Functional Assessment of the Vanderbilt Multigrasp Myoelectric Hand: A Continuing Case Study

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Abstract— **This paper presents a case study involving the functional assessment of the Vanderbilt Multigrasp (VMG) hand prosthesis on a single transradial amputee subject. In particular, a transradial amputee subject performed the Southampton Hand Assessment Procedure (SHAP) using the hand prosthesis and multigrasp myoelectric controller in a series of experimental sessions occurring over a multi-week time span. The subject's index of function (IoF) improved with each session, although essentially plateaued after the fourth session, resulting in a IoF score of 87, which compares favorably to SHAP scores published in previous studies.**

I. Introduction

The human hand is extensively articulated, possessing approximately twenty major degrees-of-freedom that allow it to perform a multitude of grasps and postures. In contrast, the body-powered and myoelectric terminal devices traditionally used to replace the hand after amputation possess only one degree-of-freedom (DoF), and are therefore only capable of a single grasp (i.e., they may be opened and closed). While this reduction to a single DoF is a significant physical abstraction of the native hand, single grasp devices greatly simplify the control interface required for their use (in both the body-powered and myoelectric cases), and the consistency of a single grasp may facilitate manipulation in the absence of proprioception and haptic sensation. Nevertheless, surveys concerning single grasp devices indicate that increased articulation [1] and greater functionality [2] are among the top design priorities for the individuals who use them.

Enabled by recent technological advances, several multigrasp prosthetic hands have begun to emerge in both academic research and commercial trade (see, for example [3-8]). These prosthetic hands have increased articulation and fidelity of motion relative to single DOF terminal devices and, as such, are intended to provide greater functionality during the activities of daily living (ADLs). Despite this, very few functional assessments have been conducted to formally examine the capability of multigrasp hands, particularly as compared to single grasp devices. In [9] and [10] the performance of a single grasp Otto Bock DMC Plus is compared to a multigrasp Touch Bionics i-Limb representing, to the authors knowledge, the extent of such comparative investigations. As noted in [11], this type of information is critical to the prescription and continued development of upper extremity terminal devices. This is particularly true with regard to multigrasp hands, and the need to utilize validated, objective measures to generate a body of knowledge regarding functional outcomes has been made evident [11, 12].

In prior work, the authors described a multigrasp myoelectric controller (MMC) which enables the attainment of three hand postures and six hand grasps with a multigrasp hand using a standard, two-site surface EMG interface [6]. This paper describes a case study involving the functional assessment of the VMG hand and MMC interface as used by an amputee to perform tasks requiring manipulation and interaction with the physical environment. The aim of this work is to provide evidence that the prosthetic system has the potential to enhance the functional capability of upper extremity amputees in performing the activities of daily living and thereby motivate further study. The VMG prosthesis prototype and MMC controller are described briefly in Section II; the assessment methods and experimental trials are described briefly in Section III; and a brief discussion of the results is presented in Section IV.

II. VMG Prosthesis

The Vanderbilt Multigrasp (VMG) Hand is a 9 joint, 9 degree of freedom (DOF) myoelectric hand driven by 4 brushless DC motors. The actuation scheme of the VMG was designed to explicitly provide both precision and conformal grasp capability, where the configuration of the thumb and index finger are determined uniquely as commanded by the motor units, while the configuration of the remaining digits is determined by a combination of the motor unit command and the nature (i.e., shape) of the object being grasped through compliant coupling. The allocation of actuators and coupling between DOFs is illustrated in Fig. 1, while the achievable postures and grasps are shown in Fig. 2. A detailed description of the hand is provided in [5].

The VMG hand is controlled by a multigrasp myoelectric controller (MMC). The MMC, diagrammed in Fig. 3, is an event-driven, finite-state controller which interprets high-level commands issued by the user to coordinate the motion of a multigrasp prosthesis using a standard, two-site myoelectric interface (i.e., utilizes the same electrode sites as the other myoelectric devices assessed here). The magnitude of the contraction dictates either the speed of movement (if

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moving in space) or magnitude of force (if grasping an object). A detailed description of the MMC can be found in [6].

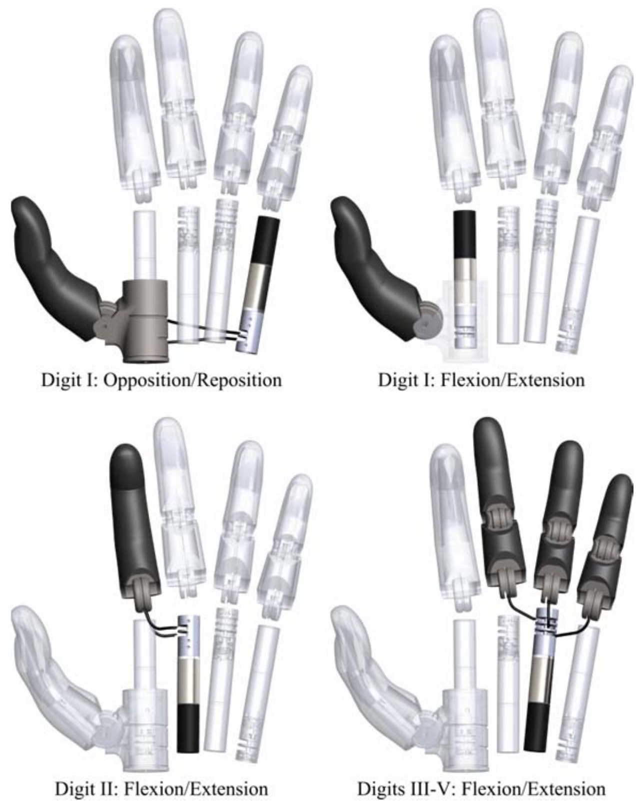

Fig. 1. Allocation of actuation in the VMG prosthesis.

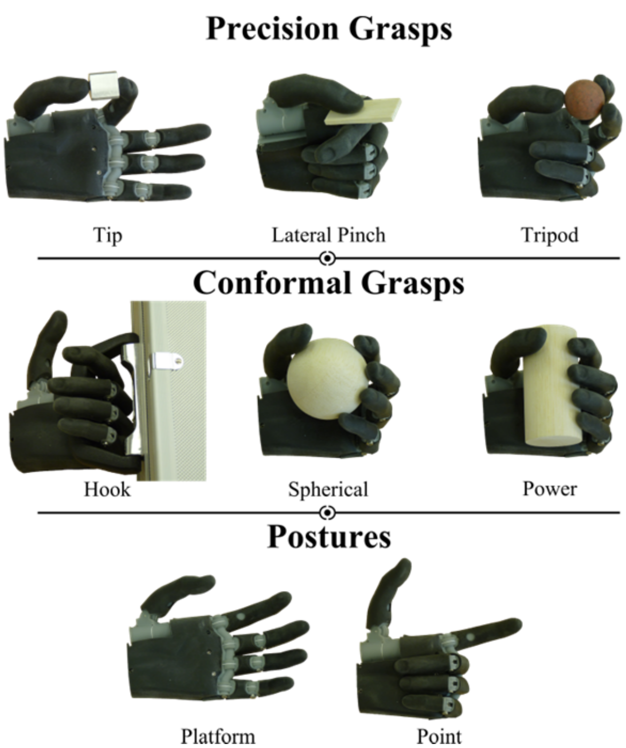

Fig. 2. Grasps and postures provided by the VMG prosthesis.

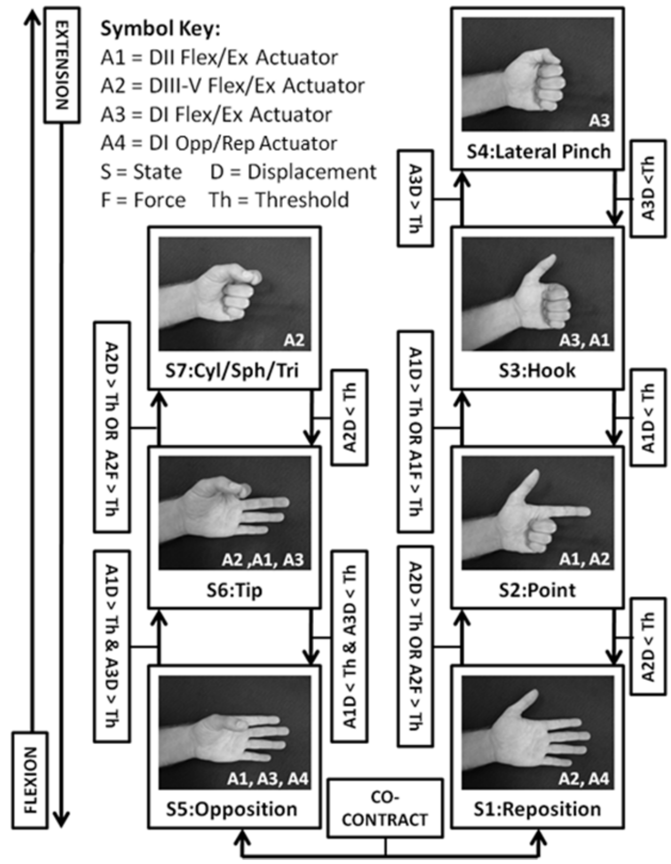

Fig. 3. Structure of the control architecture.

III. Methods

A. Hand Functionality Assessment

The Southampton Hand Assessment Procedure (SHAP) [13] was selected as an assessment instrument primarily because it provides an objective, quantitative measure of multiple grasps and postures. The SHAP is comprised of a series of self-timed tasks which require the manipulation of 12 abstract objects and the performance of 14 exercises representative of the activities of daily living (ADLs). The exercises specifically require use of the spherical, tripod, power, lateral, tip and extension grasps. The ADLs utilized in the SHAP consist of: picking up coins, undoing buttons, simulated food cutting, turning pages, removing a jar lid, pouring from a glass measuring cup, pouring from a carton, lifting a heavy jar, lifting a light can, lifting a tray, rotating a key, opening/closing a zipper, rotating a screw, and using a door handle. A set of composite performance scores are calculated from the individual recorded times for each task, resulting in an Index of Function (IoF), which provides an overall indication of function, and a Functionality Profile (FP), which provides scores specific to the six prehensile forms above. SHAP IoF scores indicative of typical healthy function range from 95-100, with lesser scores indicating some degree of impairment and greater scores indicating exceptional performance. For a detailed description of the SHAP assessment, including how scores are determined, the reader is referred to [13].

B. Participant Details

The participant in this study was a 33 year old male having bilateral transradial amputation as the result of traumatic injury sustained in 2008. The participant's right and left residual forearms are 15.2 cm and 17.8 cm in length as measured from the medial epicondyle. Prior to injury the participant was right hand dominant. In this study, functionality of the left hand was investigated. The participant is an active individual, and uses both body-powered and myoelectric prostheses in daily activities. The participant is shown wearing the VMG prosthesis in Fig. 4.

C. Assessment Protocol

The amputee participant was introduced to the MMC control methodology and performed the SHAP test with the VMG Hand. The prosthesis was attached to the participant's left forearm socket using a quick disconnect myoelectric adapter. For each experimental session, the subject was allowed to rehearse each task until the appropriate strategy could be reliably reproduced. The tasks were then repeated until the time required for each settled, and significant improvement ceased. After completing each testing session, the subject returned in 1-2 week intervals to repeat the SHAP assessment, until the respective IoF scores had essentially plateaued (i.e., until the subject had completed the learning curve, as defined by the subsequent increment in score of less than 2, which is below the increment considered significant in the SHAP [13]). For this subject, the IoF scores plateaued after four experimental sessions. The study was therefore concluded after the fourth trial, after which functional performance was considered to have converged. Figure 5 shows the composite IoF score from the SHAP assessment corresponding to each experimental session, showing the associated learning curve. Table I shows the composite IoF and the individual grasp scores associated with the fourth trial. Figure 6 provides a graphical representation of the individual grasp scores associated with the fourth trial.

Fig. 4. Transradial bilateral amputee wearing the Vanderbilt Multigrasp Myoelectric Hand (left arm). EMG electrodes are located under the prosthetic socket.

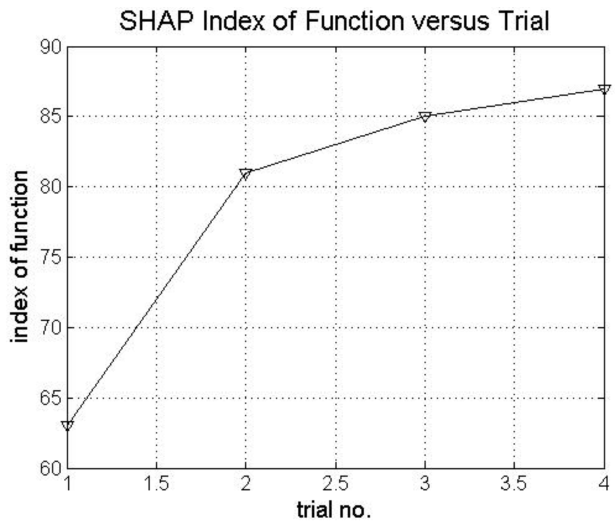

Fig. 5. SHAP Index of function vs. trial number, indicating improvement over the course of the study.

TABLE I
IOF AND FP SCORES ASSOCIATED WITH THE VMG PROSTHESIS

Index of Function (IoF)	**Functionality Profile (FP)**						**FP Mean**	**FP Std Dev**
	Pow.	Sph.	Ext.	Trip.	Lat.	Tip		
87	85	90	90	82	89	78	86	4.9

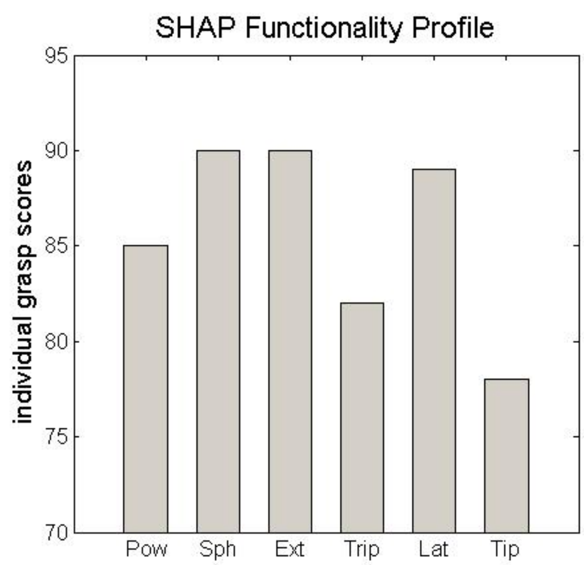

Fig. 6. SHAP scores for individual grasps during the fourth trial.

IV. RESULTS AND CONCLUSION

As indicated in Table I, using the VMG/MMC prosthesis and controller, the subject achieved an IoF of 87, with individual grasp scores varying between 78 and 90. As a reference, Kyberd et al. recently published a study, using the SHAP assessment instrument to characterize the functionality of eight amputee subjects using single-grasp myoelectric prostheses [14]. In that study, IoF scores ranged between 17 and 80, with an average IoF of all subjects of 50, with a standard deviation of 23. Although a comparison between different sets of subjects must be interpreted with caution, the multigrasp prosthesis and control method incorporated by the authors compare favorably to results reported for single-grasp prostheses.

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