Al-Khwarizmi Engineering Journal, Vol. 16, No. 2, June, (2020)
P. P. 14- 23

Al-Khwarizmi Engineering Journal

Analysis of Different Hand and Finger Grip Patterns using Surface Electromyography and Hand Dynamometry

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(Received 19 November 2019; accepted 5 May 2020)
https://doi.org/10.22153/kej.2020.05.001

Abstract

Recording an Electromyogram (EMG) signal is essential for diagnostic procedures like muscle health assessment and motor neurons control. The EMG signals have been used as a source of control for powered prosthetics to support people to accomplish their activities of daily living (ADLs). This work deals with studying different types of hand grips and finding their relationship with EMG activity. Five subjects carried out four functional movements (fine pinch, tripod grip and grip with the middle and thumb finger, as well as the power grip). Hand dynamometer has been used to record the EMG activity from three muscles namely; Flexor Carpi Radialis (FCR), Flexor Digitorum Superficialis (FDS), and Abductor Pollicis Brevis (ABP) with different levels of Maximum Voluntary Contraction (MVC) (10-100%). In order to analyze the collected EMG and force data, the mean absolute value of each trial is calculated followed by a calculation of the average of the 3 trials for each grip for each subject across the different MVC levels utilized in the study. Then, the mean and the standard deviation (SD) across all participants (3 males and 2 females) are calculated for FCR, FDS and APB muscles with multiple % MVC, i.e 10, 30, 50, 70 % MVC for each gesture. The results showed that APB muscle has the highest mean EMG activity across all grips, followed by FCR muscle. Furthermore, the grip with the thumb and middle fingers is the grip with the highest EMG activity for 10-70% MVC than the power grip. As for the 100% MVC, thumb and middle fingers grip achieved the highest EMG activity for APB muscle, while the power grip has the highest EMG activity for both FCR and FDS muscles.

Keywords: *Electromyogram (EMG), hand grip force, Myotrace 400, Maximum Voluntary Contraction (MVC), Hand dynamometer.*

1. Introduction

Electromyogram (EMG) signals from the skin surface are considered as a source of neural control information and are traditionally employed as inputs to the controller of upper-limb prosthetic hands [1], helping disabled people to use the remaining parts of their own forearm/hand to accomplish the activities of daily livings (ADLs) [2]. The term EMG has been also associated with the process of detecting, recording, and evaluating the action potential produced by the muscles of the body [3], denoted as Electromyography. The central nervous system (CNS) is the origin of EMG action potential by which the motor neurons carry the information transferred along the nerve in pulse repetition or known as frequency [3]. The action potential is generated by the flow of ions through the muscle fibers' membrane, which spreads across the interfacing tissues to reach the electrode detection surface placed on the skin [1]. Surface EMG electrodes are placed on the skin above the muscle of interest to measure the EMG signal.

Surface EMG is widely used as a non-invasive method to map the relationship between electrical activity of the muscles and the generated muscle force. Therefore, the estimation of the hand force by using the sEMG signal is very essential in many applications such as design and control of a cybernetic prosthetics, sport medicine, medical rehabilitation, clinical diagnostics, kinesiology and biomechanics [3,4,5]. However, the number of muscles of interest, EMG needed channels, the number and location of surface electrodes and type of gestures can all affect the relationship between muscle force and muscle activity [7,8].

Daud et.al [3] studied the effect of two adjacent muscles on finger pinch and hand grip force. The muscles were two adjacent flexor muscles: flexor digitorum superficial (FDS) and flexor carpi radialis (FCR), two adjacent extensor muscles: extensor carpi radialis longus (ECRL) and extensor digitorum communis (EDC). Nine subjects (seven males and two females) were chosen to perform seven types of hand movements with different percentage of MVC. Despite the promising results of that study, they concluded that using a single muscle channel instead of adjacent muscles could provide an optimized data for pattern recognition or classification.

The relation of EMG signal to hand grip force at varying wrist angles had been studied by Sidek et al [4]; in this study, the authors investigated the relationship between forearm EMG, hand grip force, and wrist angles recorded by surface electrodes located on FCR, FDS; and EDS muscles. MVC range was 2 to 30% and recorded with 90^o, 60^o and 120^o degrees of wrist angle. However, the research focused only on the effect of change in angle of the wrist without using any other hand grip gestures.

The hand force and EMG signal are taken in consideration in some clinical implications and clinical issues. Martin et al. [2] studied the quantification of six functional movements and acceleration which was measured in real time. Six muscles were used to record the EMG signals which showed that each muscle could have a different effect on hand gesture. Li et al. [9] investigated the effect of Diabetes Mellitus on the dynamical coordination of hand intrinsic muscles during precision grip. The test was done using a costume design apparatus with stable and unstable loads. The EMG signal was recorded from abductor pollicis brevis (APB) and first dorsal interosseous (FDI).

To the best of our knowledge, only power grip was investigated with EMG recorded from different muscles, with different %MVC, while no other types of grips were considered, such as the fine pinch or tripod grip. In this study, we investigate the EMG activity of fine pinch, tripod grip and grip with the middle and thumb finger, as well as the power grip.

The main aim of this study is to investigate the relationship between EMG signal recorded from 3 muscles namely, FCR, FDS and, APB; and four different hand grips under different %MVC (10-100%).

2. Methodology

2.1 Participants

In this study, five healthy subjects (three males and two females) aged between 30-40 years old (as illustrated in Table 1) are recruited to perform several finger pinches and hand grasping movements. Subjects provided informed consent before participating in the experiments. The subjects are clearly indicated with no muscle disorder or abnormal limbs. The data have collected at the university of Baghdad, Al-Khwarizmi College of Engineering. The participants sat on a chair in front of a battery powered computer with Myotrace 400 (Noraxon, USA). The raw signals and force power are displayed on computer to help the subject to perform the hand movement with the necessary MVC contractions. The experimental protocol has been done according to the Deceleration of Helsinki and its later amendments.

Table 1,

Characteristics of the participants of the study.

Participant ID	Gender	Age	Height	Neuromuscular disease
CON1	Male	33	168	None
CON2	Male	38	170	None
CON3	Female	32	161	None
CON4	Female	37	158	None
CON5	Male	33	168	None

2.2 Electrodes Position

The skin of the subject is cleaned and prepared with abrasive skin preparation gel (NeuroPrep, USA). Six pairs of Ag/AgCl electrodes are placed at the center area of each muscle and the elbow joint is used as reference to mark the electrode locations. Figure 1 shows the location of each electrode for all muscles.

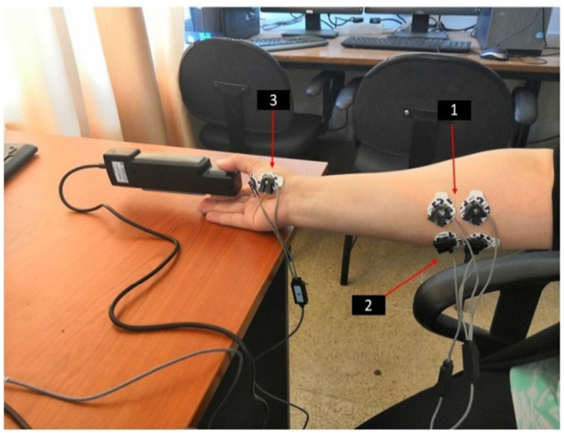

Fig. 1.Surface electrode locations on each muscle. 1. Flexor Carpi Radialis (FCR), 2. Flexor Digitorum Superficialis (FDS), and 3. Abductor Pollicis Brevis (ABP).

2.3 Signal Acquisition

Myotrace 400 (Noraxon, USA) data acquisition system has been used to record all data. The system has four channels, three channels for EMG signals and one for Vernier hand dynamometer (Vernier, USA) which is used to record hand grip force and pinch force. The signals are sampled at a rate of 1000 Hz with 16-bit resolution data acquisition. All channels have a low pass anti-alias filter set to 500 Hz. Figure 2 shows the apparatus that was used to measure EMG and hand grip force.

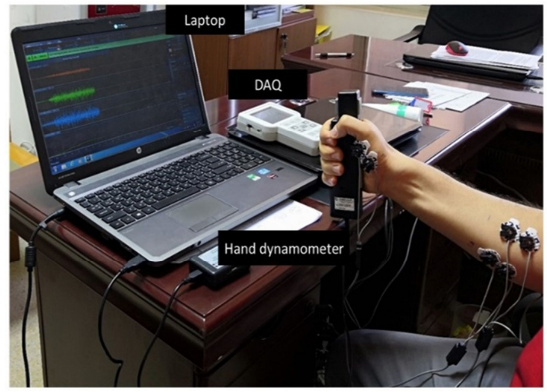

Fig. 2. EMG and hand grip force measurement experimental setup, computer laptop, data acquisition (DAQ) device with Myotrace 400, and Vernier hand dynamometer

2.4 Experimental Protocol

Four different grip patterns are investigated in this work as shown in figure 3: 1) fine pinch with thumb and index fingers, 2) tripod with thumb, index and middle fingers, 3) thumb middle pinch with thumb and middle fingers, and 4) power grip. EMG signals are recorded using surface electrode arrays from Flexor carpi radialis (FCR), Flexor digitorum superficialis (FDS), and Abductor pollicis brevis (ABP) muscles. Each hand movement has three trials record while each motion is sustained for a period of 6 seconds only with 6 seconds resting period given between motions. Each subject has asked to perform maximum voluntary contraction (MVC) during recording, then has to perform different percentage of MVC (10%, 30%, 50%, 70%, and 100%).

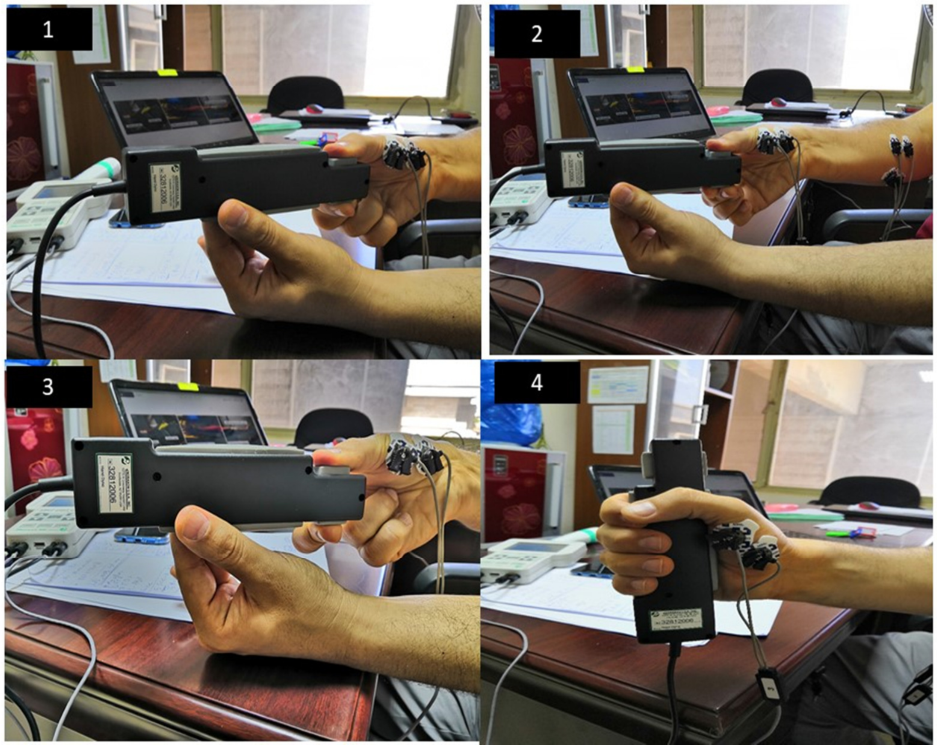

Fig. 3. Four types of hand movements: 1. fine pinch with thumb and index fingers. 2. tripod with thumb, index and middle fingers. 3. Thumb middle pinch with thumb and middle fingers. 4. power grip.

2.5 Data Analysis

Data have recorded from three forearm muscles (FCR, FDS, and ABP) of five subjects, with each subject performing four hand and finger gestures with multiple levels of %MVC (i.e.,10,30,50,70, and 100 % MVC).

In order to analyze the collected EMG and force data, we have utilize the mean of absolute value (Eq. 1) for each trial and then calculate the average of the three trials of each grip for each subject with different % MVC levels. Then, the mean and standard deviation (SD) across all participants (three males and two females) are calculated for FCR, FDS and, APB muscles with multiple % MVC, i.e 10, 30, 50, 70 % MVC for each gesture as will be presented in section 3.

As for the 100% MVC, the mean of the absolute value across the two recorded trials are calculated across three subjects as well as the SD as shown in section #.

$$\text{Mean of the absolute value} = \frac{1}{N}\sum_{n=1}^{N}|x_n| \quad \ldots(1)$$

Where N is the number of samples in the trial, x_n is the EMG sample of position n in the trial.

2.6 Statistical Analysis

In the last part of the data analysis, we evaluate the statistical significance of the achieved results using an N-way analysis of variance (ANOVA) with three grouping variables (factors): the different MVC levels (10, 30, 50, 70 and 100%), the different types of grips (Fine Pinch, Tripod Grip, Grip with Thumb+Middle, and Power Grip), and the different muscles considered (APB, FDS, and FCR). We also have teste the two-factor interactions, with the interaction terms being represented by MVC levels*type of grips, MVC levels*the different muscles, and types of grips*the different muscles in the ANOVA table. The significance level for confidence bounds in the above analysis has set to 0.05. A p-value that is smaller than the significance level of 0.05 indicates that the mean responses for the different levels of the considered factor(s) are significantly different.

3. Results and Discussion

In Figure 4, three trials of EMG signal for three FCR, FDS and APB muscles are shown with the force measurement for power grip gesture at 50 % MVC for participant 1 whereas Figure 5 shows the same plots but for tripod grip with 30 % MVC for participant 2. In both figures, EMG activity of APB seems to be higher than that of FCR and FDS for both participants. Similar trend can be observed in Figure 6 for female participant for fine pinch movement with 70% MVC.

It can be also noted from the force plots in the bottom Figures 4, 5, 6 that there are little variations between the force measurements produced by the participants across the three trials.

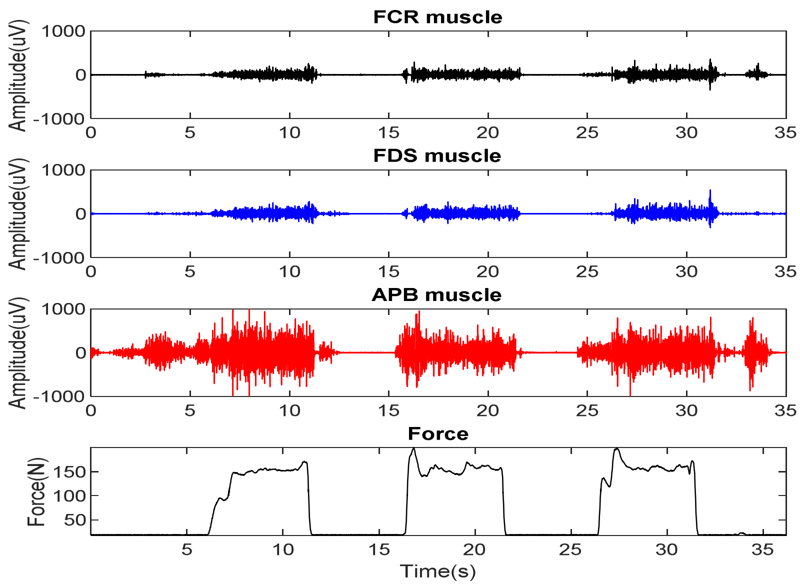

Fig. 4. A plot of the EMG for the power grip with 50% MVC for participant 1 (male participant). The top 3 figures represent the 3 trials of EMG from the FCR, FDS and APB, respectively. The bottom figure is the force signal measured in Newton with hand dynamometer.

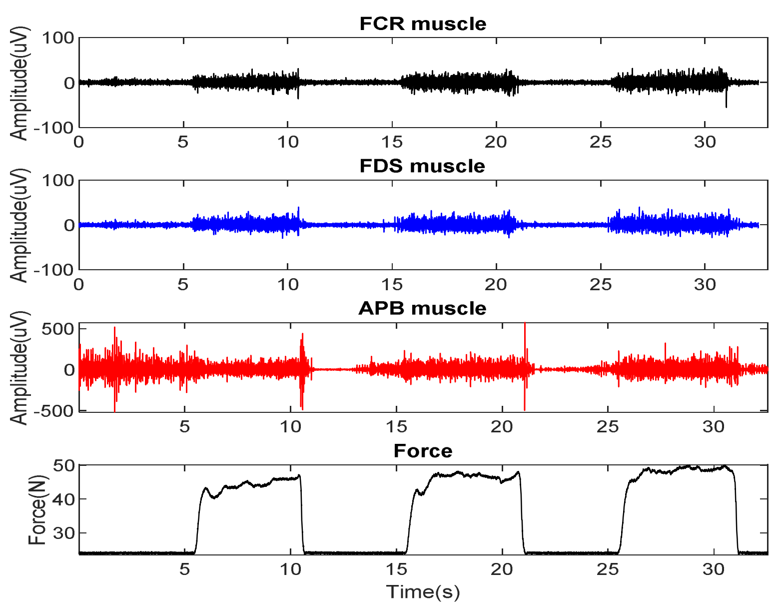

Fig. 5. A plot of the EMG for the tripod grip with 30% MVC for participant 2 (male participant). The top 3 figures represent the 3 trials of EMG from the FCR, FDS and APB, respectively. The bottom figure is the force signal measured in Newton with hand dynamometer.

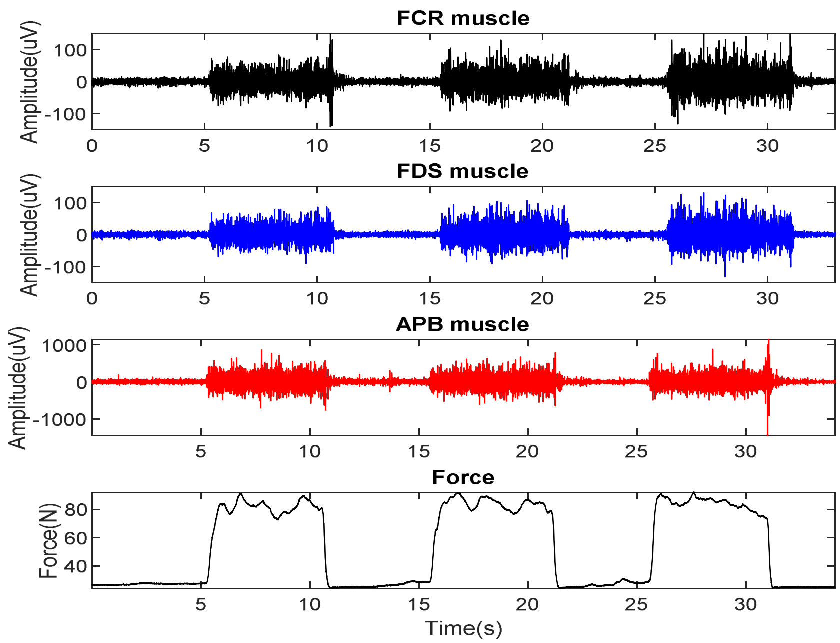

Fig. 6. A plot of the EMG for the fine pinch with 70% MVC for participant 3 (female participant). The top 3 figures represent the 3 trials of EMG from the FCR, FDS and APB, respectively. The bottom figure is the force signal measured in Newton with hand dynamometer

Table 2 illustrates the mean values of the EMG and standard for five participants for three muscles with four types of grips for 10% MVC. The grips with the thumb and middle finger have the highest mean of the EMG activity 25.8 uV compared to other grips. Additionally, APB is the muscle with the highest activity across all group types where mean activity is equal to 45 uV. It should be noted that ABP is an extrinsic muscle which lies inside the hand compared to FCR and FDS that are external actuators of the finger and the wrist located on the forearm.

The standard deviation for the APB is higher than that of FCR and FDS muscles since the subject EMG activity has more variability for APB muscle than other muscles, i.e. FCR and FDS.

Table 2,
Mean values of EMG activity (mean ± SD) in in (μV) of different grips types for the case of 10% MVC for 5 subjects for FCR, FDS and APB muscles.

	FCR	FDS	APB	Mean
Fine Pinch	5.1 ± 1.3	5.1 ± 2.5	33.2 ± 20	14.4
Tripod Grip	5.8 ± 1.5	5.4 ± 2	39.3 ± 20.6	16.8
Grip with Thumb+Middle	7.3 ± 3.7	6.1 ± 2.8	**64.1 ± 37.9**	**25.8**
Power Grip	**8.4 ± 2.2**	**10.5 ±1.8**	43.3 ± 19.5	20.7
Mean	6.6	6.8	**45.0**	

Table 3, Table 4, and Table 5 illustrate the results of the mean of the EMG activity, for the three muscles with different types of grips investigated in this study, for 30% MVC, 50% MVC, and 70% MVC respectively.

From Table 2, Table 3 and Table 4, it is noteworthy to mention that the grip with the thumb and middle fingers has the highest EMG activity compared to other grips for 30%, 50% and 70% MVC. Furthermore, the EMG activity from APB muscle is the highest for 30%, 50 %

and 70 MVC similar to that of 10% MVC illustrated in Table 1.

As for FDS muscle, 30, 50, 70% MVC, the power grip is the grip with the highest EMG activity as the main finger flexor is FDS located on the forearm.

Table 3,
Mean values of EMG activity (mean ± SD) in in (µV) of different grips types for the case of 30% MVC for 5 subjects for FCR, FDS and APB muscles.

	FCR	FDS	APB	Mean
Fine Pinch	5.9 ± 2.2	6.7 ± 2.5	38.2 ± 25.9	16.9
Tripod Grip	7.5 ± 2.8	7.4 ± 1.9	57.7 ± 30.1	24.2
Grip with Thumb+Middle	14.1 ± 10.5	10.0 ± 5.3	**95.9** ± 59.4	**40.0**
Power Grip	**14.4 ± 3**	**22.2 ± 6.5**	70.2 ± 34.1	35.6
Mean	10.5	11.6	65.5	

Table 4,
Mean values of EMG activity (mean ± SD) in in (µV) of different grips types for the case of 50% MVC for 5 subjects for FCR, FDS and APB muscles.

	FCR	FDS	APB	Mean
Fine Pinch	9.2 ± 4.7	12.1 ± 9.4	55.6 ± 29.7	25.7
Tripod Grip	10.8 ± 5.6	10.1 ± 3.3	87.0 ± 54.1	36.0
Grip with Thumb+Middle	23.7 ± 19.2	20.1 ± 10	172.7 ± 94.1	**72.2**
Power Grip	23.6 ± 8.9	36.6 ± 16.1	86.7 ± 35.3	49.0
Mean	16.8	19.7	**100.5**	

Table 5,
Mean values of EMG activity (mean ± sd) in in (µV) of different grips types for the case of 70% MVC for 5 subjects for FCR, FDS and APB muscles.

	FCR	FDS	APB	Mean
Fine Pinch	13.2 ± 5.3	19.4 ± 15	99.5 ± 48.3	44.1
Tripod Grip	17.4 ± 9.5	15.7 ± 7.7	120.9 ± 56.3	51.4
Grip with Thumb+Middle	29.4 ± 15	31.1 ±16.8	241.3 ± 145.4	**100.6**
Power Grip	35.3 ± 13.3	56.2 ± 21.8	113.0 ± 61.5	68.1
Mean	23.8	30.6	**143.7**	

Figure 7 show the mean of the absolute value of the EMG activity for the three muscles of different grips for 100% MVC. Standard deviation across five subjects is illustrated with error bars.

The grip with the thumb and middle fingers has the highest activity for APB muscle, while the power grip has the highest activity in both the FCR and FDS muscles.

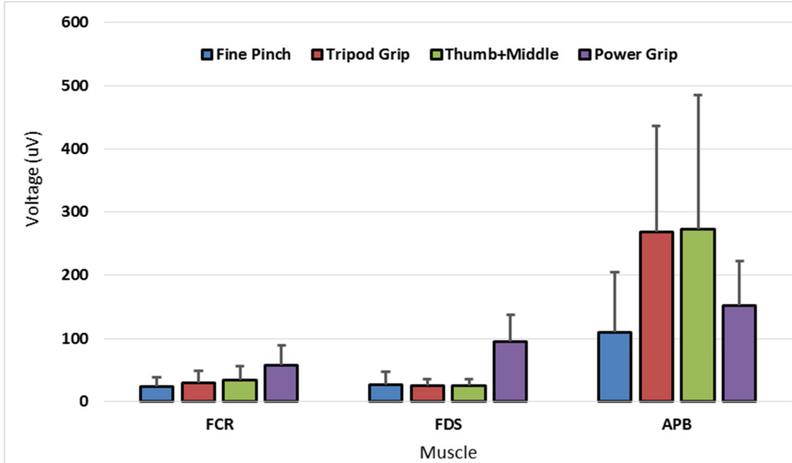

Fig. 7: Mean of the absolute value of EMG for 3 muscles for different grip types (fine, tripod, grip with thumb and middle fingers and power grip) for 100% MVC. Error bars represent standard deviation across the 5 subjects.

Figure 8 shows the mean value of the recorded force with hand dynamometer in Newton (N) for all subjects for different grip patterns with 10, 30, 50, 70, and 100% MVC. The mean is calculated across all trials, grip types and subjects. The measured force of contraction increases as the % MVC increases for all grip patterns as seen in Figure 4. This clearly shows the high accuracy of the recording protocol to measure the correct level of the %MVC for all subjects.

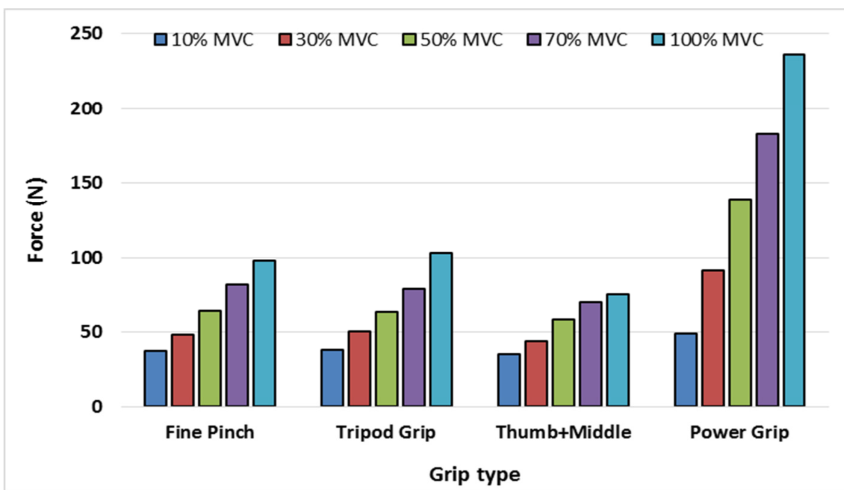

Fig. 8. Mean of the force measurements in newton (N) for 5 subjects with different grips for different levels of %MVC (i.e. 10, 30, 50, 70 and 100% MVC).

In the final part of the experimental results we analyzed the data statistically using n-way ANOVA. The resulting ANOVA table revealed that, across each of the considered factors or simply the main effects, the mean values of the EMG signals are significantly different across the different %MVC levels (p-value $\leq$ 0.001), the different muscles (p-value $\leq$ 0.001) and across the different hand grips (p-value $\leq$ 0.001). However, testing the two-factor interactions revealed no evidence of statistically significant interaction between the different %MVC levels and the different hand grips (p-value = 0.594) as the generated force increased with changing the %MVC, but the generated patterns of force levels across the different grips are consistent as shown in Figure 4. On the other hand, significant interactions are observed between the %MVC levels and the different muscles (p-value $\leq$ 0.001) and between the different hand grips and the different muscles (p-value $\leq$ 0.001). This is in turn justified as the mean values of the EMG signals changed more significantly with the different %MVC levels and the different muscles involved than that with the different hand grips.

The results of the current study may be compared to the study of Martin et al. [2], where the researchers had been studied the quantification of six functional movements and acceleration which was measured in real time. The grip and pinch movements were terminal pinch, termino-lateral pinch, tripod pinch, power grip, extension grip and ball grip while the EMG signals recorded from six muscles. They obtained that the spherical grip had greater electrical activity and the muscle with the highest record was the thenar region. In our study, we have investigated different muscles under different levels of % MVC and obtained that APB muscle has the highest mean EMG activity across all grips, followed by FCR muscle. Furthermore, the grip with the thumb and middle fingers is the grip with the highest EMG activity for 10-70% MVC, then the power grip. As for the 100% MVC, thumb and middle fingers' grip achieved the highest EMG activity for APB muscle, while the power grip has the highest EMG activity for both FCR and FDS muscles.

The major limitation of our study is the small sample size of the participants. As a future goal, more participants will be recruited to increase the reliability of the study. In addition to that, we are planning to record EMG signal from different muscles with different hand gestures to find out the relation between EMG signal and muscle force with different % MVC.

4. Conclusion

In this paper, we investigated, with the use of hand dynamometer, the quantification of EMG activity for different types of grips for three muscles: FCR, FDS, and APB under different %MVC levels (i.e. 10, 30, 50, 70 and 100 %MVC).

Analysis of the mean absolute value of the EMG activity for all trials, muscles, grip types, and subjects showed that for (10 - 70) % MVC, APB has the highest mean EMG activity across all grips, followed by the FCR muscle. In addition, grip with the thumb and middle fingers is the grip which has the highest EMG activity for (10-70) % MVC, followed by the power grip. As for the 100% MVC, the grip with the thumb and middle fingers has the highest activity for APB muscle, while the power grip has the highest EMG activity for both the FCR and FDS muscles.

ABP muscle, an intrinsic muscle in the hand, may be used for rehabilitation applications, while FCR can be a good candidate to target the forearm muscles. As for the grip selection, grip with the thumb and middle fingers is the grip with the highest EMG activity then the power grip comes in the second place.

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تحليل انماط مختلفة لقبضة اليد و الاصابع عن طريق تسجيل اشارات العضلات و جهاز مقياس قبضة اليد

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الخلاصة

يعتبر تسجيل اشارة العضلات الكهربائية (EMG) من الطرق الاساسية لتشخيص حالة العضلة و الخلايا العصبية الحركية. استخدمت اشارة العضلات الكهربائية (EMG) كمصدر للسيطرة على الاطراف الصناعية لمساعدة الاشخاص لإنجاز انشطة الحياة اليومية. ومع ذلك دراسة انماط مختلفة من قبضات اليد و ايجاد العلاقة مع نشاط اشارة العضلات الكهربائية تعتبر واحدة من اهم التحديات. تم اجراء الدراسة على ثلاثة اشخاص حيث قاموا بإجراء اربع حركات مختلفة (fine pinch, tripod grip and grip with the middle and thumb finger, as well as the power grip). تم استخدام جهاز مقياس قبضة اليد لتسجيل فعالية العضلات من ثلاثة عضلات وهي (Flexor carpi radialis (FCR), Flexor digitorum superficialis (FDS) and Abductor pollicis brevis (ABP)) بمستويات قوى مختلفة ١٠-١٠٠% MVC . من اجل تحليل جميع البيانات المسجلة تم حساب متوسط القيمة المطلقة لكل محاولة بعدها تم حساب المعدل للمحاولات الثلاثة لكل قبضة و لكل شخص لمستويات قوة مختلفة. ومن ثم تم حساب المعدل و الانحراف المعياري لكل الاشخاص المشاركين لكل عضلة بمستويات قوة مختلفة (١٠، ٣٠، ٥٠، ٧٠ % MVC) لكل حركة. وقد اظهرت النتائج ان عضلة (APB) لها اعلى معدل فعالية عضلية لكل القبضات و تليها عضلة (FCR). بالإضافة الى ذلك بينت النتائج بان حركة الابهام مع الاصبع الوسطي تملك اعلى فعالية عضلية للقوة من (١٠%-٧٠ % MVC) و تليها حركة (power grip). اما بالنسبة للقوة ١٠٠% MVC حركة الابهام و الاصبع الاوسط سجلت اعلى فعالية عضلية بالنسبة لعضلة (APB) بينما سجلت حركة (power grip) اعلى فعالية عضلية لعضلات (FCR and FDS).