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Fatigue Assessment in the Brachii Muscles During Dynamic Contractions

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Abstract

Fatigue in brachii muscles is an important aspect of human physiology and can be observed via various tools including surface electromyography (sEMG) and mechanomyography (MMG). Fatigue could occur due to static, intermittent or dynamic contractions. A lot has been done in static and intermittent scenario, and is well developed area. Assessment of muscle fatigue during dynamic contractions using sEMG and MMG is still under question. It is an undeveloped area and much work is needed in it. sEMG and MMG are two most important tools that have been used by researchers for the assessment of muscle activity, particularly fatigue. The objective of this study is to analyse the literature for fatigue analysis in upper brachii muscles during dynamic contractions using EMG and MMG. The literature shows that these two techniques provide reasonable approximation to muscle fatigue but a lot is still uncovered. During dynamic contractions, signal contamination is a big problem in both techniques and proper precautionary measures are needed to be taken before data processing.

Keywords: muscle fatigue, dynamic contractions, EMG, MMG

INTRODUCTION

Type of contractions in which force produced by muscles that in turn causes the joint angles to change, are termed as dynamic contractions. In these kinds of contractions, there is a visible movement for the load. Both isotonic and isokinetic type of movements come under the broader category of dynamic contractions. Examples of such contractions are elbow flexion and extension during push-ups, movements of arms during tennis etc. Assessment of fatigue during dynamic contractions has been a challenge for researchers for decades. Due to inherent effect of dislocation and changes in muscle position, it is difficult to observe different muscle activities during dynamic contractions. These contractions are not only responsible for most of the daily activity movements, but also majorly contribute in sports, exercises, trainings etc. In contrast, static contractions are easy to handle and have limited applications in day to day activities but are easy to observe using technologies like surface electromyography (sEMG), mechanomyography (MMG) and such. Static (sustained / isometric) contractions are type of contractions in which joint angle does not change with the production of force. Examples of such contractions are planks, pushing against a wall, forceful hand grip (for forearm and upper muscles) etc.

Fatigue can be defined in many ways. There is no clear-cut definition of localised or peripheral muscle fatigue and different definitions overlap due to difficulty in isolation of different mechanisms of fatigue [1]. It is task dependent phenomenon and is highly dependent on the type of activity inducing it [2]. Previously, researchers focused on decline in the force producing ability of a muscle or group of muscles to produce any more force due to sustained activity and consider it as fatigue. Hence, fatigue can also be defined as anticipated contractile response or a response that is less than expected for a given task / stimulation. Although the subject may maintain the activity but inability of producing enough force after onset of fatigue gives fatigue its definition [3]. Physiologically, fatigue may be defined as exhaustion of the energy resources of muscles that tend to produce contractions in muscles [4]. The amount of energy derived by muscle to produce force is increased due to increase in the wastage of energy, and lesser energy is available for force production. In terms of motor units, it is decrease in the number of active motor units [1]. During the onset of fatigue, the motor units fire more rapidly and / or the motor units fire at regular intervals in a synchronized manner, causes the electrical activity of muscles to increase and hence sEMG amplitude is increased [5]. The synchronization of motor unit firing rates causes sEMG mean or / and median frequency to decrease and this phenomenon provides the information about onset of muscle fatigue. In terms of MMG, this synchronization causes the vibrations of muscles more frequent and hence increase in MMG amplitude.

There are several types of muscles in our body. Skeletal muscles are ones that can be controlled voluntarily. Localised (peripheral) muscle fatigue is normally caused in these muscles. Skeletal muscles could consist of fast twitch or slow twitch muscle fibres, which is the speed of contractile twitch. As explained in [1], a motor unit (MU) is composed of a single motor neuron that is fired from spinal cord and innervates at muscle. When the MU is fired, an electrical impulse, also termed as action potential, is carried to the muscle over the nerve. This electrical activity of motor unit is termed as motor unit action potential, and this particular phenomenon can be observed by electromyography (EMG). For fatigue, this motor unit action potential recruitment rate is increased. Fatigue limits the physical performance of a muscle. This could be due to inability of MU to reach the muscle (central fatigue) or less number of available twitching fibres (peripheral fatigue). In [6], it has been claimed that fatigue is a natural way to protect the human body, or in particular muscles, from injury due to continued effort or exercise.

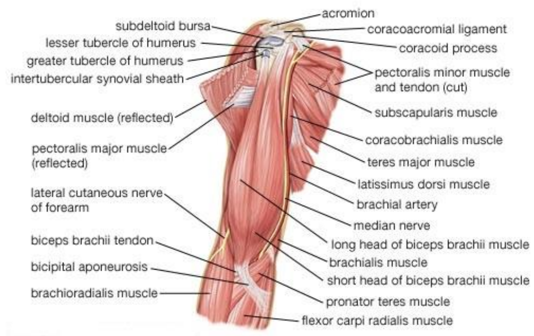

Figure 1: Brachii muscles (source: Encyclopaedia Britannica)

Brachial muscles are responsible for tasks done by arms, such as elbow flexion, extension, supination, pronation, handgrip etc. These muscles play key role in many sports activities, rehabilitation, exercise as well as day to day tasks such as writing, griping something, picking up load and many more. Fig. 1 shows typical brachii muscles. Some of these muscles are composed of fast twitch fibres (e.g. triceps brachii (TB)) and some slow twitch fibres (e.g. biceps brachii (BB)). During swimming, brachii muscles are responsible for almost 85% propulsions as this is horizontal movement and lower limbs contribute very less in such movements [7; 8]. Muscles, such as pectoralis major, triceps brachii and anterior deltoid are reported consistently as the primary muscles that are involved in the push phase on level surfaces like wheelchair propulsion, swimming, skiing etc.

Observation of peripheral muscle fatigue in brachii is a hot topic and many researchers are working in this area. Observation of peripheral fatigue during isometric contractions is common and easy to deduce results but results are rather difficult to observe with dynamic contractions. sEMG and MMG are major techniques used for such observations but both have limitations for dynamic contractions. To the best of our knowledge, there is no study that is particularly summarising the studies involving fatigue in brachii muscles during dynamic movements. There is a critical review on central and peripheral fatigue during resistance training [9]. This study missed other activities that may involve dynamic contractions such as sports, rehabilitation etc. Another study [10] discussed the limitations of EMG signals for the observation of muscle coordination via cross talk, spatial variability of activity of muscles. These researchers look into the matter particularly from EMG point of view. [11] discussed the MU recruitment patterns for dynamic movements and hence focused more on MU working patterns, rather fatigue. Studies involving neuromuscular function after induced muscle damage have been summarized in [12] but lack many dynamic movements. This particular review takes on many studies that involves dynamic movements in sports, exercise, rehabilitation and other activities and is novelty of this work.

TOOLS TO MEASURE DYNAMIC CONTRACTIONS

There are many tools / techniques used for the measurement of muscle activity but EMG and MMG are most prominent of all. As mentioned in the previous section, EMG measures the electrical activity of muscles and is well explained and well developed method for the observation of muscle activity. MMG, on the other hand, observes the mechanical vibrations of muscles and hence can be used to analyse muscle activity. MMG is beneficial over EMG in terms of higher signal to noise ratio, lesser pre-experimental preparations and independence of sensor location on muscle. EMG, on the other hand, in beneficial technology in terms of lesser signal contamination due to neighbouring muscles, invasive EMG can observe single MU activity etc. Both techniques have been used to observe fatigue during dynamic contraction in brachii muscles.

SENSORS / ELECTRODES FOR OBSERVATION

As observed in literature, EMG signals for most of the experiments were observed using Ag-AgCl electrodes, placed longitudinally on the belly of muscle in line with muscle fibre in bipolar fashion. This is generic position for the electrode placement as recommended by SENIAM [13]. This placement not only gives maximum EMG signals but also reduces the crosstalk from nearby muscles, thus provide with stable and reliable EMG signals. Another important parameter defined by [14] is inter-electrode distance. After careful experimentation and using different combinations, the authors of [14] suggested that 20 mm is the most optimized inter-electrode (between the same pair of electrode) distance for trapezius muscle to avoid crosstalk and other noise factors.

MMG signals can be observed by different sensors such as accelerometers, piezoelectric, microphone and condenser sensors. As seen in literature, piezoelectric sensors are majorly used for dynamic contractions in brachii muscles [15; 16]. Goniometer is also used for fatigue observation in brachii muscles during dynamic contractions as seen in [17]. It is not yet standardized and there is no obvious reason for the use of a particular sensor for dynamic contractions. Usage of different MMG sensors for particular applications has been summarized in [18]. Placement of MMG sensor over the muscle is not yet standardised and signals can be captured independent of location (in contrast to EMG) with only effect of amplitude of observed signal.

The major setback of sEMG sensors while observing dynamic contractions is that they do not provide any information regarding range of motion (ROM) of observed muscle. It is expected from EMG to provide sufficient information about muscle activity and ROM but there is no such relation available. Similar issue is observed in goniometer, which has limitations of measuring angle when ROM is less than 1.0^{o} [19].

EMG AND MMG PARAMETERS

Parameters that are considered for the observation of fatigue during dynamic contractions using EMG and MMG utilize both time and frequency domain. Frequency domain parameters include median / mean frequency, mean median frequency, whereas time domain parameter includes RMS amplitude, signal period, and signal power. Usually, frequency parameters are shifted to lower values with the onset of fatigue [20; 21] and increase in amplitude is observed of time-domain parameters [8; 22]. Similar parameters are used for MMG to observe fatigue during dynamic contractions [16; 23].

OBSERVATIONS

Table 1. is summarizing the studies including fatigue analysis in brachii muscles with dynamic contractions. The trend of frequency and RMS amplitude is almost same throughout the literature with few exceptions. This is the same trend as observed in static or isometric contractions. These studies are discussed in the next section.

DISCUSSION

Research has been there with both EMG and MMG for the determination of fatigue during dynamic contractions. As mentioned by [10], it is yet to be researched topic that whether muscle coordination during dynamic contractions can be measured precisely or not by the use to sEMG and MMG. Conventional features i.e. mean power frequency, mean frequency, median frequency, power spectral frequency, RMS amplitude, average rectified value and such are good enough for fatigue observation during isometric or static contractions. For dynamic contractions, these features do provide efficient results but due to signal contamination, it is difficult to deduce results. As observed by [24], crosstalk is an issue with EMG signals during dynamic contractions that can be handled with extra precautionary measures and using proper filtration techniques. Crosstalk is also a big problem in MMG, as depicted by [25]. This crosstalk is prominent in small and closer muscles such as forearm muscles, and hence need to be addressed while deducing results.

Placement of electrodes on skin is very important in case of EMG. The signals are changed to great extent if position is slightly varied even on the same muscle. [26] in his research showed that when EMG electrodes are placed on separate locations of biceps brachii, the output signals are different for the same set of movements. As there is inherent movement in dynamic contractions, hence placement of electrodes cannot be guaranteed for a fixed location. Also, [14] researched and recommend a 20 mm interelectrode distance for the observation of EMG signals over trapezius muscle. The researcher claimed and is well known that interelectrode distance is very important for EMG signals. This interelectrode distance remained constant during isometric or static contractions but could vary in dynamic contractions. This variation produces a random error in captured signals and must be removed prior to signal processing.

Table 1.

Article	Tool	Parameter	Trend	Activity Type	Movement Type
[21]	EMG	Median Frequency	Decreasing	♦	a
[8]	EMG	PSF, ARV	Decreasing, Increasing	♦	a
[27]	EMG	Mean median Frequency	Decreasing	♦	a
[7]	EMG	Mean frequency, ARV	Not clear	♦	a
[28]	EMG	Frequency, amplitude	No change	♦	b
[22]	EMG	Amplitude	Increasing	♣	b
[29]	EMG	Amplitude, Frequency	Increasing, Constant for patients	♣	b
[30]	EMG	HD-EMG intensity	Increasing	♣	c,b
[31]	EMG	Frequency	Small decrement	♠	dl
[32]	EMG	Intensity	Increasing	♠	dl
[20]	EMG	Instantaneous MPF	Decreasing	◘,◙	c,b
[33]	EMG	Amplitude	Increasing	◘,◙	c,b
[16]	MMG	Mean, median frequency	Decreasing	♠	a
[15]	MMG	MPF	Increasing (decrease fatigue)	◘,◙	f
[34]	MMG	Davies-Bouldin index (DBI)	Can separate fatigue and non-fatigue	♠	f
[35]	MMG	MPF	Constant	♠	c
[23]	MMG	MPF, MDF	Decreasing	♠	f

[a]isokinetic movements; [d]concentric movements;[c]eccentric movements; [dl]delicate movements; [f]dynamic contractions;

♦sports; ♣rehabilitation; ♠exercise/training; ◘elbow flexion; ◙elbow extension

One of the important application of dynamic contractions is there in hypertrophy. It normally depends upon the ROM, muscle coordination and muscle activation. While EMG and MMG provide information about muscle activation only, no relationship has yet been observed between ROM, muscle coordination and muscle activation. Hence, it is not possible to deduce any information related to ROM and muscle coordination using EMG and MMG data. As mentioned previously, it is yet to research field and is limitation to EMG [36]. At the same time, sports activities such as swimming [8; 21], tennis [37], cricket [38; 39] etc has been observed by many researchers using EMG. The results have been accepted by the research community, even though there are lot of unanswered things. Not many researchers observed crosstalk for dynamic fatiguing contractions in both MMG and EMG. Signal contamination due to change in interelectrode distance, change in the position of electrode on muscle, effect of external noise and such. As mentioned in [1], hot bodies around the electrodes contaminate the EMG signals. These hot bodies could be in surrounding or even the human body itself. Effect of chemical actions within body, which can cause the impedance of conduction to vary, is another cause of signal noise. The motor unit firing rate should be surpassed as it is also in the same frequency range as those of EMG signals i.e. 0 – 20 Hz [40]. Combining all these noise source may contaminate the signals to a level where they are no more acceptable. These contaminations could be rectified by taking care during recording session, and use of appropriate filers in post processing of signals. HD-EMG is solution to many questions of EMG noise issues but many of its features are yet to be explained. MMG have benefit over EMG as it is independent of most of these noises. But signal contamination due to neighbouring muscles (cross-talk) is a big issue and research is still open in this area. Further, there is a positive correlation between muscle torque and MMG RMS amplitude [41], and this observation could be extended for fatigue assessment in dynamic environment.

A study [42] introduces EMG spectral indices for the study of fatigue during dynamic contractions. These indices were found reliable irrespective of variability of EMG signals as they have greater sensitivity then those of traditionally used features. Traditional features such as mean or median frequency have some limitations. As can be seen in the table above, study [29] shows that the EMG frequency for patients remain constant while that of normal subjects decreased (shows the occurrence of fatigue). This unchanged frequency might lead researcher to conclude that the patient is not yet fatigued but it is not the case. This lack in frequency change could be due to loss of communication between central nervous system and the muscle. Hence, such parameters are not reliable in every scenario. Care must be taken while deducing conclusions as the dynamic contractions are very different from isometric ones, and same hypothesis cannot be made for both.

CONCLUSION

Assessment of peripheral fatigue during dynamic contractions using EMG and MMG has been done by many researchers but some aspects were compromised during these observations. Harsh dynamic activity, such as swimming do employ EMG for the assessment of muscle activities but still there are many limitations. MMG has not yet been tested for sports activities neither for hypertrophy or muscular trainings. Its results are welcoming for dynamic activities and have some inherent benefits over EMG but much of activities are yet to be tested. EMG, on the other hand, is well researched field and have major footprint in the field. Many researchers are working on devising new spatial, spectral parameters so that dynamic contractions can be observed by EMG in more simpler manner. Although it is normally believed that EMG and MMG are not proper tools for observations during dynamic contractions but literature shows the opposite trend.

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