FEASIBILITY OF THE GLIDE MYOELECTRIC CONTROL ALGORITHM TO PARTIAL HAND PROSTHESIS CONTROL

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ABSTRACT

While the number of individuals with partial hand limb loss is ten times greater than all other upper limb amputation categories combined, the state of available technology for this underserved patient population is relatively poor. Even though studies report preference towards myoelectric partial hand prostheses, patient adoption of myoelectric devices has been stunted by the limitations of the only control methodology commercially available, direct control. To address this challenge, we suggest the novel application of the *Glide* myoelectric control strategy to individuals with partial hand limb loss. In this work, we describe preliminary investigations with two individuals with partial hand limb loss, one with standard, intrinsic musculature of the residual hand and another who has undergone state-of-the-art surgical interventions.

INTRODUCTION

Approximately 600,000 people live with partial hand amputations in the United States, with an estimated 14,500 new cases occurring each year [1], [2]. The level of impact on the functionality of the limb after amputation depends on which finger or fingers are affected. For example, loss of both the index and middle fingers results in 40% and 36% impairments of the hand and upper extremity respectively, and 22% impairment of the whole body [3]. In fact, individuals with partial hand limb loss (PHLL) self-report a higher level of disability compared to individuals with other major unilateral upper limb loss (ULL) [4]. But while the number of individuals with PHLL is 10 times greater than all other upper limb amputation categories combined, the state of available technology for this underserved patient population is relatively poor [5]. Prosthetic solutions for partial hand amputations are considered only after reconstructive surgical procedures have failed [6]. If prostheses are an option, individuals with PHLL have three main options for prosthetic care: 1) passive prostheses; 2) body powered prostheses operated by flexing the proximal joints; and 3) myoelectric prostheses operated by electronic input from the patient's residual limb [7], [8], [9]. While some studies report preference towards myoelectric devices [10], prosthetic selection should be based on a patient's individual needs and include personal preference, prosthetic experience, and functional needs [11]. Advantages of myoelectric prostheses include increased comfort, natural control, greater range of motion, reduced compensatory movements, perceived sensory feedback, and more cosmetic acceptance [10], [12].

Despite the above potential advantages of myoelectric prostheses, the adoption of such devices is poor. The primary reason for this is related to the control methodology. Current myoelectric systems are typically limited to operating one degree-of-freedom (DOF) using 2 electrodes from intrinsic myoelectric signals. The only available control strategy for partial hand myoelectric prostheses is Direct Control (DC), wherein the activity of a single electromyography (EMG) electrode is correlated directly with the actuation of a single DOF. However, because DC requires isolated control signals, the close proximity of intrinsic hand muscle sites creates significant cross-talk from sensors and limits the number of sensors that can be used [13]. Although recent variations of DC have allowed users to directly map "discrete" electrode functionality to individual or coupled finger motions, these strategies still require signal isolation (some even suggesting surgical intervention). To get around this limitation, manufacturers have created other methods of switching between grasps using mobile apps, EMG triggers, or accelerometer-based switching features, techniques that have not been well received by individuals with PHLL.

In this work, we explore the feasibility of a directional control algorithm (i.e., *Glide*) as an alternative control strategy for myoelectric partial hand prostheses. Originally designed for individuals with above-wrist amputation, the *Glide* control strategy uses the vector summation of the amplitude of EMG signals from multiple electrodes to navigate a *Glide* cursor to angular positions within a circular map (i.e., the *Glide* domain) [14], [15], [16]. The *Glide* domain can be partitioned into user-adjustable slices, each correlated with a specific motion of the user's prosthesis. By modulating the relative amplitude across EMG channels, users drive the *Glide* cursor to a desired slice of the *Glide* domain, resulting in volitional prosthesis movement. In contrast to DC, the *Glide* algorithm allows patients to control multiple DOFs even when individual electrodes suffer from crosstalk and co-activation. Due to the custom partitioning of the *Glide* domain, the *Glide* algorithm can leverage synergistic co-activity to provide additional dimensions of control. Here we explore the suitability of the *Glide* control strategy to individuals with PHLL

METHODS

This study was conducted in accordance with a protocol approved by the Johns Hopkins University School of Medicine Institutional Review Board. Two individuals with PHLL were recruited by study team members to trial the use of a commercial equivalent *Glide* system, driven by the residual musculature of their partial hand.

Participant 1 (P1) is a woman in her mid-30s who underwent amputations of the middle, ring, and little digits of her left hand due to a workplace accident. Since her amputation, she has operated a set of passive positional prosthetic digits (GripLock Fingers®, Naked Prosthetics, Olympia, Washington) in her daily life; she had no experience with myoelectric devices.

Participant 2 (P2) is a man in his early-50s who underwent amputations of the middle, ring, and little digits of his right hand due to a workplace accident. During his amputation surgery, his clinical care team performed a double Starfish transfer [17] of his second and third dorsal interossei muscles in the hopes of providing him with independent digital control of myoelectric partial hand prostheses. While P2 was prescribed externally powered myoelectric digits (i-digits® quantum, Össur hf., Reykjavík, Iceland), he has not used them regularly in his daily life due to his inability to generate consistent EMG patterns.

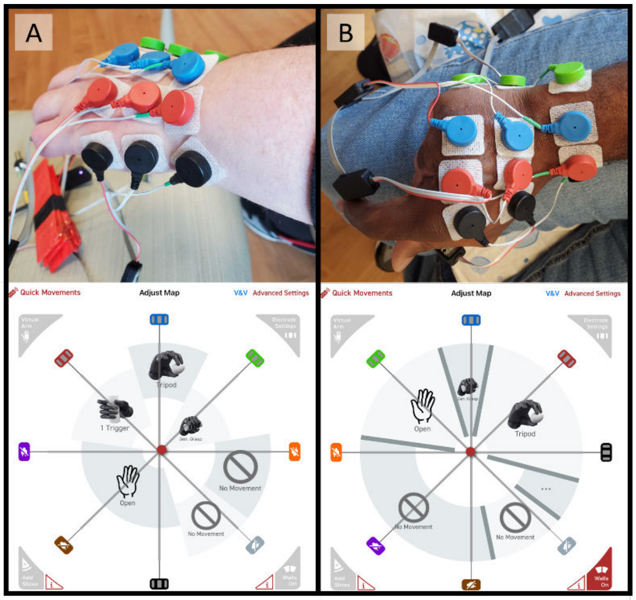

Figure 1. Pilot evaluations of the *Glide* control strategy with individuals with PHLL. (A) P1 had undergone amputations of her middle, ring, and little digits of her left hand and was naïve to myoelectric control strategies. After an hour, she was able to achieve four separate functions given the *Glide* map shown, left. (B) P2 had undergone amputations of his middle, ring, and little digits of his right hand as well as a double Starfish transplantation of his interossei. P2 had abandoned daily use of his myoelectric device due to an inability to generate consistent, distinct EMG patterns of activity. After a single evaluation session, P2 was able to elicit three separate functions given the *Glide* map shown below, right.

During the feasibility study, participants were fit with four pairs of bipolar, surface EMG electrodes (Infinite Biomedical Technologies, Baltimore, MD), targeted over the first, second, and third dorsal interossei muscles as well as the abductor digiti minimi of their partial hand (Figure 1). After electrode placement, participants were trained on the use of the *Glide* system and were prompted to attempt to activate each recorded myosite independently by flexing the targeted, underlying intrinsic muscle. To prompt activation, participants were shown a cue of which electrode to activate (Black, Red, Blue, or Green) in a random order with the cue being presented for 1 s before data collection began. During data collection, the root-mean-square (RMS) of each electrode channel was recorded for 5 s. Kernel density estimates of the observed RMS values for each electrode were then used to define an activation profile for each prompted flexion (Figure 2). These activation profiles were useful in determining how many individual movements participants should aim to begin with for a specific electrode configuration. Using the observed activation profiles, a *Glide* map was constructed for each participant. Over the course of the evaluation period, algorithm parameters (i.e., electrode gains, EMG smoothing, onset delay, etc.) were tuned to balance each participant's control stability and performance.

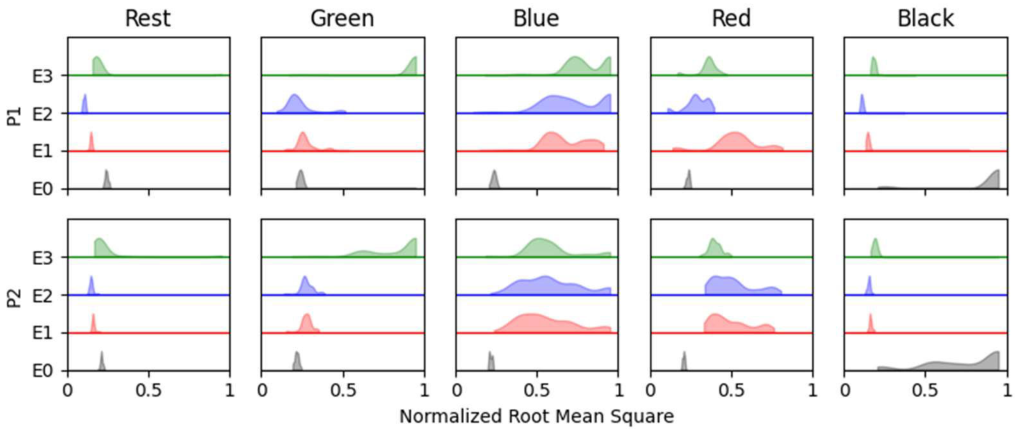

Figure 2. Activation profiles of each participant. Each electrode subplot represents the distribution of RMS values recorded while attempting to activate each electrode independently. (Top) P1 exhibits good separation for the Green and Black electrodes with severe to moderate co-activity present when attempting to isolate the Blue and Red electrodes. (Bottom) P2 exhibits similar intrinsic muscle activation profiles, albeit with greater co-activation between the Blue and Red electrodes.

RESULTS

Attempts at individual muscle flexions revealed that both P1 and P2 were prone to co-activation of neighbouring interossei (observed most prominently in the Blue and Red electrodes, Figure 2). In the case of P1, this is unsurprising as they were naïve to myoelectric control and therefore had difficulty isolating individual myosites. Similarly, prior to this evaluation with the *Glide* control algorithm, P2 was historically unable to elicit discriminable activity on more than two sets of electrodes (i.e., the abductor digiti minimi and all dorsal interossei), allowing only two available functions in an agonist-antagonist pairing. The activation profiles of P2 seem to support these limited independent control axes, with the Red and Blue electrodes exhibiting highly correlated activity.

Despite both participants being prone to interossei co-activity, after adjusting the gain of each individual electrode to fine-tune and bias their responses, both participants were able to consistently control multiple distinct movements via the *Glide* user interface. While both participants began with the simplest *Glide* map (an agonist-antagonist movement pairing), both were able to achieve a more complex, functional map by the end of evaluation (Figure 1). P1 was able to control four movements (one for each electrode): three synergistic hand grasps and one antagonistic movement mapped to Hand Open. P2 was able to control three movements: two synergistic hand grasps and one antagonistic movement mapped to Hand Open. Continued testing with these *Glide* maps over the course of 1 hr confirmed that each participant was able to reliably reproduce each assigned movement, even without the visual feedback of the user interface.

DISCUSSION

The results from this preliminary study highlight several strengths of the *Glide* control strategy when applied to individuals with PHLL. Primarily, results suggest that *Glide* allows individuals to independently control multiple DOF, despite existing co-activations inherent to the intrinsic muscle activity. In contrast, DC requires completely independent control sites free from co-activity [18], [19], [20], [21]. And while emerging surgical interventions, such as the Starfish procedure [17], may alleviate some limitations by increasing the separation between muscle sites, the size of the patient population who have received such interventions (≤ 20 [22]) is dwarfed by the total amount of patients living with a partial hand amputation. The *Glide* system does not require the independence of control sites (or surgical interventions) expected by DC.

Additionally, these results suggest that a progressive training regimen with the *Glide* system may help individuals with PHLL attain greater functionality as they become accustomed to their control capabilities. Both participants had initial difficulties eliciting independent myosite activations, despite one participant even having undergone the aforementioned Starfish procedure. Despite these challenges, we were able to begin with a simplified *Glide* map, focusing on just a pair of agonist-antagonist movements, increasing the complexity of their maps as they became more comfortable. This scalable nature of the *Glide* system contrasts with DC, wherein an additional electrode would need to be added for each desired additional DOF.

Of course, this work is not without its limitations. For one, as a preliminary investigation, the sample size is small; a subsequent study will require greater participant recruitment. Additionally, these investigations are motivated by the assumption that access to more DOFs will result in greater functionality for individuals with PHLL. And while this assumption has largely held true for individuals with other upper limb amputations, it has not been shown in this patient population (largely due to the lack of available myoelectric control strategy options). Follow-up studies should directly compare the effect the choice of myoelectric control strategy (i.e., DC or *Glide*) has on partial hand prosthesis functionality. However, as a preliminary investigation, this work demonstrates the feasibility of successfully applying the *Glide* control strategy to the partial hand myoelectric control problem.

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REFERENCES

[1] K. Ziegler-Graham, E. J. MacKenzie, P. L. Ephraim, T. G. Travison, and R. Brookmeyer, "Estimating the Prevalence of Limb Loss in the United States: 2005 to 2050," *Arch. Phys. Med. Rehabil.*, vol. 89, no. 3, pp. 422–429, Mar. 2008, doi: 10.1016/j.apmr.2007.11.005.

[2] T. R. Dillingham, L. E. Pezzin, and E. J. MacKenzie, "Limb amputation and limb deficiency: epidemiology and recent trends in the United States," *South. Med. J.*, vol. 95, no. 8, pp. 875–883, Aug. 2002.

[3] R. D. Rondinelli, "Commentary on Reliability of the AMA Guides to the Evaluation of Permanent Impairment," *J. Occup. Environ. Med.*, vol. 52, no. 12, pp. 1204–1205, Dec. 2010, doi: 10.1097/JOM.0b013e31820061f3.

[4] J. Davidson, "A comparison of upper limb amputees and patients with upper limb injuries using the Disability of the Arm, Shoulder and Hand (DASH)," *Disabil. Rehabil.*, vol. 26, no. 14–15, pp. 917–923, Aug. 2004.

[5] Committee on the Use of Selected Assistive Products and Technologies in Eliminating or Reducing the Effects of Impairments, Board on Health Care Services, Health and Medicine Division, and National Academies of Sciences, Engineering, and Medicine, *The Promise of Assistive Technology to Enhance Activity and Work Participation*. Washington, D.C.: National Academies Press, 2017. doi: 10.17226/24740.

[6] C. Lake, "Partial Hand Amputation: Prosthetic Management," in *Atlas of Amputations and Limb Deficiencies: Surgical, Prosthetic, and Rehabilitation Principles*, Rosemont: American Academy of Orthopaedic Surgeons, 2004.

[7] M. Lang, "Challenges and solutions in control systems for electrically powered articulating digits," Myoelectric Symposium, 2011.

[8] C. Lake, "Experience With Electric Prostheses for the Partial Hand Presentation: An Eight-Year Retrospective," *JPO J. Prosthet. Orthot.*, vol. 21, no. 2, p. 125, Apr. 2009, doi: 10.1097/JPO.0b013e3181a10f61.

[9] J. E. Uellendahl and E. N. Uellendahl, "Experience Fitting Partial Hand Prostheses with Externally Powered Fingers," in *Grasping the Future: Advances in Powered Upper Limb Prosthetics*, United Arab Emirates: Bentham Science Publishers, 2012.

[10] S. G. Millstein, H. Heger, and G. A. Hunter, "Prosthetic Use in Adult Upper Limb Amputees: A Comparison of the Body Powered and Electrically Powered Prostheses," *Prosthet. Orthot. Int.*, vol. 10, no. 1, pp. 27–34, Apr. 1986, doi: 10.3109/03093648609103076.

[11] S. L. Carey, D. J. Lura, M. J. Highsmith, CP, and FAAOP, "Differences in myoelectric and body-powered upper-limb prostheses: Systematic literature review," *J. Rehabil. Res. Dev.*, vol. 52, no. 3, pp. 247–262, 2015, doi: 10.1682/JRRD.2014.08.0192.

[12] R. B. Stein and M. Walley, "Functional comparison of upper extremity amputees using myoelectric and conventional prostheses," *Arch. Phys. Med. Rehabil.*, vol. 64, no. 6, pp. 243–248, Jun. 1983.

[13] P. Parker, K. Englehart, and B. Hudgins, "Myoelectric signal processing for control of powered limb prostheses," *J. Electromyogr. Kinesiol.*, vol. 16, no. 6, pp. 541–548, Dec. 2006, doi: 10.1016/j.jelekin.2006.08.006.

[14] J. L. Segil, M. Controzzi, R. F. ff. Weir, and C. Cipriani, "Comparative study of state-of-the-art myoelectric controllers for multigrasp prosthetic hands," *J. Rehabil. Res. Dev.*, vol. 51, no. 9, pp. 1439–1454, 2014, doi: 10.1682/JRRD.2014.01.0014.

[15] J. L. Segil, S. A. Huddle, and R. F. ff. Weir, "Functional Assessment of a Myoelectric Postural Controller and Multi-Functional Prosthetic Hand by Persons With Trans-Radial Limb Loss," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 25, no. 6, pp. 618–627, Jun. 2017, doi: 10.1109/TNSRE.2016.2586846.

[16] J. Segil, R. Kaliki, J. Uellendahl, and R. Weir, "A Myoelectric Postural Control Algorithm for Persons with Transradial Amputation: A Consideration of Clinical Readiness," *IEEE Robot. Autom. Mag.*, pp. 0–0, 2019, doi: 10.1109/MRA.2019.2949688.

[17] R. G. Gaston, J. W. Bracey, M. A. Tait, and B. J. Loeffler, "A Novel Muscle Transfer for Independent Digital Control of a Myoelectric Prosthesis: The Starfish Procedure," *J. Hand Surg.*, vol. 44, no. 2, p. 163.e1-163.e5, Feb. 2019, doi: 10.1016/j.jhsa.2018.04.009.

[18] F. R. Finley and R. W. Wirta, "Myocoder-computer study of electromyographic patterns," *Arch. Phys. Med. Rehabil.*, vol. 48, no. 1, pp. 20–24, Jan. 1967.

[19] R. N. Scott, "Myoelectric control of prostheses and orthoses," *Bull. Prosthet. Res.*, vol. 7, p. 93, 1967.

[20] J. H. Lyman, A. Freedy, and R. Prior, "Fundamental and applied research related to the design and development of upper-limb externally powered prostheses," *Bull Prosthet. Res*, vol. 13, pp. 184–195, 1976.

[21] J. T. Belter and A. M. Dollar, "Performance characteristics of anthropomorphic prosthetic hands," in *2011 IEEE International Conference on Rehabilitation Robotics*, Jun. 2011, pp. 1–7. doi: 10.1109/ICORR.2011.5975476.

[22] S. K. Denduluri, A. Rees, K. M. Nord, B. J. Loeffler, and R. G. Gaston, "The Starfish Procedure for Independent Digital Control of a Myoelectric Prosthesis," *Tech. Hand Up. Extrem. Surg.*, vol. 27, no. 1, pp. 61–67, Mar. 2023, doi: 10.1097/BTH.0000000000000412.