improvements in perceived disability using the DEKA Arm. Subject 2's comment that controlling the DEKA arm was more "mentally taxing" than his own prosthesis may be due to the fact that there are more DOF requiring control in the DEKA arm as compared to his existing prosthesis (5 and 3 respectively).

Table 1: Interpretation of Measures

Self-report measures	**Interpretation**
Patient-Specific Functional Scale (PSFS)	Higher scores indicates less difficulty
Modified Upper-Extremity Functional Scale (UEFS)	Lower scores indicates less difficulty
Upper-Extremity Functional Scale (Use)	Higher scores indicates more activities done with prosthesis
Disabilities of the Arm, Shoulder and Hand Score (QuickDASH)	Higher scores indicate greater disability
Community Reintegration Computer Adaptive test (CRIS-CAT)	Higher scores indicates better community integration
Quality of Life (QOL)	Lower scores indicate worse QOL
Trinity Amputation and Prosthesis Experience Scales (TAPES)	Higher scores indicate greater satisfaction
Performance Measures	
Jebsen-Taylor Hand Function Test (JTHF)	Higher scores indicate better performance
University of New Brunswick Test of Prosthetic Function (UNB)	Higher scores indicate better performance
Activities Measure for Upper-Limb Amputees (AM-ULA)	Higher scores indicate better performance

Both subjects expressed concerns about the weight of the DEKA Arm, short internal battery life, and dissatisfaction with other features such as external cables which clearly tempered their enthusiasm for the DEKA Arm.

Table 2. Outcomes Across Time

	Subject 1			***Subject 2***		
	Baseline	End of A	End of B	Baseline	End of A	End of B
Self-report measures						
PSFS	9.0	6.8	6.6	3.0	7.5	7.0
UEFS	45.4	48.2	33.1	39.1	40.7	32.0
UEF use	0.0	1.0	0.0	0.4	0.4	0.4
QuickDASH	29.5	25.0	29.5	27.3	31.8	20.5
CRIS-CAT						
Extent	33.0	33.0	40.0	58.0	58.0	55.0
Perceived Limitations	39.0	42.0	46.0	55.0	57.0	55.0
Satisfaction	36.0	41.0	49.0	55.0	55.0	55.0
QOL Scale	3.9	4.1	4.1	6.3	6.0	6.2
TAPES Satisfaction	-	3.1	1.9	4.4	3.9	4.4
Performance measures						
JTHF						
Writing	-	0.26	0.32	0.31	0.40	0.53
Page Turning	-	0.05	0.05	0.11	0.08	0.07
Small items	-	0.05	0.15	0.13	0.03	0.03
Feeding	-	0.06	0.09	0.07	0.11	0.09
Light Cans	-	0.09	0.16	0.23	0.07	0.11
Heavy Cans	-	0.18	0.13	0.25	0.09	0.14
UNB:						
Spontaneity	-	3.5	3.3	3.3	3.4	3.7
Skill	-	3.2	3.2	2.9	3.2	3.4
AM-ULA	-	16.7	19.4	22.7	22.7	18.8

CONCLUSION

This case series demonstrated that the adapted PR control system for the DEKA Arm which we developed for this study was feasible for use in persons with transhumeral amputation who have undergone TMR surgery. Findings also suggest that the DEKA Arm may be suitable for this patient population, given adequate training. However the device may be better accepted if it were lighter, had fewer external cables and wires and a longer internal battery life.

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