Predicting Grip Aperture using Forearm Muscle Activation Data

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***Abstract*— The performance of activities of daily living (ADLs) is directly related to recovery of motor function after stroke. Because the recovery process occurs primarily in the home, there is a need for tools sensitive to this process that can be used in ambient settings. The goal of the current approach is to use surface electromyography (sEMG) acquired from wearable sensors to capture relevant ADL performance. Our specific focus is on detecting thumb-forefinger aperture. This aperture, which occurs during reach-to-grasp (RTG) movements, is an indicator of potential success of interacting with the environment. Our results suggest that sEMG data can be used to determine increasing thumb-forefinger aperture in a population of non-disabled individuals. We find a statistically significant effect of increased aperture on peak sEMG values ($p < 0.001$).**

I. INTRODUCTION

A leading cause of disability in the U.S is stroke which severely limits the functional independence and quality of life for survivors [1]–[3]. The performance of activities of daily living (ADLs) are generally used to determine the extent to which individuals post-stroke are capable of re-integrating into functional activities required for self-care and independence. ADLs can provide insight into the rehabilitation trajectory and potential long-term recovery of stroke patients [4], [5]. A common ADL which is often difficult for post-stroke patients is the reach-to-grasp (RTG) movement. RTG movements are required for interactions with the environment; however, distal movement of the fingers is often impaired after hemiparetic stroke, and can reduce functional independence [6]–[8]. A metric closely tied to RTG success is grip aperture, typically quantified by the Euclidean distance between the tips of the thumb and forefinger [9], [10]. This metric is predictive of RTG success and is therefore sensitive to the post-stroke recovery process [11]. Current approaches to monitoring thumb-forefinger aperture are typically goniometer-based and are appropriate only for laboratory settings [12], [13]. In summary, the majority of the post-stroke recovery process (e.g., the chronic phase) occurs in the home setting; however, it is difficult to monitor patients during this chronic recovery period. Additional information regarding ADL and functional performance, and specifically thumb-forefinger aperture, may lead to improved patient care [14].

Surface electromyography (sEMG) has demonstrated promise as a tool for remote monitoring of distal motor behaviors [15]–[17]. Many sensor modalities, including sensorized gloves and fine-wire EMG have proven too invasive to practically monitor individuals for extended periods of time [12], [18]. However, a new set of devices that integrate sEMG with motion sensors in a single device may overcome some of the limitations of other wearables, while also providing relevant motion and muscle activation data. These robust sensors provide a non-invasive option to monitor distal movements accurately and reliably though forearm sEMG signatures [19], [20]. Ample literature exists on RTG movements and forearm EMG using a variety of laboratory-based tools; however, there remains a gap in determining a relationship between grip aperture and sEMG to remotely monitor stroke patients in the home setting.

The purpose of our approach is to determine a relationship between forearm sEMG features and grip aperture. Doing so can help quantify RTG movements and provide better insight into stroke patient ADL recovery, with the long-term goal of developing real-time monitoring and assessment tools. Our initial investigation focuses on pilot validation of the approach in a population of un-impaired adults. In this population we predict that increased grip aperture will correspond to increased root-mean-square (RMS) of sEMG data. Additionally, we predict that there exists a linear relationship between aperture and RMS of sEMG. We expect this study to provide a foundation for further investigation of the difference in this relationship between healthy and neuromotor-impaired individuals. In Section II, we describe the study design; in Section III, we present our results. Finally, we provide implications of our findings relative to existing literature in Section IV.

II. METHODS

A. Participants

10 non–disabled participants (10M, 22.5 ± 0.5 years) were recruited from a convenience sample at California Polytechnic State University, San Luis Obispo according to the standards of the California State University Institutional Review Board (IRB).

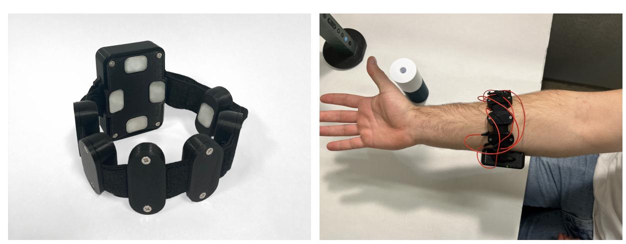

Fig. 1. The MindRove armband consists of 8+2 (bias + reference) radially spaced EMG sensors. The armband was placed approximately 2 inches distal from elbow joint (olecranon).

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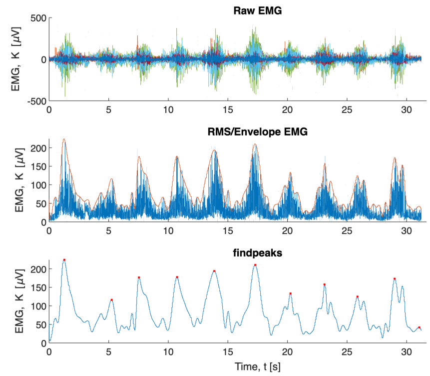

(a) Raw EMG and corresponding peak values for a single participant

A1(0.5)	A2(1.0)	A3(1.5)	A4(2.0)	A5(2.5)
	130.88	108.95	145.85	224.29
101.8	116.9	153.98	100.20	116.63
71.89	131.85	91.91	137.86	176.87
74.05	106.69	106.89	98.31	177.20
78.6	98.62	111.49	92.61	194.14
48.47	68.47	116.54	120.23	210.60
64.45	75.9	109.11	132.74	133.85
70.71	80.84	101.61	141.11	158.14
71.25	81.66	88.64	116.30	124.75
83.09	95.05	103.71	135.33	173.53

(b) Data for a single participant corresponding to peak values from (a) across the five appertures (with diameters, in inches, indicated in parentheses)

Fig. 2. The raw EMG data were processed into individual peak values for each participant. The data processing pipeline, including raw data of 8 EMG nodes, RMS and enveloping of raw data, and peak-finding resulted in summary data for each participant.

B. Setup & Equipment

The MindRove armband (www.mindrove.com) is a commercially available armband designed to detect muscle activation and movement (Figure 1). The armband utilizes 8 surface electromyography (sEMG) nodes, a 3-axis gyroscope, and a 3-axis accelerometer. For this study, the armband is placed approximately 2 inches distal to the olecranon, with the inertial measurement unit (IMU) rotated counterclockwise 90°of the palm in a supine position (Figure 1). In this location, the armband is capable of detecting EMG activation in both the extensor and flexor muscle groups. Because of the nature of the grip aperture movement, the armband positioning was selected to monitor the extensor muscle group, including the extensor digitorum, pollicis longus, extensor pollicis brevis.

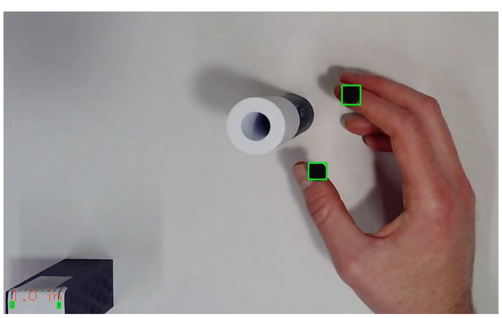

Fig. 3. Experimental setup, using a cylinder as a visual stimuli for the grasping motion. Note ruler in bottom left placed at height even with hand to allow for scaling.

C. Procedure

After obtaining informed consent, we asked participants to sit in a resting position at a table. The armband was then placed on the participant's wrist. A hand dynamometer was used to perform a maximum grip strength test for subsequent standardization of participant sEMG data. For the study procedure, five cylinders of increasing radii were placed in front of the participant (0.5", 1", 1.5", 2", 2.5"). For convenience, we refer to these as apertures A1, A2, A3, A4, and A5 (respectively). These cylinders served as visual indicators to the participant of the necessary grip aperture. The participant, without moving their hand towards the cylinder, simulated a grasp by opening their hand to an aperture which would allow them to grasp the corresponding cylinder. Each grasping motion was repeated 10 times for each cylinder radius to promote task consistency. Grip aperture was recorded using a document camera and a researcher-developed computer vision algorithm (Figure 3). The algorithm was initially validated in fulfillment of a computer vision upper division course, demonstrating promising initial functionality. To allow for ease of measurement and the algorithm to locate finger positioning, black markers were placed on the insides of the thumb and forefinger. All participants followed an identical procedure.

Following task performance, eight channels of raw EMG data were analyzed using MATLAB 2023 (www.mathworks.com, Natick, Massachusetts, United States). We calculated the root mean square of muscle activation data (RMS_{EMG}) using all eight sEMG channels using:

$$f_{RMS} = \sqrt{\frac{1}{n}(x_1^2 + x_2^2 + ... + x_n^2)} \tag{1}$$

Data were further processed using the MATLAB signal processing toolbox command `envelope`. This command reduces noise of the RMS_{EMG} signal, while accurately capturing peak signal values, as demonstrated in Figure 2(a). Following enveloping, `findpeaks` was used to identify peak locations and amplitudes. These values were used in subsequent analyses.

D. Data Analyses

1) Obtaining Ground-Truth Finger Aperture: We sought to determine a relationship between true (ground-truth) aperture as measured by our custom computer vision algorithm and the maximum EMG for each repetition. We do not, however, expect this relationship to be consistent across par-

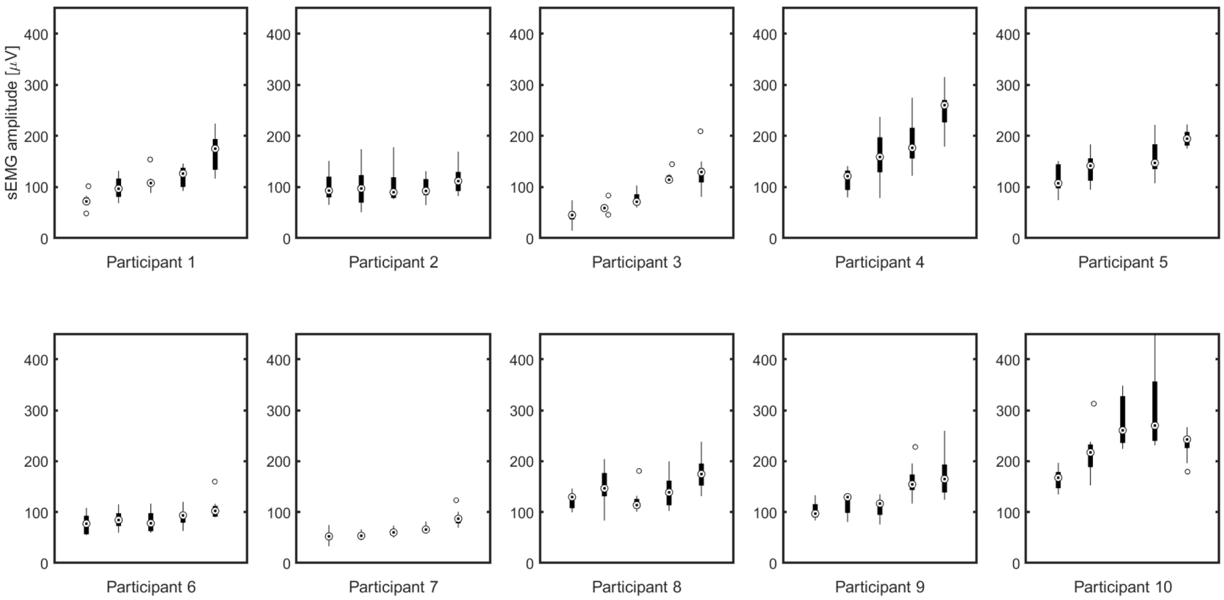

Fig. 4. Box and whisker plots for participants 1–10 indicating sEMG amplitude across the five apertures

ticipants who have varied musculoskeletal anatomy. Therefore, we perform correlation analyses within participants to compare aperture and EMG amplitude. We use the non-parametric Spearman's rank correlation to evaluate this relationship for each participant.

2) Determining Effects of Diameter: The study is designed as a one way (cylinder diameter) analysis, with five levels of diameter ($D1$, $D2$, $D3$, $D4$, and $D5$). After conducting a test for normality of EMG recordings for each aperture, the non-parametric Friedman Test was selected to test for differences in EMG values between cylinder diameters with significance level of $\alpha = 0.05$. For post-hoc analysis to determine which groups varied from each other, a Wilcoxon signed-rank test was employed with a Bonferroni correction applied. All statistical tests were performed using SPSS (IBM SPSS Statistics for Windows, Version 29.0. Armonk, NY).

Participant ID	Spearman's ρ	p-value
1	0.758	<0.001
2	0.208	0.152
3	0.883	<0.001
4	0.660	<0.001
5	0.700	<0.001
6	0.408	0.004
7	0.801	<0.001
8	0.304	0.033
9	0.746	<0.001
10	0.604	$<$ 0.001

TABLE I
RELATIONSHIPS BETWEEN GROUND TRUTH APERTURE AND DIAMETER

III. RESULTS

A. Individual Participant Data

We first explored visually individual participant data (Figure 4). Analyses were performed for individual reaches, but reaches are grouped here (by diameter) for clarity. From these data, we see a general trend of increasing median sEMG with increasing aperture. To evaluate the relationship between ground truth aperture and sEMG, we evaluated Spearman's rank coefficient within-subjects. Nine of the ten participants demonstrated significant, positive correlation (Table I).

B. Group Data

We performed a Friedman test on data collected from study participants to determine the effect of diameter on peak sEMG. The affect of diameter was found to be statistically significant ($p < 0.001$). The post-hoc analyses with Wilcoxon signed-rank tests with a Bonferroni correction indicated statistically significant differences between all apertures ($p < 0.001$) except between apertures 2 and 3 (with $p = 0.018$). (Figure 5).

IV. DISCUSSION

A. Individual Performance

Analyses of individual performance revealed a consistent trend indicating a positive relationship between cylinder diameter and EMG signal amplitude. Within each subject, as the diameter of the cylinder increased, there was a corresponding increase in EMG signal. This suggests a direct relationship between grip aperture and muscle activation. Additionally, within the same diameter groups, the variability

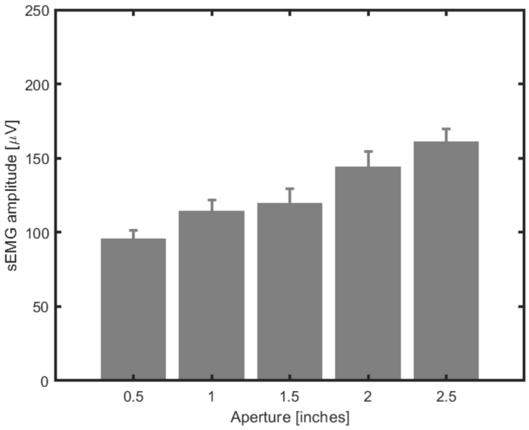

Fig. 5. Summary data for all participants across apertures

of EMG signals among individuals was lower compared to the variability observed across different diameters. This highlights a similar muscle activation across participants when interacting with objects of the same size, whereas more significant differences in muscle activation patterns become apparent when comparing across varying cylinder diameters. It is important to note that the raw sEMG values for each diameter do vary across participants. This is not surprising, given the different musculoskeletal characteristics of participants. Identical movements across participants may engage varying volumes of muscle spindles.

B. Group Performance

As expected, we found a significant effect of cylinder diameter on peak sEMG signal. The relevant diameters were selected to provide a range of values at which sEMG might vary. However, because the majority of prior studies investigate maximum aperture, or a single aperture, there is little prior work indicating the sensitivity of diameter to sEMG. For this reason, it is possible that equal increments may not result in equal changes in sEMG (in other words, there may not be a constant slope). This is supported by our findings which indicated that all diameters differed from each other besides $D2$ and $D3$. This suggests that future studies may instead use $D1$, $D2$, $D4$, and $D5$ (or perhaps a larger ultimate value).

It is important to acknowledge the potential effects of the protocol on our findings. Other work investigating hand posture and forearm sEMG has exposed a variety of factors that influence study outcomes. For instance, Qing et al. found that fatigue and acquisition time may effect the quality of classifier models trained on sEMG data [21]. Our study did not involve power grips or other more strenuous activities; further, duration of data acquisition was generally under 20 minutes per participant. Our use of a repeated task is also relevant; Wang et al. showed that as repetition rate increased, model accuracy deteriorated in certain cases [22]. While we do not expect our findings to be drastically affected by these factors, any potential influence should be used to contextualize these and future results.

C. Next Steps

In future work, the instructions given to participants can be refined to allow for more consistent aperture responses, as certain participants reached apertures not in alignment with the cylinder's dimensions. Furthermore, inclusion of a small set of solely male participants presents a limitation of the study. Finally, we recognize that the included analyses provide insight on relevant features sensitive to thumb forefinger aperture. For practical long-term monitoring, it remains necessary to develop models capable of extracting such features from continuous, longitudinal data. Future applications of this approach should extend this procedure to include post-stroke individuals, as this can give valuable insight into the motor recovery of this population in the home setting.

V. Acknowledgement

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