Choice of Mechanomyography Sensors for Diverse Types of Muscle Activities

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***Abstract*—Skeletal muscles contribute to the movement produced in the human body. They are therefore of vital importance for the study of muscles in various applications of movement including exercise, sports, prosthesis, rehabilitation, etc. The movement produced by skeletal muscles can be analyzed through various techniques like mechanomyography (MMG) and electromyography (EMG). MMG is a novel technique to assess skeletal muscle function through the oscillations produced during muscle contractions. MMG advocates well for its reliability, performance, and ease in application to other presently used techniques. MMG employs several types of sensors to observe vibrations in skeletal muscles. These sensors vary widely from application to type of movement and muscle. This review provides a comprehensive chunk of information on MMG sensor selection according to its placement, muscle function and condition, and limb movement and application. Recommendations for the choice of MMG sensor are given through extensive literature search over here.**

***Index Terms*—Activity; Sensors; Mechanomyography; Muscle Skeletal Muscles.**

I. INTRODUCTION

Muscles constitutes the largest part in human body and are significantly important due to their function as well. Skeletal muscles contribute majorly in body and limb movements whether voluntary or stimulated. So, they always face risk of damage, injury, accidents, loss of control etc. [1]. There are various tools to measure muscle performance and assess their working to cope with the challenges of muscles being at risk. These techniques are electromyography, sonomyography, vibrometery and mechanomyography. Mechanomyography is further subdivided into diverse types like acceleromyography, phonomyography and vibromyography [2] according to the type of sensors. Mechanomyography is a novel tool in this field of muscle study but it could be considered a good option in comparison to electromyography because of its easy handling in equipment, cost-effectiveness in set up, reduced number of steps in procedure, reliability in acquired signal and good relatability of the technique to muscle physiology. Mechanomyogram is a mechanical portray of the whole muscle mechanics. Being a novel technique, MMG needs to be explored well in terms of its equipment, sensors, application areas and muscle movements involved which are better studied with this technique. The purpose of this review is to highlight a few of the darker zones in this field and open some questions untouched till now for upcoming mechanomyographers. In this review, the choice of sensors in terms of sensor application and appropriateness for muscle functions is discussed. Through detailed literature search, it was possible to divide the types of sensors used in past into five distinct categories namely accelerometers, displacement sensors, microphones, piezoelectric sensors and composite sensors. Although there were many challenges for choice of sensor like motion artifact, size of signal and sensor reliability for sensor. The challenge of mitigation from motion artifact has been fulfilled using microphones as MMG sensor [3]. Similarly, the use of lightweight accelerometers also came in use to reduce the disturbance in signal due to sensor mass [4].

II. BENEFITS OF MMG SENSORS

Mechanomyography sensors employ numerous benefits over other techniques like electromyography (EMG). They offer higher signal to noise ratio, smaller sensitivity in sensor placement, lightweight equipment and easy handling of set up with the reliability of data [5]. There is also no need of skin preparations as MMG deals with mechanical vibration produced only. Hence, skin impedance is also not an issue of concern.

III. MMG SENSOR PLACEMENT

Mechanomyography being a technique which measures mechanical oscillations of skeletal muscles are more pronounced to be placed over muscle belly because this area gets maximum of the vibrations [6, 7]. There are many examples from literature which assures this location issue for MMG. So, MMG parameters and proper description of sensor location with anatomical landmarks should be declared clearly. MMG amplitude and frequency are most widely used parameters for signal analysis and study of mechanomyogram.

Table 1
Summary of Sensors Used for Several Types of Muscle Assessments

No.	Studies Found	Subject Details	Sensor Employed	Sensor Application for Muscle Activity
1.	Tarata[8]	18 in total including 9 men and 9 women	Accelerometers	To measure muscle fatigue
2.	Beck et al.[9]	12 in total including 6 men and 6 women	Piezoelectric crystal contact sensor	To observe the change in torque production due to isokinetic muscle action

No.	Studies Found	Subject Details	Sensor Employed	Sensor Application for Muscle Activity
3.	Gregori et al.[10]	Number of subjects not mentioned	Piezoelectric MMG membrane	To make an observation on muscle vibrations and contractions
4.	Evetovich et al.[11]	18 in total including 10 men and 8 women	Piezoelectric crystal contact sensor	To see torque production in muscle for static stretching
5.	Beck et al.[12]	8 in total including 6 men and 2 women	Piezoelectric crystal contact sensor	To measure eccentric torque production
6.	Beck et al.[13]	10 in total including 5 men and 5 women	Piezoelectric crystal contact sensor and accelerometer	To observe torque response for isokinetic and isometric muscle actions
7.	Madeleine et al.[14]	14 men in total	Microphone and accelerometer	To observe the trend in fatigue progress for muscle under sustained contractions
8.	Pisot et al.[15]	10 men in total	Displacement sensor	To measure muscle stiffness
9.	Yang et al.[16]	5 in total including 4 men and 1 woman	Microphone	To measure fatigue
10.	Šimunič et al.[17]	15 men in total	Digital displacement sensor	To study muscle deformations
11.	Lei et al.[18]	7 men in total	2 axis Accelerometer	To estimate torque using MMG
12.	Cè et al.[19]	15 men in total	Single axis accelerometer	To study neuromuscular activity through MMG under cooling of muscle and fatigue
13.	Cè et al.[20]	15 men in total	Single axis accelerometer	To study muscle relaxation under fatigue
14.	Tosovic et al.[21]	10 in total including 5 men and 5 women	Laser displacement sensor	To study muscle fatigue
15.	Hill et al.[22]	18 in total	Accelerometer	To study the effect of gender on torque and MMG response
16.	Than et al.[23]	19 in total	Displacement sensor	To study muscle contractile properties through MMG

Table 1 elaborates 16 different records for sensor types in MMG with chronological order. Details for subjects recruited, the name of sensor employed and application of sensor for muscle assessment are given against each entry of Table 1. Tarata[8] used the accelerometer to measure muscle fatigue. Accelerometers were also used by Lei et al.[18] to estimate torque produced by muscle. Cè et al.[19] used this sensor to study neuromuscular activity and muscle relaxation under fatigue. Then, Hill et al.[22] used this sensor to study the effect of gender on torque and MMG response.

Piezoelectric crystal contact sensor has been used by Beck et al.[9,12,13] in three different studies as listed in Table 1. Piezoelectric crystal contact sensor was used mainly in these studies to observe the change in torque production for muscle under isokinetic and isometric contractions. Torque production was also observed by Evetovich et al.[11] using the same sensor. While Gregori et al.[10] made an observation on muscle vibrations using piezoelectric MMG membrane.

The microphone has been employed as MMG sensor for fatigue assessment by Madeleine et al.[14] and Yang et al.[16].

Displacement sensor was used by Pisot et al.[15] to measure muscle stiffness and by Šimunič et al.[17] to study muscle deformation. Laser displacement sensor was employed to study muscle fatigue by Tosovic et al.[21]. Displacement sensor was also used to study muscle contractile properties via MMG by Than et al.[23] as per Table 1.

IV. Types Of MMG Sensors Employed

The muscle contraction can be measured in different forms of the physical quantities like acceleration, sound, displacement and vibration[24,25]. Hence the shape of the signal acquired may also vary[1] and according to the application area, there are the following types of MMG sensors already been discussed in the literature [26]. The major concern in a choice of sensor is the ratio between the mass of sensor and that of muscle under observation. The mass of sensor should be in the safer limit to avoid deformation on the skin. Hence lightweight sensors are preferred. This is also suitable in terms of ergonomic safety.

A. Accelerometers

Muscle contraction measured in terms of acceleration is accomplished by the accelerometer and the signal yielded is known as acceleromyogram[24]. The evidence of using single axis[19,20], dual axis[8,18] and tri-axis accelerometers[27] are found in literature, where each axis corresponds to signal directed in one direction. A tri-axis accelerometer measures muscle displacement while contractions in three dimensions including longitudinal, lateral and transverse to muscle fiber[28]. Accelerometers are most widely used for MMG sensors due to their easy setup, lightweight design and reliability in signal acquisition. The maximum transducer weight recommended for the accelerometer is 5g [29]. Accelerometers have been used to detect muscle fatigue through various parameters like muscle torque [22].

B. Displacements Sensors

When the muscle contractions need to be assessed through their displacement, then displacement sensors are employed in MMG signal acquisition. Laser displacement sensor has been used to assess muscle fatigue[21]. For investigation on contractile properties of muscle, displacement sensors are also used[17,23,25].

C. Condenser Microphones

Condenser microphone gives less signal to noise ratio in MMG signal as compared to the accelerometer for dynamic contractions [3]. Dynamic contractions in muscle pronounce muscle functional activities better[30].

D. Piezoelectric Contact Sensors

During limb movement and dynamic muscle contractions, piezoelectric contact sensors are also more suitable as they are less affected by motion artifact [31, 32]. They are also employed for upper limb torque assessment in many studies like [9, 11-13]. But these sensors are unable to get a steady voltage when the force applied is constant[33]. Therefore, these sensors depict MMG dynamics at the low level of muscle displacement.

E. Composite Sensors

Although there are only two records [10, 34] in literature for composite sensors but the new area for more MMG sensors to be developed have been opened. Composite sensors could be used for fatigue assessment. Sensors for muscle strength and stiffness assessment could also be developed in the same fashion.

V. ASSESSMENT OF MUSCLES THROUGH SENSORS

Muscle activity and muscle force produced is greatly influenced by many of the anthropometric parameters like muscle size, gender, age, body fat and length of limb producing movement[35]. Muscle activity also depends on the joint angle between parts of limb involved in movement[36]. Hence depending on the nature of muscle assessment under consideration, the choice of sensors in mechanomyography is significant. If the muscle assessment is for dynamic contractions and there are some angular movement produced visibly in the limb, then torque is produced and need to be measured through some torque meter. The MMG sensor for this experimental protocol is piezoelectric contact sensor usually.

Contractile properties of muscle can be assessed through MMG to have a deeper insight into the muscle physiology and are better measured by displacement sensors.

Accelerometers give an improved signal to noise ratio in comparison to other sensors [3]. This could serve as a core benefit of application of this sensor for muscle vibration assessment during dynamic contraction.

The most commonly used MMG sensor is an accelerometer for its reliability in a signal acquired, light weight physical structure and simplicity in application. But a reason for the absence of documentation on accelerometer application advancement is not known [1]. Accelerometers are being employed for various muscle studies including fatigue assessment[14,20,27], muscle strength[37], muscle properties[16,38]. All the three types of accelerometers based on a number of axis for measurement like single axis, double axis and triple axis sensors are used for MMG signal measurement, but transversal wave propagation and vibration measurement in muscle is most prominent and hence of greater interest [4].

VI. CONCLUSION

Mechanomyography is a useful tool to measure mechanical counterpart of muscle contractions. Besides, there are various records in literature, MMG is facing its stage of childhood. So, this review article reveals some of the key issues and limitations for MMG sensor selection according to the type of contraction and muscle activities to be analyzed. This article also leaves some open ends for future researchers especially in the employment of a sensor in MMG signal acquisition. It basically directs the research in MMG towards a good collection of arguments on the matter of sensor selection or rejection. A few of the major conclusions made through this review are listed as: (i) lightweight accelerometers are very good solution to the mass issue of transducers, (ii) Piezoelectric crystal sensors are more precise at low rates of muscle displacement (iii) Hence accelerometers and laser displacement sensors are considered most reliable tools in MMG signal detection during both voluntary and stimulated muscle contraction.

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