A rigorous examination of electromyography forearm muscle response in grasping and swinging scenarios

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ABSTRACT

This study examines the use of electromyography (EMG) in analyzing forearm muscle responses in hand grasping force with swinging motions. We start by establishing the basics of hand grasping force and swinging motions, laying the groundwork for subsequent discussions. The paper critically assesses various EMG techniques, highlighting how they reveal muscle activity during hand grasping in dynamic situations. We explore how swinging motions affect hand grasping force biomechanics, emphasizing the role of EMG in capturing dynamic muscle activity. A thorough examination of methodologies used in EMG studies provides insights into current practices and emerging trends. Practical applications across fields like rehabilitation and robotics underscore the relevance of this research. The study concludes by addressing current challenges and suggesting future research directions. This synthesis provides a straightforward resource for researchers, practitioners, and technologists seeking a deeper understanding of EMG indices in hand-grasping force analysis with swinging action.

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1. INTRODUCTION

Understanding how the hand applies force during swinging motions is beneficial for a variety of practical applications [1]. From designing more intuitive tools to improving rehabilitation strategies, the biomechanics of hand grasping in dynamic situations play a significant role [2]–[7]. This reanalysis examination aims to provide insight into the current state of research focusing on hand grasping force during swinging motions, with a specific emphasis on the application of electromyography (EMG), as shown in Figure 1.

The significance of investigating hand grasping force in swinging motions lies in its direct relevance to daily activities [8]–[11]. Consider the act of reaching for an object while walking or grasping a moving handle, these scenarios demand a unique understanding of how muscles coordinate during dynamic movements [12], [13]. By unraveling the complexities of hand grasping force in such situations, we can enhance our ability to design technologies and interventions that better align with natural human movements [2], [3], [11], [14]. The primary purpose of this examination is to provide a comprehensive overview of studies that utilize EMG to analyze muscle response to hand grasping force with swinging motions. By doing so, we aim to consolidate existing knowledge, identify gaps in understanding, and propose potential directions for future research.

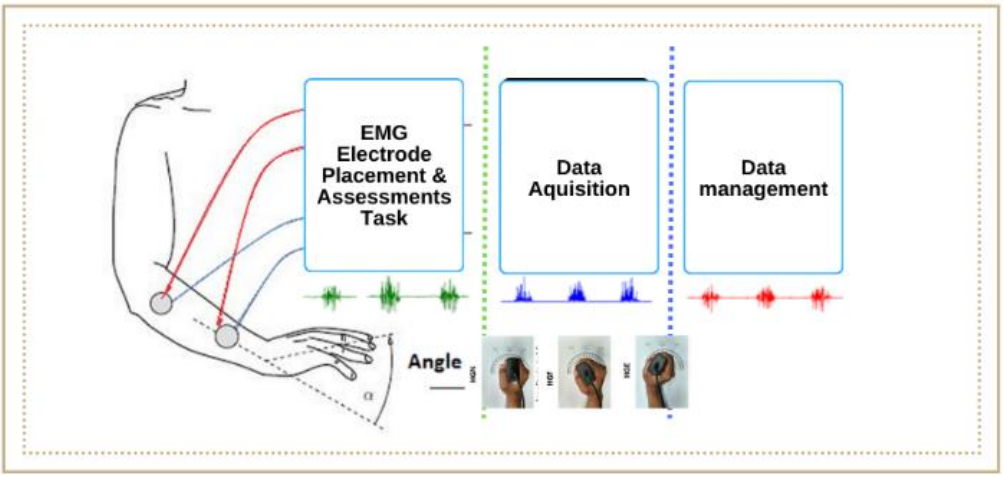

Figure 1. EMG general recording process

EMG is a technique that records the electrical activity of muscles and serves as a key tool in unraveling the intricacies of hand grasping force during swinging motions [15], [16]. It allows researchers to observe and quantify muscle activity, providing valuable insights into the dynamics of hand movements [3], [11], [17], [18]. This rigorous examination will explore how EMG has been applied in this context and its role in advancing our understanding of the biomechanics involved.

Hand grasping force refers to the strength applied by the hand when seizing or manipulating an object. This force is dynamic, especially during swinging motions, where the hand encounters changes in velocity, direction, and acceleration [3], [19], [20]. Biomechanically, hand grasping force is influenced by the coordination of muscles, tendons, and joints. The physiological aspects include muscle contraction, joint movement, and the distribution of force across the hand [21]. In swinging motions, these biomechanical and physiological factors undergo constant adaptation to maintain an effective grip in dynamic environments [19]. In the context of hand grasping force during swinging motions, biomechanics elucidates how muscles generate force to control hand movements [19], [22]. Understanding these biomechanical principles is fundamental to designing tools and technologies that align with the natural capabilities of the human [19]–[21], [23].

2. METHOD

2.1. Material and methods

Several key muscles contribute to hand grasping force, each playing a specific role in the intricate choreography of hand movements. Muscles such as the flexor digitorum profundus, flexor digitorum superficialis, and opponens pollicis are crucial for fine motor control and precision grip [19], [20]. EMG signals offer valuable information about the level of activation and coordination required for different grasping tasks [20]. Understanding the specific muscles involved enhances our ability to perceive the variations of hand grasping force dynamics [13], [23]–[26].

Researchers employ various EMG methodologies and technologies to capture and interpret muscle activity during hand grasping [19], [20], [22], [27]–[29]. Surface EMG involves placing electrodes on the skin above targeted muscles, providing a non-invasive way to monitor muscle activity [30]–[32]. This approach is commonly used in studies assessing overall muscle engagement during different grasping tasks. The choice of EMG methodology depends on the research goals, the level of detail required, and the practical constraints of the study environment. By exploring these varied approaches, researchers can tailor their methods to the specific refinements of hand grasping force analysis during swinging motions.

In this study, we examine how muscle responds to swinging motions and hand grasping force by revealing the strength of our exceptional seven volunteers. Figure 2 shows the experiment setup. Our carefully chosen team comprises four outstanding males and three exceptional females. Their flawless health records, free from musculoskeletal disorders or nerve diseases, ensure the reliability of our study. All righthanded and aged 21 to 25, they bring youthful energy to our research. The day before the experiment, they were advised to avoid strenuous forearm or hand exercises. Together, we move forward, poised to uncover groundbreaking insights into muscle activity.

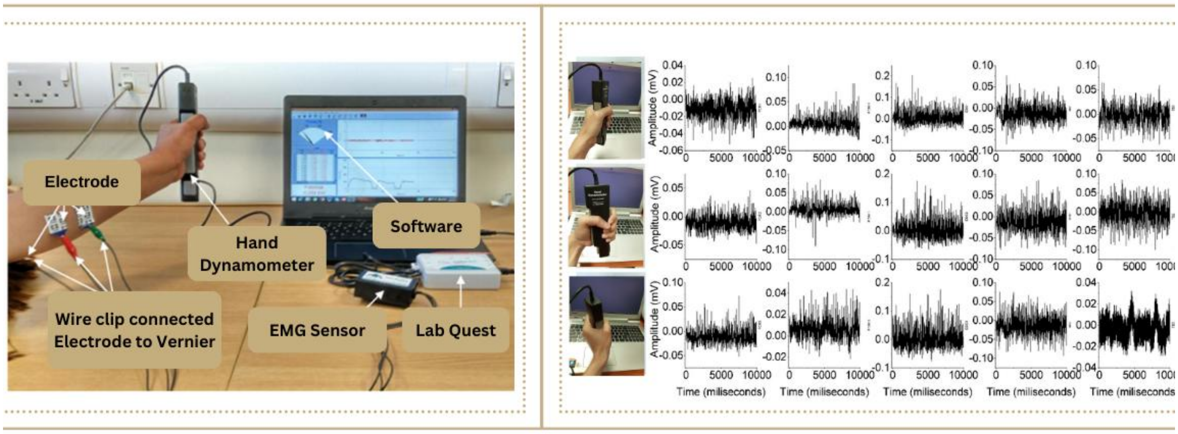

Figure 2. Experiment setup for EMG data recording

Facilitating progress through comprehensive documentation, we thoroughly recorded essential details—gender, weight, dominant hand, age, and height—for comprehensive future reference. Our commitment to excellence extends to the data collection setup, finely tuned for participant comfort and efficiency. By minimizing fatigue and streamlining preparation time, we prioritize an environment conducive to groundbreaking discoveries. The device used for data collection is the Vernier LabQuest Mini, a multiple-channel surface EMG system (refer to Figure 2). We advise participants to relax before electrode placement and apply an alcohol swab to clean the skin and prevent high impedance, thereby avoiding harm. We use disposable EMG electrodes (Nihon Kohden) with a 10 mm diameter in the experiment. The recording surface is estimated to cover around 5 mm. The EMG sensor is placed on the right forearm and wrist, with electrodes on two forearm muscle groups: flexor carpi radialis and flexor pollicis longus. Participants sit on a chair with an adjustable armrest for comfort, performing a swing with handgrip force using the Vernier hand dynamometer. For effective signals, each channel uses a bipolar configuration with a 15 mm distance between two electrodes. Because the EMG signal is very noisy, robust features are needed to get the best surface EMG indices for further study. Table 1 describes the selected features.

Table 1. Features extraction selection, expression, and description

Features	Expression formula	Description
Means absolute value (MAV)	$MAV = \frac{1}{N}\sum_{N=1}^{N} \lvert X_n \rvert$	It reflects the effective value of the EMG signal, which is proportional to the force generated by the muscle [30], [33], [34].
Root mean square (RMS)	$RMS = \sqrt{\frac{1}{N}\sum_{n=1}^{N} X_n^2}$	It reflects the overall magnitude of the EMG signal, but it can be affected by the baseline noise and the polarity of the signal [30], [35].
Standard deviation	$STD = \sqrt{\frac{1}{N-1}\sum_{n=1}^{N} X_n^2}$	Represents EMG signal confidence interval between statistical data [33], [34], [36].

3. RESULTS AND DISCUSSION

As shown in Figure 3, for MCV 0%, hand muscle EMG signal amplitude was relatively small demonstrating the participant at relaxed condition, while MCV 50% increases, demonstrated that the hand grip force increase, showing that the hand muscle EMG signal amplitude increases as well. While the participant instructed to add swing motion, as MCV 100%, show that the hand muscle EMG signal amplitude enormously increases. Initial data show that the contraction of the muscle increases as the handgrip force increases and even more after adding swing motion movement. The collected data is then processed for muscle responses assessment. Thus, the mean and RMS analysis is performed at the average percentage of maximal voluntary contraction (MVC) handgrip and swinging level scenarios. The data in Table 2 provides information about the relationship between muscle contraction and hand grip force during swing action.

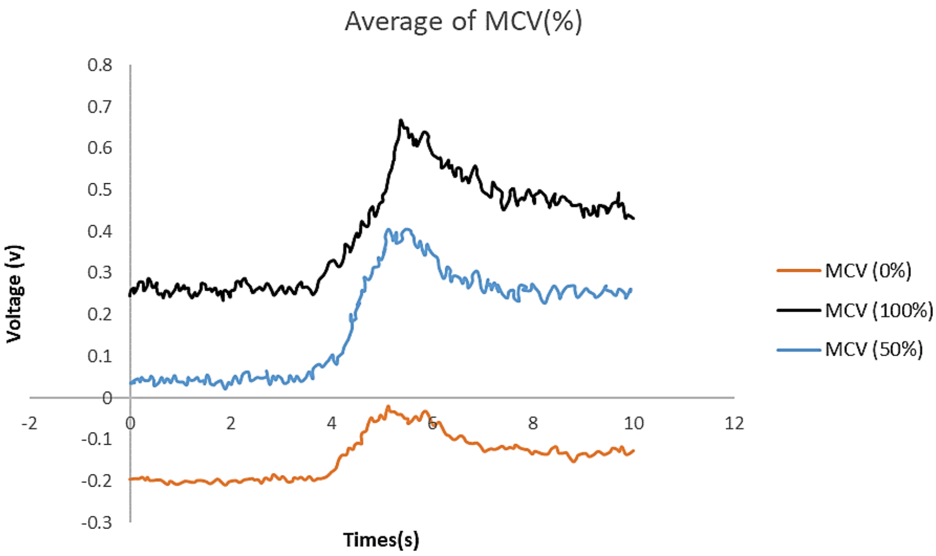

Figure 3. Response of muscle for average of MCV

Table 2. RMS vs mean results (%MVC)

	0% MVC	50% MVC	100% MVC
Mean (mV)	-81.35	287.1	491
RMS (mV)	93.1	306.8	505.3

The mean value can be negative if the signal is below the baseline, as shown in Table 2 for the 0% MVC condition. It reflects muscle at rest. Table 2 shows the mean and RMS values of the EMG activity of a muscle during different levels of contraction, expressed as a percentage of the MVC. The table shows that both the mean and RMS values of EMG increase as the level of contraction increases from 0% to 100% MVC. This is consistent with the fact that more muscle fibers are recruited and activated as the contraction intensity increases [22], [27]. The table also shows that the RMS values are higher than the mean values for all levels of contraction, which indicates that the EMG signal has some variability and fluctuation around the mean value.

For the feature recommendation, one possible way to interpret the table is to compare the mean and RMS values of EMG with the torque produced by the muscle at each level of contraction. Torque is the rotational force that the muscle exerts on the joint, and it is usually measured by a dynamometer [3]. By plotting the mean or RMS values of EMG against the torque values, we can obtain the EMG-torque relationship, which can reveal the efficiency and fatigue of the muscle. For swinging phase motion scenario, the percentage of each MVC is analyzed using the boxplot. The comparison of the median and interquartile range (IQR) values of the EMG signal for each level of MVC percentage is shown in Figure 4, which is a boxplot of the EMG signal for each level of MVC percentage. A boxplot is a graphical method that shows the median, the IQR, and the outliers of the data. 100% MVC has the highest mean, IQR, and average standardized amplitude compared to those in Table 2. Table 3 shows the median and IQR differences of the EMG activity of a muscle between different levels of contraction, expressed as a percentage of the MVC. The median is the middle value of the EMG signal over a certain period, and the IQR is the difference between the 75th and 25th percentiles of the EMG signal over the same period. The median and IQR reflect the central tendency and variability of the EMG signal, respectively.

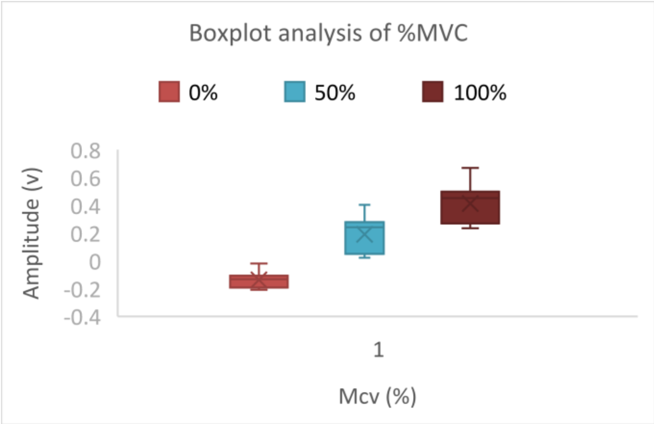

Figure 4. Boxplot analysis of percentage (%) MVC

Table 3. IQR difference vs average median

MVC (%)	Median difference (mV)	IQR difference (mV)
0-50	661.86	103.65
50-100	136.78	51.03
Total	799.64	154.68
Average	**266.54667**	**77.34**

Table 3 shows that the median difference of EMG is much higher between 0% and 50% MVC than between 50% and 100% MVC. This means that the EMG signal increases more rapidly in the lower range of contraction than in the higher range of contraction. This is due to the recruitment of more muscle fibers and motor units in the lower range of contraction, which increases the amplitude and frequency of the EMG signal. The table also shows that the IQR difference of EMG is higher between 0% and 50% MVC than between 50% and 100% MVC. This means that the EMG signal has more variability and fluctuation in the lower range of contraction than in the higher range of contraction. This is due to the asynchronous activation and deactivation of different motor units in the lower range of contraction, which causes the EMG signal to have more peaks and valleys.

Table 3 also shows the total and average values of the median and IQR differences of EMG across all levels of contraction. The total values are the sum of the median and IQR differences between 0% and 50% MVC and between 50% and 100% MVC. The average values are the mean of the median and IQR differences between 0% and 50% MVC and between 50% and 100% MVC. These values can be used to compare the overall change and variation of the EMG signal across the whole range of contraction. The table shows that the total and average values of the median difference of EMG are much higher than the total and average values of the IQR difference of EMG. This means that the EMG signal changes more in terms of its central tendency than in terms of its variability across the whole range of contraction. By analyzing the data in Tables 2 and 3, researchers can identify patterns and trends that can help them develop training programs and techniques to improve hand grip strength and performance for rehab, robotics, or sport applications.

4. CONCLUSION

The EMG activity of the muscle increases as the level of contraction increases from 0% to 100% MVC and has more variability and fluctuation in the lower range of contraction than in the higher range of contraction. The interplay between muscles during dynamic tasks poses challenges, and researchers have employed diverse methodologies to decipher the intricacies of hand grasping force. The significance of specific muscles, signal processing techniques, and the impact of swinging motions on individual responses have emerged as crucial considerations.

One possible way to interpret the results is to compare the mean, RMS, median and IQR differences of EMG with the torque produced by the muscle at each level of contraction. Torque is the rotational force that the muscle exerts on the joint, and it is usually measured by a dynamometer. By plotting the fusion of mean, RMS, median or IQR differences of EMG against the torque differences, we can obtain the EMG-torque relationship, which can reveal the efficiency and fatigue of the muscle. For example, if the EMG-torque relationship is linear, it means that the muscle is efficient and can produce more torque with less EMG change. If the EMG-torque relationship is nonlinear, it means that the muscle is fatigued and needs more EMG change to produce the same torque.

One notable challenge is the complexity of interpreting EMG signals in dynamic environments. Swinging motions introduce additional variables, such as acceleration and deceleration, which can impact the accuracy of muscle activity assessments. Researchers grapple with the need for more sophisticated signal processing techniques to distinguish genuine muscle activations from motion artifacts during dynamic tasks. Another challenge lies in the variability of individual responses to swinging motions. Human biomechanics are inherently diverse, and factors such as age, fitness level, and previous injuries can influence how individuals adapt their hand grasping force during swinging. Understanding and accounting for this variability presents ongoing challenges in ensuring the generalizability of research findings to diverse populations. Moreover, expanding research to include virtual reality environments offers a controlled yet immersive setting for studying hand grasping force during swinging motions. Virtual reality setups can simulate dynamic scenarios, providing a bridge between controlled laboratory studies and the unpredictable nature of real-world activities.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Mohammad Osman Tokhi	✓		✓	✓	✓		✓			✓	✓	✓		
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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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