INFLUENCE OF GENDER ON MUSCLE ACTIVITY PATTERNS DURING NORMAL AND FAST WALKING

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ABSTRACT

Electromyography (EMG) signals are often described as electrical manifestation of neuromuscular activation associated with the muscles. These signals are commonly utilized as principal input signals to control several prosthetic devices such as prosthetic hands, arm, lower limbs, and exoskeleton robots as well as in designing of rehabilitation and assistive devices. It is well proven that EMG signals vary among subjects and gender is one of the major factors that play a significant role in this variation. This study detects the possible gender differences by measuring changes in the EMG activity during different phases of human walking by acquiring the surface EMG signals from Gluteus Maximus, Hamstrings (biceps femoris), Quadriceps (rectus femoris) and Soleus muscles of the leg with the healthy subjects walking barefoot at two paces-normal and fast. The statistical analysis of the results showed no gender differences at normal speed of walking but when speed of walking changed; it showed clear differences in the behavior of these muscles. The results from this study would aid in designing closed loop control strategy for designing a smart functional electrical stimulator (FES) which is the larger goal of this research.

KEYWORDS

Electromyography, Walking, gender

1. INTRODUCTION

Analysis of human walking is a significant area of research in which measurements of muscle activity using EMG signals have often been used. As per the established literature, EMG signal has proved to be a significant tool in the analysis of gait related disorders [1,2]. It is commonly employed as principal input information to the controller for utilization in wide range of medical applications ranging from powered assistive devices, bio-amplifiers to exoskeletons and rehabilitation devices such as functional electrical stimulator (FES) [11,12,18].

The EMG signals normally show tendency to vary among individuals. It is a proven fact that no two individuals have same gait pattern and EMG variations may be observed for performing the similar task within the same individual, making it unreliable at times [1,2]. Nevertheless it is still utilized by different research group(s) worldwide working in the above mentioned areas for providing innumerable healthcare benefits. When designing closed loop strategy for FES devices, characteristics of EMG must be carefully considered for providing proper input information to the controller. Gender has been found to play a significant role and is one of the important factors that affect EMG activity in different motor tasks [7, 10]. Murray et al. found that the amplitude of normalized EMG activity decreased as walking speed decreased in normal women subjects [17]. M.C. Chiu etc. all. Found that increased walking speed caused significant increase in the muscle activities of lumbar erector spinae, biceps femoris, and medial gastrocnemius, lumbar motion, as well as the vertical ground reaction force in the loading response and mid-stance phases of the human gait cycle [5]. E.S. Chumanov et. al. findings indicated that females display greater non-sagittal motion [6]. Nardo et. al. reported propensity of females for a more complex recruitment of the muscles such as gluteus and tibialis during gait [10].

Based on these studies, the main objective of this paper was to evaluate possible gender related differences in the EMG activity of four significant lower limb muscles Gluteus Maximus, Soleus, Quadriceps (rectus femoris) and Hamstring (biceps femoris) for both the legs. Gluteus Maximus, Quadriceps and Hamstring muscle group are considered to be large prime movers during walking along with soleus being utilized for plantar flexion of the ankle, from [3] we can conclude that Soleus is more active muscle compared with the gastronomies during walking. Rectus femoris is opted from the quadriceps muscle group because it is a hip flexor muscles, as it attaches to the Ilium which is a crucial indicator during walking or running. It swings the leg forward into the ensuing step during walking [15, 19]. Biceps femoris is selected from the hamstring muscle group because it is considered to be major antagonist muscle to the quadriceps during the deceleration of knee extension during walking [15, 19].

We hypothesized that significant gender related differences would be found during normal and fast walking, in this paper 80- steps/min is considered as a slow walking and 120steps/min is considered as a fast walking. The results of this analysis would provide significant information on gender-related differences thereby suggesting the researchers and clinicians with an alternative approach for males and females when designing closed loop strategy for prosthetic devices by employing EMG signals.

2. METHODOLOGY

The methodology followed for carrying out the above study is shown schematically in Figure1.

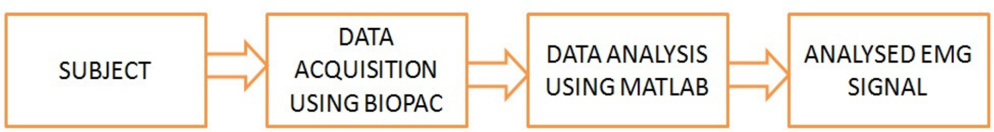

Figure – 1

A. Participants

Twenty healthy adult volunteers were recruited. 10 male, 10 Female, mean age for male 23±2 year, for Female 22±2 year, Mean height for male 164±5 in cm, for female 152±3 in cm and mean weight for male 68±6 in Kg ,for female 54±5 in kg. The Mean (± SD) age, height and weight are shown in Table I.

Category	Age in Years (Mean ± SD)	Height(cm) (Mean ±SD)	Weight (Kg) (Mean ±SD)
Female	22±2	152±3	54±5
Male	23±2	164± 5	68±6

TABLE I: CHARACTERSTICS OF FEMALEAND MALE SUBJECTS

EMG activity was recorded from the selected muscles of both the left and right lower limbs of all subjects during barefoot gait. Inclusion criteria excluded subjects having any medical conditions/ contractures/ deformities in the joint or suffering from skin condition which might impede the fixation of the electrodes on the body surface. Before participating in the study each participant was explained about the purpose and protocol to be followed for the study. The participants agreed to provide written informed consent/ patient informed consent (PIC) form as per requirement of the Ethics Committee before participating in the study.

B. Instrumentation

EMG Signals were acquired using Multi-Channel Wireless EMG BIOPAC Inc. (CMRR: 110dB at 50/60 Hz and Gain: 5-50,000, Input Impedance: 2 MΩ) available in the laboratory for the study. The skin was rubbed with cotton containing alcohol to minimize the skin impedance, thereby improving signal acquisition. Disposable Circular electrodes (44 x 32 x 1 mm) were placed on the subjects for the above muscles, with respect to longitudinal location of the sensor on the muscle and halfway the distal motor endplate zone and the distal tendon, with respect to the transversal location of the electrode [20]. The subject preparation was carried out following standard protocols [14] for placing electrodes on subject's pre-identified muscles to acquire EMG simultaneously from both the legs. In order to avoid the cross talk between corresponding muscle fibers, we placed the electrodes around the optimal sensor location directed parallel to the muscle fibers with an inter-electrode distance of 20 mm.

C. Data Acquisition

The study is carried out for each subject in a quiet laboratory room away from the main entrance having very few visitors. The subject and research team cannot interact once the experiment has started. Test duration is about one hour per subject including the time required for mounting the devices to the subject. In order to prevent contamination of the signal, the cables of the sensor are fixed to the subject's body using the straps. Sampling rate during acquisition was set to 2000Hz as per Nyquist criteria Schematic view of experimental environment is shown in Figure 2.

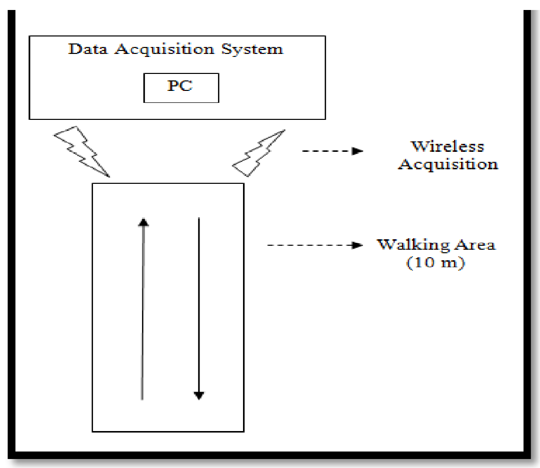

Figure 2: Schematic view of experimental environment

Maximum voluntary contraction (MVC) tests were conducted on the muscles for intra subject comparisons by applying the resistance manually to resist the subject's movement. For the Gluteus Maximus muscle, the subject was made to lie on prone position and the MVC test was performed both in extended and flexed knee position with slightly outward rotated legs and for Soleus muscle the subject was asked to sit in up-right position to perform unilateral Plantar flexion. In case of Quadriceps muscle, the subject was asked to sit in upright position to perform knee flexion position and for Hamstring muscle the subject was made to lie on prone position to perform unilateral knee Flexion. Four sets of voluntary data were acquired, with the subjects barefoot walking in the selected area at an average speed 80steps/min for normal and 120 steps/min for fast walking. It was determined to ask the subjects to walk at different speeds, as it is usually observed that individuals usually walk at either slow or fast pace daily on different occasions as per their task requirements. The collected data was stored using Acknowledge 4.3 software available with the data recording system.

D. Data Processing

For processing of EMG signal, normalization of the EMG signal acquired from each subject with its isometric MVC. Notch filter was then applied in order to remove 50 Hz noise interference from the signal. Subsequently, Wavelet transform (WF) was performed for removing baseline drift in the signal. The WF technique permits time-frequency representation of the signal thereby allowing inspection of different signal waveforms at different scales and resolution. Cascaded low-pass (20 Hz) and a high-pass filter (450 Hz) were then applied in order to remove other noise sources from the signal. The raw EMG signals acquired from the subjects were quantified with the help of MATLAB. The Signal Processing applied onto the raw EMG signals is explained and shown in Figure 3.

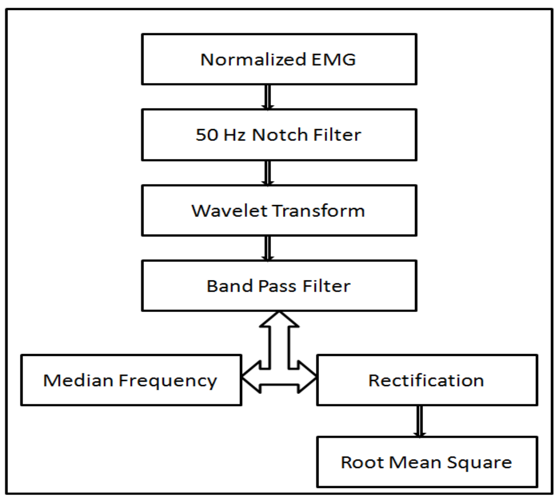

Figure 3: Signal Processing Steps

All four recorded data sets for each subject were analyzed to calculate two major parameters from the filtered EMG: Root Mean Square (RMS) and Median Frequency (MDF), Since the MDF decreases with an increase in EMG signal amplitude which is the strong indication of the muscle fatigue. The filtered EMG signals were rectified in order to calculate the RMS values. The mean values of all the walking trials (normal and fast pace) were identified and averaged to derive the mean values for these two parameters.

1) Root Mean Square (RMS)

RMS is the square root of the arithmetic mean of the squares of the set of values. Let X_t represent the rectified EMG signal then RMS value is represented by equation 1

$$\mathbf{RMS}=\sqrt{\frac{1}{T-t}\sum_{t}^{T}(\mathbf{X_t})^2} \qquad \mathbf{(1)}$$

Where, X_t is the rectified signal and T, t is the two time intervals at which signal acquisition takes place. It is most frequently used parameter for the EMG analysis because during muscle contractions, it reflects the level of physiological activity in the motor unit. It is considered to be the most meaningful EMG analysis technique, since it gives a measure of the mean power of the signal [9].

2) Median Frequency (MDF)

MDF is a frequency at which the EMG power spectrum is divided into two regions with equal amplitude [9] as shown in equation 2:

$$\sum_{j=1}^{MDF} P_j = \sum_{j=MDF}^{M} P_j = \frac{1}{2}\sum_{j=1}^{M} P_j \qquad (2)$$

Where, P_j= EMG power spectrum at the frequency j and M= length of frequency

It helps the clinician to focus on injury prevention strategies, especially during the restorative phase of rehabilitation [14].

E. Statistical Analysis

For detailed analysis, statistical validation is done by applying one way ANOVA that depicted the influence of gender is statistically significant during variations in walking speed. Least Significant differences (LSDs) among the categories defined were then conducted using Post hoc analysis in order to have multiple comparisons between the categories using SPSS software (IBM). The level of significance was set to $p< 0.05$.

3. RESULT

The data is divided into four categories namely female with normal walk (FNW), female with fast walk (FFW), male with normal walk (MNW) and male with fast walk (MFW). According to Table II, the comparison between the categories MNW and MFW and FFW and MFW were found to be statistically significant at 0.05 level. Other categories mentioned in table such as MNW with FFW or FNW with MFW were found to be invalid. All the other groups were found to be statistically insignificant at 0.05 level. The results so obtained from the comparison through statistical analysis using LSD ignoring the ANOVA table are shown in Table II.

TABLE II: LEAST SIGNIFICANT DIFFERENCES BETWEEN THE GROUPS OF RMS AND MDF VALUES

Trace titles RMS_G_R, RMS_S_R, RMS_Q_R, RMS_H_R, RMS_G_L, RMS_S_L, RMS_Q_L and RMS_H_L refer to the RMS value obtained from Gluteus,

Dependent Variable	Category I	Category J	Sig.	Dependent Variable	Category I	Category J	Sig.
RMS_G_R	FNW	FFW	0.307	MDF_G_R	FNW	FFW	0.965
		MNW	0.591			MNW	**0.001**
		MFW	0.11			MFW	**0.039**
	FFW	MNW	0.644		FFW	MNW	**0.001**
		MFW	0.532			MFW	**0.035**
	MNW	MFW	0.292		MNW	MFW	0.157
RMS_S_R	FNW	FFW	**0.004**	MDF_S_R	FNW	FFW	0.981
		MNW	0.636			MNW	**0.007**
		MFW	**0.003**			MFW	**0.019**
	FFW	MNW	**0.015**		FFW	MNW	**0.007**
		MFW	0.915			MFW	**0.02**
	MNW	MFW	**0.013**		MNW	MFW	0.699
RMS_Q_R	FNW	FFW	0.148	MDF_Q_R	FNW	FFW	0.716
		MNW	0.198			MNW	0.451
		MFW	0.203			MFW	0.318
	FFW	MNW	**0.009**		FFW	MNW	0.688
		MFW	**0.01**			MFW	0.516
	MNW	MFW	0.987		MNW	MFW	0.808
RMS_H_R	FNW	FFW	0.241	MDF_H_R	FNW	FFW	0.6
		MNW	0.732			MNW	**0.018**
		MFW	**0.008**			MFW	**0.099**
	FFW	MNW	0.421		FFW	MNW	**0.005**
		MFW	**0.106**			MFW	**0.034**
	MNW	MFW	**0.021**		MNW	MFW	0.444
RMS_G_L	FNW	FFW	0.266	MDF_G_L	FNW	FFW	0.966
		MNW	0.268			MNW	**0.021**
		MFW	**0.004**			MFW	**0.081**
	FFW	MNW	0.981		FFW	MNW	**0.023**
		MFW	**0.05**			MFW	**0.088**
	MNW	MFW	**0.059**		MNW	MFW	0.543
RMS_S_L	FNW	FFW	0.357	MDF_S_L	FNW	FFW	0.999
		MNW	0.261			MNW	**0.059**
		MFW	0.357			MFW	**0.062**
	FFW	MNW	0.815		FFW	MNW	**0.059**
		MFW	**0.006**			MFW	**0.062**
	MNW	MFW	**0.013**		MNW	MFW	0.983
RMS_Q_L	FNW	FFW	0.272	MDF_Q_L	FNW	FFW	0.924
		MNW	0.298			MNW	0.583
		MFW	0.307			MFW	0.562
	FFW	MNW	**0.039**		FFW	MNW	0.522
		MFW	**0.041**			MFW	0.502
	MNW	MFW	0.985		MNW	MFW	0.976
RMS_H_L	FNW	FFW	0.179	MDF_H_L	FNW	FFW	0.857
		MNW	0.292			MNW	**0.009**
		MFW	**0.004**			MFW	**0.013**
	FFW	MNW	0.794		FFW	MNW	**0.005**
		MFW	**0.084**			MFW	**0.009**
	MNW	MFW	**0.055**		MNW	MFW	0.861

Soleus, Quadriceps and Hamstrings respectively for right and left leg. Similarly, the trace titles MDF_G_R, MDF_S_R, MDF_Q_R, MDF_H_R, MDF_G_L, MDF_S_L, MDF_Q_L and MDF_H_L refer to the MDF values obtained from Gluteus, Soleus, Quadriceps and Hamstrings respectively for right and left leg.

Further analysis demonstrates the processed EMG data through the results of descriptive statistics for the RMS and MDF values is depicted as shown in Figure 4. and Figure 5. From the figures, it can be observed that the mean RMS value of the signal amplitude tends to increase from normal to fast walking for all the muscles of both the limbs, which can be attributed to increase in motor activity and recruitment of more fibers with increase in speed of movement. MDF value follows an inverse pattern which is opposite to the variations in time domain feature of the EMG signal. It decreases when walking speed changes from normal to fast indicating development of muscle fatigue in fibers.

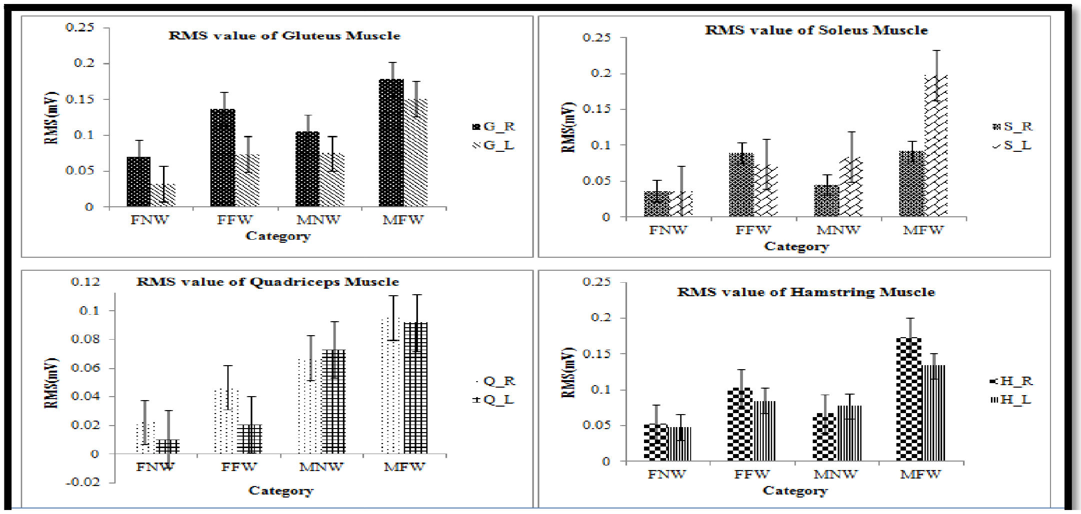

Figure 4: Comparison of RMS values on basis of gender

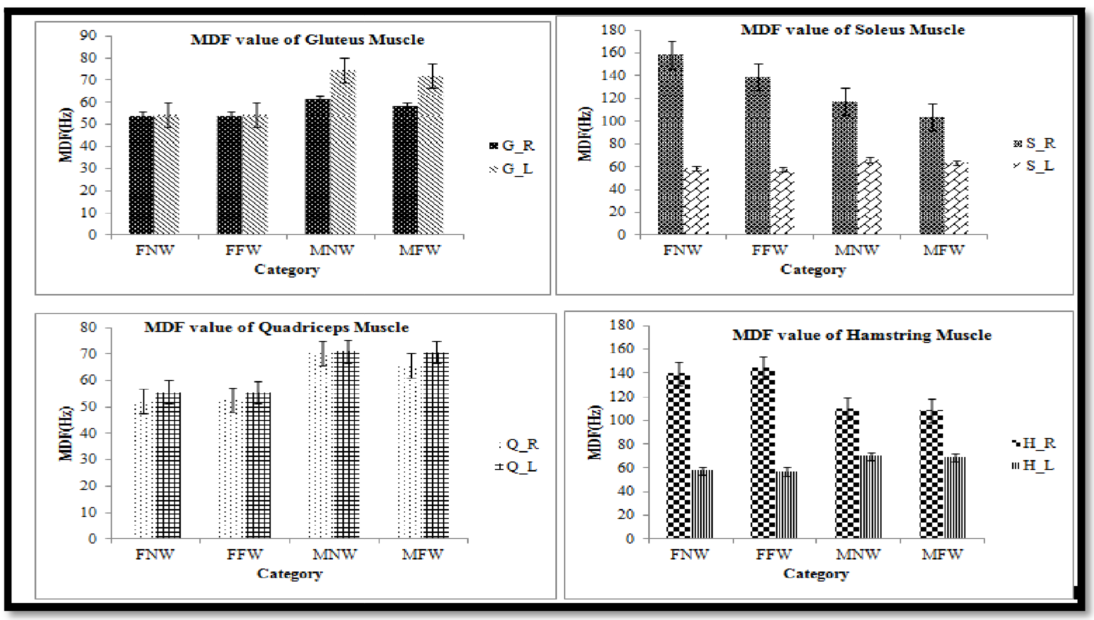

Figure 5: Comparison of MDF values on basis of gender

4. DISCUSSION OF FINDINGS

The paper evaluated the gender differences on the major lower limbs muscles namely, Gluteus Maximus, Hamstring (biceps femoris), Quadriceps (rectus femoris) and Soleus with the help of surface EMG during barefoot walking. Quantification of EMG signal was done using both time and frequency domain parameters. For time domain, RMS was chosen to assess the level of muscle activity, since it is not affected by the superposition of action potential on motor units [9]. For frequency domain, parameter opted for study was median frequency because it is sensitive to the physiological processes that occur within the muscles during sustained contractions. The statistical analysis showed no gender differences during normal walking but when speed of walking changed from normal to fast, gender differences were prominent and found to be significant for all the muscles under study. These results are partly in line with our hypothesis stated above.

It is observed through the results of descriptive statistics that RMS value of males is much higher than that of females RMS values obtained for Gluteus, Quadriceps (rectus femoris) and Hamstring (biceps femoris) muscles shows that right leg is predominant over left leg for both males and females. However, the Soleus muscle of male left leg is predominant over right leg. This may due to the fact that during walking soleus activity is greatest on left side for most male subjects under study.

MDF values also indicate the propensity of males over females to show changes in the muscle activity patterns when the speed of walking changed. For Gluteus and Quadriceps muscles, left leg is predominant over right leg for both males and females but for Soleus and Hamstrings muscles, the right leg is predominant over left leg. This may be due to reasons such as the modulation in recruitment affecting firing rate of the motor units and synchronization of the EMG signal. Moreover, the variations in the fiber diameters and due to gender differences may also be one of the causes for such changes observed [4,8,13]. For Gluteus and Quadriceps muscles, the MDF value is much higher in males than in females.

Understanding the above analysis, it is evident that in the healthy males significant changes are shown in MDF and RMS values when walking speed changes from normal to fast. No such changes were shown in females when walking speed changes. This shows the propensity of males over females for muscle activity patterns of gluteus, Soleus, rectus femoris and biceps femoris which are contrasting to the results reported by earlier researchers [6, 10].

There are limitations to the current study that can be further investigated. The lack of kinematic and kinetic data means that confounding variables may be present. The group of participants observed here consisted of young participants and these findings may not be generalized to older populations. Despite these issues, this would also help to identify the normal ranges of EMG variations for a local adult population under study for developing EMG based controls in wide range of clinical and engineering applications in near future.

5. CONCLUSION

The final are the conclusive remarks of the study:

1) Root Mean Square (RMS) increases when pace of walking changed from normal to fast
2) Median Frequency (MDF) value decreases when pace of walking changed from normal to fast.
3) Statistical analysis showed significant variation in the MDF and RMS values when walking speed changes from normal to fast in healthy males.
4) No significant changes were shown in females when walking speed changes.
5) The statistical analysis showed no significant changes in gender differences were found during normal walking but when speed of walking changed from normal to fast, gender differences were found to be significant for all the above muscles.
6) Overall propensity of males is found to be superior over females for muscle activity patterns of gluteus, Soleus, rectus femoris and biceps femoris.

This information suggests considering a separate approach for males and females when designing a closed loop controller strategy for rehabilitation devices such as FES, prosthetic limbs using electromyography (EMG) signals.

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SUBMISSION STATEMENT

We represent that this submission is original work, and is not under consideration for publication with any other journal.

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