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Mechanomyogram for Identifying Muscle Activity and Fatigue

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Abstract - **Mechanomyogram is the recording of the acoustic activity associated with the muscle contraction. While discovered nearly a decade ago with the intention of providing an alternate to the surface electromyogram, it has not yet been investigated thoroughly and there are no current applications associated with MMG. This paper reports an experimental study of MMG against force of contraction and muscle fatigue during cyclic contraction. The results indicate that there is a relationship between the intensity of the MMG recording and force of contraction. A change in the intensity of MMG is also observed with the onset of muscle fatigue. However, the inter-subject variation is very large. The results also indicate that the spectrum of the MMG is very inconsistent and not a useful feature of the signal.**

I. INTRODUCTION

Surface electromyogram (EMG) is an indicator of muscle activity. It is non-invasive and easy to record and identifies the strength of muscle contraction. Applications of sEMG include sport training, identifying posture imbalance, aiding muscle relaxation, and human machine interface. While it is extremely useful, there are some shortcomings in the use of sEMG. It is a noisy signal and suffers poor reliability when the muscle activity is low. Its effective range is highly limited. And, while inexpensive, sEMG requires specialized equipment.

The mechanomyogram (MMG) is the recording of mechanical oscillation associated with the muscle contraction. It is detectable on the skin surface overlying the muscle. It is produced by the lateral dimensional changes in active muscle fibres that generate pressure waves. It can be measured using an accelerometer or a microphone placed on the skin over the belly of the muscle. This is an indicator of the mechanical activity of muscle fibres and in the recent past has been considered as an alternate to sEMG for measuring muscle activity. It appears to have some benefits over sEMG particularly that it does not require electrodes to be mounted on people [1, 7]. However, its properties and applications have yet not been well explored. While there are number of well-defined protocols for recording sEMG, there is very little information available for MMG [7, 9].

One of the pioneers in the development of MMG is Orizio [11]. He has compared MMG recordings with EMG and force measurements taken from the tibialis anterior (TA) muscle during electrically induced fatigue at maintained 50% MVC contraction and have reported that MMG is an indicator of the changes in the mechanical properties of muscle at fatigue. The work studied the MMG magnitude and muscle contraction, and determined that the changes in MMG were attributable to the difference in muscle fiber fusion during sustained contraction that leads to fatigue. They determined that the relationship of MMG and EMG with force of contraction varied for different muscles. It was also found that there was a high correlation between the MMG and the second derivative of the force [11].

Moritani et al [1] studied the MMG of the gastrocnemius muscle, and found that the amplitude of MMG are not only dependent on muscles mean force, it increases with the increase of muscle force and decreased with onset of fatigue following muscle force and the close relationship during the recovery phase. They also determined that there was a change in the relationship under different rate of contractions.

Other important works in the development of MMG analysis include Silva et al [9] and Ceson et al [7] who have reported on the methods and equipment required to record MMG signal. Tarata [8] reported the study of changes in the EMG and MMG due to the onset of muscular fatigue. Their work compared the differences showing that MMG signal can be used for indication of the degree of muscle activation and for monitoring the muscle fatigue when the application of surface EMG was not feasible.

However, despite the above mentioned and other works, MMG is yet not routinely studied and there appear to be no application where MMG is used. It appears to be in the early stages and there is need for identifying the relationship between MMG and the conditions of the muscles.

There is no well-defined model that explains the generation of MMG. There is also lack of understanding of the reliability and robustness of the recordings. While some researchers have studied the relationship of MMG with force of contraction and muscle fatigue, there is very limited information available in this area.

The impact of the properties of the muscle such as the size and location has not been well documented. The range of MMG for various levels of muscle contraction and the suitable features do not appear to have been studied yet. Most importantly, there is lack of understanding of the suitable features of MMG and suitable recording devices that are most suitable for any application. There is need to develop MMG from its current infancy to a modality that could have real world applications.

This paper reports the experimental study of using MMG in identifying the level of force of muscle contraction and muscle fatigue during isometric and cyclic contractions. The level of force has been identified as a percentage of the maximum voluntary contraction (MVC). The paper has studied two features of MMG; magnitude as measured using

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root mean square (RMS), and frequency measured using median frequency (MF). The paper also reports preliminary experiments where different types of microphones were used.

II. METHODOLOGY

Experiments were conducted to evaluate the performance of the proposed MMG experiments on both non-fatigue and fatigue conditions. The proposed method aims to study the impact of muscle fatigue on raw MMG signal and RMS of MMG signal, which indicates the MMG amplitude. In these experiments, muscle forces were tested with a force measuring device to see the level of recorded muscle force before and after fatigue.

A. Subjects

Experiments were conducted on five subjects, ages ranging from 21 to 32 years (four males and one female). None of the participants had any known history of myo or neuro-pathology, and no evident abnormal motion restriction.

B. Equipment for the Experiments

No clear directions of the choice of the microphones were available form literature. Hence preliminary experiments were conducted with a range of microphones including electronic stethoscope to determine the most suitable microphone. The results were most stable with Shure condenser microphones of diameter 10 mm.

The MMG was recorded using electret condenser microphone (Shure Cardioid Condenser Lavalier Microphone MX183) sampled at 44100 samples/sec. Each channel had a preamplifier with voltage gain of three, and a MOTU sound signal processing equipment with 32 bit A/D converter. The data was recorded and segmented using *Adobe audio* software.

The microphone was placed on the belly of the biceps brachii muscle as shown in Fig. 1. The microphone was firmly taped using medical plaster tape to the arm, and tested to observe any movement artifacts.

C. Experimental Protocol

During the experiments, subjects were asked to sit on a chair in a relaxed position with their forearms in supine position with their palms facing up. As the first step, the maximum voluntary contraction (MVC) of the subject was measured by making the subject attempt to lift a fixed horizontal lever with the force sensor attached to the middle of the forearm. This was repeated five times to obtain a good estimate of the MVC.

The next step was the subject performed isometric contractions where they attempted to lift the fixed horizontal lever at different MVCs for two minutes, or till the time they got fatigued. The MVCs were labeled as follows:

- MVC – I : approximately 100%
- MVC – II : approximately 100%
- Partial MVC – I : approximately 60% – 80%
- Partial MVC – II : approximately 60% – 80%

The subjects were asked to repeat the experiments twice. They were given five minutes rest time between each experiment. MMG was recorded for each MVCs and the files were saved with file names indicating the subject number, the activity and percentage of MVC. A sample of the MMG recording is shown in Figure 2.

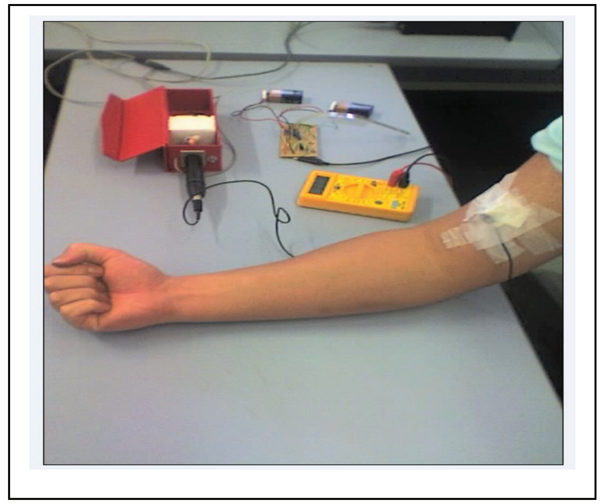

Fig.1 Experiment setup for recording MMG

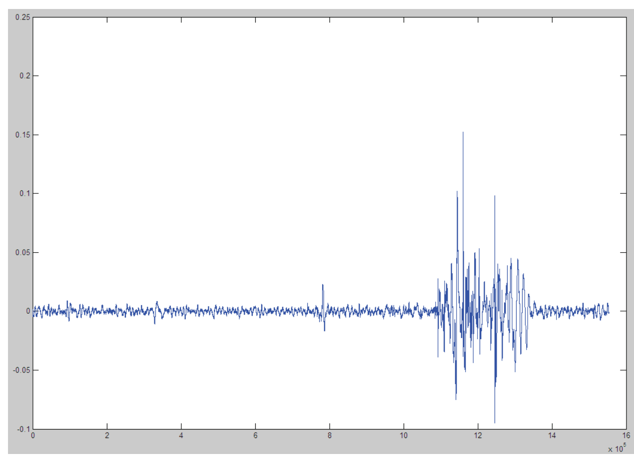

Fig.2 A sample MMG recorded from the designed system

D. Data Analysis

The recorded data was visually scanned to identify any artifacts such as movement artifacts. The spectrum of some of the recordings were observed and it was observed that there was no observable spectrum above 500 Hz. Based on this, the recordings were then passed through a low pass filter with a cutoff of 1000 Hz, and down-sampled to 2000 samples/ second.

The signal was then segmented into one second segments. The first and the last segment of each recording were discarded to minimize the artifacts arising due to the start and end of the recording. Of the remaining, the first and last segments were analyzed. For 100% and 50% MVC cases, the first segment represented the muscle prior to the onset of

TABLE I: RMS of MMG during initial and final segments at different levels of contraction

Subjects	MVC - I		MVC -II		Partial MVC -I		Partial MVC -II		Relax	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
1	8.2E-04	5.33E-04	2.28E-04	1.35E-04	1.71E-04	1.24E-04	1.49E-04	1.06E-04	4.12E-05	3.68E-05
2	4.5E-04	6.39E-04	8.88E-04	4.29E-04	1.36E-04	1.61E-04	9.62E-05	8.82E-05	NA	NA
3	1.9E-04	1.26E-04	6.38E-05	5.83E-05	6.11E-05	7.92E-05	3.18E-05	2.50E-05	1.74E-05	1.44E-05
4	6.7E-04	3.37E-04	9.33E-05	9.90E-05	1.29E-04	1.45E-04	7.39E-05	8.89E-05	2.43E-05	2.13E-05
5	2.1E-04	1.91E-04	9.28E-05	8.24E-05	1.06E-04	6.13E-05	4.10E-05	4.16E-05	NA	NA
Mean	**4.71E-04**	**3.65E-04**	**2.73E-04**	**1.61E-04**	**1.20E-04**	**1.14E-04**	**7.84E-05**	**7.00E-05**	**1.66E-05**	**1.45E-05**
SD	**2.82E-04**	**2.19E-04**	**3.49E-04**	**1.53E-04**	**4.07E-05**	**4.27E-05**	**4.71E-05**	**3.48E-05**	**1.74E-05**	**1.55E-05**

TABLE II: Median Frequency of MMG during initial and final segments at different levels of contraction

Subjects	MVC - I		MVC -II		Partial MVC -I		Partial MVC -II		Relax	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
1	23.50	20.50	19.47	18.18	17.46	20.20	19.84	21.72	29.30	23.13
2	18.49	21.36	20.02	20.62	17.21	16.29	17.52	16.72	NA	NA
3	22.64	19.77	18.74	16.47	19.35	17.15	16.30	17.63	15.01	13.85
4	27.77	23.92	19.59	24.35	24.05	21.91	20.08	21.60	17.46	17.82
5	17.33	16.72	15.44	13.79	17.58	14.89	17.09	16.78	NA	NA
Mean	**21.95**	**20.46**	**18.65**	**18.69**	**19.13**	**18.09**	**18.16**	**18.90**	**20.59**	**18.27**
SD	**4.183**	**2.61**	**1.853**	**4.02**	**2.877**	**2.88**	**1.697**	**2.55**	**7.64**	**4.65**

TABLE III: Ratio of initial to final segments for different levels of contraction

Subjects	MVC - I		MVC -II		Partial MVC -I		Partial MVC -II		Relax	
	RMS	**MF**	**RMS**	**MF**	**RMS**	**MF**	**RMS**	**MF**	**RMS**	**MF**
1	0.645	0.873	0.592	0.934	0.723	1.157	0.715	1.095	0.893	0.790
2	1.394	1.155	0.483	1.030	1.187	0.947	0.917	0.955	1.000	1.000
3	0.658	0.873	0.914	0.879	1.296	0.886	0.786	1.082	0.827	0.923
4	0.499	0.862	1.061	1.243	1.129	0.911	1.202	1.076	0.876	1.021
5	0.932	0.965	0.888	0.893	0.581	0.847	1.015	0.982	1.000	1.000
Mean	**0.826**	**0.844**	**0.874**	**1.025**	**0.928**	**1.015**	**0.878**	**0.947**	**0.919**	**0.947**

fatigue while the last segment represented the fatigued situation. Root mean square (RMS) and median frequency (MF) was computed for these segments and the results were tabulated. Descriptive statistical analysis was conducted on the tabulated data to determine the statistical significance of the results. All the analysis was done with MATLAB R2008b.

III. Results And Observations

The results of the isometric contraction have been tabulated in Tables I, II and III. Table I shows the results of the RMS values for the first and last segment of each of the recordings for different levels of muscle contraction. Table II shows the values of the median frequency for the same conditions. For Subject 2 and Subject 5, the signal strength was very low during relaxed conditions, the median frequency was not considered for the analysis. Table III shows the ratio of fatigue to non-fatigue of MMG for all subjects using RMS and Median frequency.

From Table I, the mean value for RMS for 100% MVC at the start was 3.72E-04 while after fatigue it reduced to 2.76 E-04.The mean of RMS for partial MVC condition was lower, and was 0.992 E-04 which only reduced slightly to 0.92 E-04. During the relax state, this was much lower at 1.74 E-05 which did not change much during the 2 minutes and was finally at 1.45 E-05.

These results indicate that there is an increase in the value of RMS with increase in the force of contraction. Based on the 100% MVC condition, it is evident that there is significant change in the RMS with the onset of fatigue. This is not observed during the partial MVC condition, indicating that perhaps the subjects were not fatigued at the end of the two minutes, or the mechanism was different. From the relaxed condition, it is observed that there is very little change in the MMG level for the duration of the experiment when the muscle is relaxed, indicating the reliability of the results. This is also observed from Fig.3 where the results have been displayed, as is observed from the ratio of the start and end conditions in Table III.

However, the standard deviation from Table I is large compared when considering ratios (Table III). This indicates that even though there is a very large inter-subject variation, there is a consistent change in the RMS of MMG with strength of contraction and onset of fatigue. From Table II however, the median frequency varies inconsistently and there is no pattern in the same.

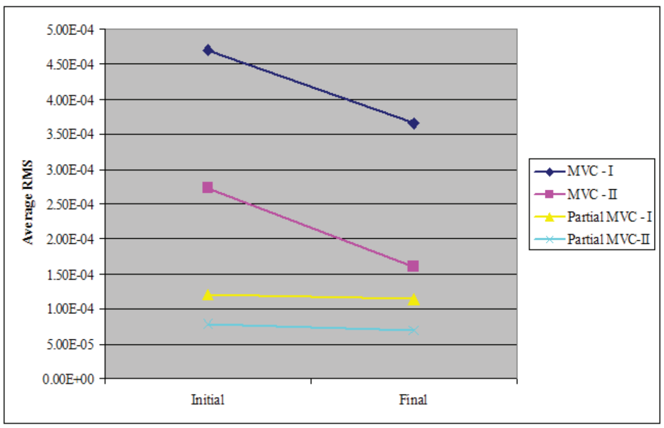

Fig.3 Average RMS of MMG during Initial and Final period of the MVC

IV. Discussion and Conclusion

The results indicate that there is a very large inter-subject variation in the intensity of MMG recorded from the muscles during cyclic muscle contraction. While there was a consistent increase in the value of intensity of MMG measured based on the RMS of the recording, there are large inter-subject and inter-experimental variations. The normalized results (taking the ratio) were more consistent.

The results also indicate that the median frequency (MF) of the MMG was not a measure of the strength of contraction or muscle fatigue and varied erratically. This suggests that MF is not a useful feature of MMG.

The results from the fatigue experiment indicate that there is a consistent decrease in the value of MMG with muscle fatigue. While there are large inter-subject variations in the absolute values, the ratio between the intensity of the fatigued and non-fatigued shows a consistency.

While this is a study with a small sample size, it does not indicate that MMG could be used to replace EMG in the current format. The authors believe that the future work required for MMG is the need to develop and establish an experimental protocol and suitable equipment. The authors would like to suggest a detailed study should be conducted that would improve the understanding of the size and location of microphone, and determine the impact of gel applied to the surface of the microphone prior to determining the efficacy of MMG to identify muscle activity. There is also need for studying the different muscles, and the impact of cross talk if any on the quality of the recordings. Further, the authors believe that suitable filtering techniques may also have to be developed to improve the quality of the recording by eliminating noise.

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