Electromyography - A Reliable Technique for Muscle Activity Assessment

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***Abstract*— In recent years, many questions have been raised on the credibility of Electromyography (EMG) as a technique to evaluate muscle activity, particularly by sports and fitness community. This questioning goes farther when it comes to surface electromyography (sEMG). This paper covers an overview of EMG, addresses some basic concepts and provide rudiment for research. Muscle activity assessment through EMG has been reviewed in terms of the type of movements. There are few limitations to EMG but these confines are addressable. The problem rather lies in the interpretation and generalization of that data. Limitations are there in every technology, precautionary measures must be taken to avoid those while using it. Reservations about EMG have been summarized along with their responses. A few techniques to analyze EMG data, and possibilities to extrapolate and interpret, are also provided. Current perspectives and practical applications of EMG and sEMG are also part of this article.**

***Index Terms*— Electromyography, Muscle Activity, Activity Assessment**

I. INTRODUCTION

Electromyography is utilized for the measurement of electrical activity of muscles during contractions in them. It is as old as the very first experiment was done in the 16th century. Marey, together with Lee de Forest, coined the term "electromyography" and recorded the first bioelectric activity of a muscle in 1890 [1]. Electrical signals from CNS are not strong enough to be measured directly by EMG, these signals trigger some peripheral factors in muscle and cause the activation of their electrical activity. These peripheral factors (firing rate, number of motor units etc.) are measured with EMG. In terms of amplitude, the magnitude of EMG signal is governed by a number of motor units recruited for a particular muscle movement (contractions). It is, actually used to evaluate the functional state of motor units [1]. To measure the tension of muscle, EMG data must be scaled/modified accordingly. Increase in EMG activity indicates that CNS is attempting to produce more muscular force [2]. In case of fatigue, this extra activity is indicative of force losses due to fatigue and hence CNS attempts to generate more electrical signals for the compensation of muscular force at peripheral level [3].

Motor units are formed by muscle fibers. The recruitment rate and activation of these fibers (motor units) govern the pattern that EMG characteristic shows [4]. The concept of the motor unit was first described by Liddell in 1925 and was considered as a functional unit of the neuro-muscular system, that was held responsible for the production of tension and hence movement in muscles. EMG measures activity of these motor units and the data is then interpreted for results or generalization. Assessment of a single motor unit is done by needle based EMG (invasive EMG). Invasive EMG has its own pros and cons, e.g. it is normally done in static condition while there are isometric contractions [5]. Non-invasive (surface Electromyography (sEMG)), on the other hand, is a qualitative assessment of muscles, when they have dynamic movements. sEMG is also termed as kinesiological electromyography due to its inherent benefit of observation during free (dynamic) movements of the human body [6].

This article provides an insight into EMG technique and highlights the areas that are not researched yet. Reliable published work was followed for the preparation of this document. Special care has been taken regarding the doubts about EMG and work from reliable researchers is presented to counter that issue. While compiling limitations and applications section, we specifically took care about the most recent and up-to-date information. The subject matter has been presented in a simplified manner so that new researchers can get benefit from it and find a starting point for their research.

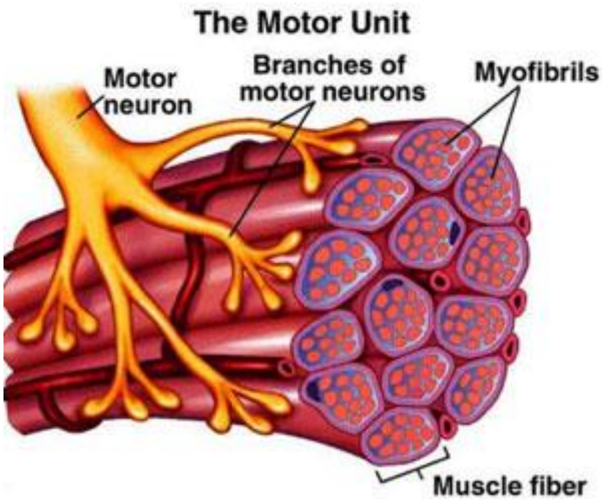

Figure 1: Motor unit attached to muscle fiber (Google images)

Similar kind of work has been presented previously by many researchers like [7, 8]. The difference between the previous work and current one is that the older work mostly reviews the standards and recommendations. They considered the electrode placement, CNS control strategy, motor unit recruitment strategy and such. This very work considered the latest advancements in the field and summarized the unanswered questions, with few misconceptions in this area that new researchers might have, and is the novelty of the research.

II. Muscle Activity Assessment

As observed in the literature, EMG can be used for almost all muscle activities such as isometric, dynamic, isokinetic, sustained contractions and such. It can also be used to observe delicate movements such as minimally invasive surgery as well as astringent movements like swimming. The use of EMG for the study of muscle coordination is still a matter of discussion in the research community. Although, EMG can be used to assess muscle activity, any method never guarantees how much the muscle is activated to its maximum activation capacity. This draw back can be overthrown by using normalization techniques, as discussed in next section.

III. Recording And Analysis Of EMG Data

The data taken from sEMG cannot be analyzed directly. The data is first rectified and mean has been taken called average rectified value (AVR). Sometimes, this is also termed as mean amplitude value and is used in literature. To observe frequency response of EMG signals, mean or median or mean median frequency is used.

Care must be taken while putting electrodes on muscles. Static charge on hairs or even small amount of dust on the skin can change the EMG signals abruptly. Hairs must be removed, skin must be cleaned with alcohol to slight redness (abraded) and electrodes must be placed along the direction of muscle fibers [9]. There should be one reference electrode placed on the electrically neutral area. During dynamic experiment performance, electrodes should be tied with some belt or tape so that their location might remain constant throughout the experiment. Due to non-invasive nature of and ease of use, sEMG can be used by doctors as well as physiotherapists. Its applications range from rehabilitation, muscle assessment, sports and athletics, exercise, training, ergonomics [10-12] and so on.

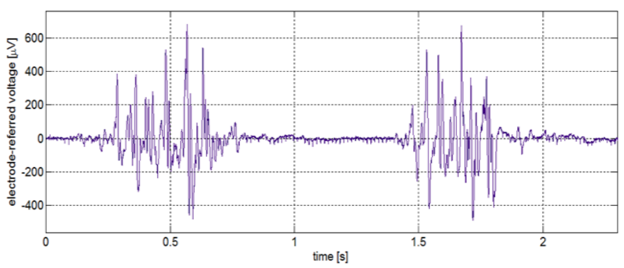

Figure 2: Typical raw EMG data

EMG provides output data in micro and milli volts. A researcher can plot the EMG data in graphical form, as time vs amplitude fashion, or frequency vs amplitude. Amplitude is normally expressed as RMS value, and is in µvolts whereas time is usually taken in milli-seconds or simply seconds. It shows the force, strength and contractions a muscle is producing. It can be seen as normalized data, in a %MVC form which enlightens that muscle is working at what % of strength it can maximum produce voluntarily. But the data can also be normalized using other references like body weight. MVC can be varied from time to time and due to this reason, researchers try to complete the experiment in one session for a particular subject.

Multiple electrodes can be used to improve the validity of sEMG data. New technology can have hundreds of mini-electrodes placed at equal distance from each other on muscle and can collect data (detection of muscle activity) very accurately. It has been shown in [13] that this technology improves sEMG by nearly 10%. Also, invalid or extra data (often termed as noise or spikes) are very common in EMG signals. These undesirable data suites can be alleviated using filtration, rectification and plotting data as RMS value in the time domain.

Recurrence quantification analysis (RQA), Principal Component Analysis (PCA) which is an advance form of coordination matrix, instantaneous mean power frequency (IMPF) calculated from wavelet transform, fast Fourier transform to name a few techniques incorporated to analyze EMG and sEMG signals offline. RMS and mean or median frequency is used by many researchers to deduce results from raw EMG signals.

IV. Applications

EMG has lots of applications in practical life, most of them are related to muscle activation. Determination of position that provokes the highest activation, muscle activation condition during restriction in blood flow, muscle activation assessment in athletes (from power lifters to marathon racers) to name a few. It can be used in rehabilitation with biofeedback training [14], prosthetic control, for the production of maximum force by muscle, provoking muscles externally for contractions and many more.

It can be utilized to identify neuromuscular diseases, dysfunctions or other abnormalities in muscles. It can be used to distinguish between subjects in normal form and in pain. For proper use of exercise machines, EMG can be used as a tool to find MVIC and hence proper posture. For the control of prosthetic hands, sEMG has been in use since long [15]. Researchers in [16] observed swallowing task using sEMG and claim that sEMG functions are reliable enough to observe such a complex task and the deductions could be used for swallowing disorder treatments.

Motion sensors, together with sEMG could be used to observe sign language with sign language primitive (SLP) for sign recognition [17]. There is a recent study [18] observing muscle activation patterns and kinematic variables using surface electromyography in elite and world-class breast-stroke swimmers. This shows the tendency of sEMG to be used in a dynamic environment and under water.

In sports, attention focus is a major attribute of playing. Although seems psychological phenomenon, sEMG could be used to determine this as seen in [19]. Coordination between different body parts (muscles) was also observed in the same study. HD-EMG is the new area in focus these days, which have applications in motion intension and level of effort [20], muscle activation [21] and much more. Conventional sEMG is not suitable for deep and compact muscles for brachii [22] and HD-EMG provides a solution to that. It has been observed in the literature that eating habits of athletes have an effect on their performance and even this phenomenon can also be observed using sEMG or EMG [23, 24].

V. DISCUSSION

EMG has been used widely for many applications. As the use is augmented, it is expected that technology should provide straight forward results that can be understood by everyone. This is not always the case. Specialized and trained persons are always required to check, verify and deduce conclusions from the data obtained from technology.

It is a common argument that one cannot distinguish between high muscle activation and fatigue while looking at electromyogram (output of EMG in graphical form). Yes, the argument is very true, no one can guess just from looking at a small portion of electromyogram whether fatigued EMG is there or it is a normal highly activated muscle's activity. An electromyogram cannot be read in parts. One can only tell about fatigue if the protocol is known, and previous (continuous) electromyogram is under observation [11, 25].

A major objection claimed about EMG is that passive movements from external sources of limbs do not produce any significant signals that can be detected by EMG. If EMG is there for the detection of kinesiological activity, it should detect movements of limbs, irrespective of the source of that activity. It is a critical argument raised by many but far away from reality. EMG measures electrical activity that causes contractions in muscles, not the movement itself. Hence this argument is inherently invalid. Also, few renowned experts (Arthur Jones in his lectures on EMG) claimed in their unpublished work that they were able to see EMG signals in cadaver, but never explained the protocol, methodology or any experimental details. Motion intension can be detected using EMG [20] when the subject is completely or partially paralyzed but this is the detection of electromyographic signals that tend to produce contractions in muscles but muscles could not generate enough force due to damage or such. These signals could then be fed to some external mechanism for movement assistance and are termed as a prosthetic control. [20] states that EMG signals have a major advantage over all other technologies in this matter because EMG signals precede the actual movements hence valuable response time can be saved.

As the electrodes of sEMG are applied on the surface of the skin, questions are raised on the validity of its data. It is claimed that it can be used for the study of superficial muscles only, but for deep muscles invasive EMG is obligatory. It is further argued that sEMG can tell, at most about deep muscles, whether they are activated or not but no information can be taken about the magnitude of activity of these muscles from sEMG. No doubt, there are some minor deep muscles like rotator cuff, in which activity of sEMG and invasive EMG is not perfectly correlated [26, 27] but in some other deep muscles like abdominal wall muscles and quadratus lumborum, the two are correlated well [28]. Even large skeletal muscles like gluteus medius and hamstrings have a positive correlation between data captured from invasive EMG and sEMG [29, 30]. Also, there is another argument about invasive EMG is that it might cause stiffness in muscles that could affect the output. It has been shown by [31] that invasive electrodes for invasive EMG, when placed in the index finger of subject did not show any deflection in force output. In favor of sEMG, [32] showed that sEMG is a better predictor of fatiguing contractions then its invasive counterpart for the assessment of muscle activity.

Maximum voluntary isometric contraction (MVIC) can be determined from sEMG and EMG graphs [33]. Sometimes, MVIC is not the maximum value. The researcher cannot know exactly whether the muscle is activated maximally or not. For that, normalized or %MVIC is used. The raw EMG data is divided by MVIC and recorded as %MVIC. Remember, it is maximal *voluntary* contraction, not absolute maximal contraction. However, when data is normalized according to it, the observations are acceptable. Also, EMG data sometimes do not pass the test-retest exam. It refers to the ability of technology to reproduce the very same results for the same experiment taken over different times. For EMG, conditions are very important. Subject's ability to perform, fatigue in the subject [34], room temperature to name a few are conditions that should remain same throughout the experiment. Placement of electrodes is very crucial in case of sEMG [35-37] which impedes it from the test-retest exam.

Some new tools or techniques like MMG have benefits over EMG in terms of signal to noise ratio (SNR) [38], less complex analysis and signal processing [39], skin preparations (pre-experimental precautions) [40], electrode placements [41] and such. Although, new techniques seem to have benefits over EMG but they are still in infant stages. A lot is yet to be explored before making final conclusions, e.g. interference in MMG signals due to involuntary tremor in limbs is yet to be explored in detail [42].

EMG is reliable in most of the cases but it must be tested and experimented before concluding something. [43] showed that sEMG is not reliable for measurement of the activation level of serratus anterior during isometric abduction and flexion, dynamic abduction and flexion and bench press, but can be used for other movements in the same muscle. Further, for hypertrophy training, the range of motion of muscle is very important [44]. As EMG measures only activation level, this activation level could be maximized by just isometrically producing maximum force [45]. Now EMG is showing maximum force but it has no or very little impact on hypertrophy training. It is yet to be researched area.

Muscle force or tension is correlated with muscle activation during isometric contractions [46], but this correlation is disturbed when it comes to fatigue or dynamic contractions [47]. Hence EMG signals cannot be generalized and must be seen with activation pattern. Also, [48] observed that force produced by elbow flexor muscles is decreased significantly but EMG activity remains almost same thus showing a limitation in EMG result deduction.

MVC produced by some muscles is inconsistent most of the time. It depends upon joint-angle, which varies from individual to individual. Also, placement of electrodes is very important. If some experiment is performed in different sessions, the position of electrodes must remain same [40]. A slight change in location of electrodes may yield very different data. While dynamic movements, the orientation of muscle can be changed, hence EMG data might change due to change in position of electrodes on muscle (although position remains same above skin but, inside muscle changed its position) hence electrodes are measuring from some other location.

External conditions like temperature or change in physiology can deflect the readings. Cross-talk, as well as external noises may severely alter the recordings. Sweating can cause conductivity of electrodes malfunction [42]. Placement of reference electrode is extremely important. It should be placed on an electrically neutral area like some bone [40]. In case of sEMG, this electrode is placed over the skin, which can cause small deflections in data readings.

VI. CONCLUSION

As with all technologies, EMG has limitations, pros and cons but still it is one of the most effective techniques to determine physiology and activity of muscles. Some scientists and researchers find EMG data a bit perplexing. The problem is not with EMG data but its interpretation. Generalization of data, its extrapolation is certainly difficult and is not standardized, as one thinks it should be, but the technique is definitely credible. What one wants to extract out of it is questionable, and the technique used to get information out of raw data is of importance. Usually, it is expected that EMG gives data that is as straight forward as temperature measurement from the thermometer, but it is not the case. Data should be extrapolated, saved for further processing and results can be deduced from that. Deduction of results from raw data is technique dependent. Hundreds of researchers are using multiple methods for this purpose. New techniques are introduced for newer areas, problems and applications. This article comprehends EMG technique; usual questions rose by people on EMG credibility and answer them technically. Assessment of muscle fatigue and dynamic contraction of muscles can be judged via EMG but research is still open in this area.

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