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Influence of Gender on the Activity of Agonist-Antagonist Muscles during Maximum Knee and Ankle Contractions

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Abstract Muscle mechanical energy expenditure reflects the neuro-motor strategies employed by the nervous system to analyze human locomotion tasks and is directly related to its efficiency. The purpose of this study was to investigate the influence of gender on the activity of agonist-antagonist muscles during maximum knee and ankle contraction in males (n1=10) and females (n2=10) adult population. Different movements of knee and ankle used for the maximum contractions were knee flexion and extension, ankle plantar flexion and dorsiflexion. The agonist-antagonist muscles considered for the study were Rectus femoris (Quadriceps Muscle group), Biceps femoris (Hamstring Muscle group), Tibialis Anterior and Soleus. The statistical analysis applied was post hoc analysis to determine least significant differences among the male and female groups. The different groups for classifying these movements were Female Dominant Leg (FDL), Female Non Dominant Leg (FNDL), Male Dominant Leg (MDL) and Male Non Dominant Leg (MNDL). The results showed no significant differences ($p \geq 0.1$) in the muscle energy expenditure for different lower limb activities among gender. In addition to this, knee flexion was found to be the activity with minimum energy expenditure in healthy males and females. Active agonist-antagonist muscle pairs during knee and ankle contractions were found to have minimum mechanical energy expenditure. This study is a part of a larger intervention study that is being carried out for designing feedback based FES devices.

Keywords: *energy expenditure, maximum contraction, gender*

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1. Introduction

Most muscles in human body are capable of functioning in several different ways depending on the motion being performed, the direction of the motion and how much resistance it must overcome [11]. The role that the muscle plays varies with the change in these variables [4,11]. For any particular movement the activity of agonist and antagonist muscle is crucial. Agonist Muscles are considered to be primary mover i.e. muscle or group of muscles that causes the motion. The motion is no longer considered functional without this muscle (or group). Muscle contracts isotonically to produce a motion or isometrically to maintain a position [4]. Antagonist muscles perform the opposite motion of the prime mover i.e. it contracts eccentrically or relaxes and lengthens to prevent, slow down or control a motion [4]. Accurate measurement of activity of agonist-antagonist muscles is required for rehabilitation purposes to assess the impact of therapeutic interventions. Direct approaches that are used for measurement of muscle activity are invasive, technically demanding and mostly used in animal models. Indirect methods that are commonly used to characterize muscle metabolism during various locomotion tasks employ computational models [18]. An alternative option involves the use of Electromyography (EMG), because EMG amplitude indicates the state of activation of the contractile element; it can provide a relative measure of the muscle metabolism [14]. Blake and Wakeling (2013) demonstrated that EMG is capable of indirectly estimating the metabolism of individual muscles with high temporal resolution [6].

As per the established literature, significant gender related differences were found in various time and frequency domain parameters of EMG during isometric and isokinetic contractions of knee and ankle [8,9,16]. These changes observed in both genders are linked to the differences in fiber composition, size, intramuscular blood flow, muscle mass and related parameters [1,5,16]. Muscle mechanical energy expenditure is also an important biomechanical quantity in human locomotion movement analysis that can be taken into consideration [23]. The propensity to complete the task with the least energy expenditure is considered to be one of the most robust characteristics of the everyday performance of motor skills. Sparrow and Newell (1998) reported that the humans and other organisms tend to adopt coordination and control solution that is economical in terms of energy expenditure [21]. This is executed in a manner that muscles perform necessary mechanical work required to complete a particular movement [13]. The relationship between changes in human mechanical energy and increased efficiency was examined in a pair of articles by Aleshinsky (1986a,b) who determined that muscular mechanical energy expenditure need not be equal to the sum of the internal and external work [2,3]. Morio et. al. in 1997 found that gender has no influence on energy expended in elderly population during light seated activities, walking, cycling, and sleep [15]. Browning et. al. (2005) observed that gender has significant influence on energy expenditure [7]. There is minimal amount of literature [7,15,17] available for the investigation of gender related differences in the energy expenditure of muscles.

The purpose of this study was to analyze the influence of gender on the agonist and antagonist muscles energy expenditure during maximum knee extension and flexion and ankle plantar-flexion and dorsiflexion. Rectus femoris (RF) and Biceps femoris (BF) were chosen from the quadriceps-hamstring muscle group along with the Tibialis Anterior and Soleus muscles as they are considered to be one of the major contributors in the dynamic stability of knee and ankle joint [22]. During knee extension, RF activity is concentric while BF activity is eccentric while during knee flexion, RF activity is eccentric while BF activity is concentric [22]. During ankle plantarflexion, Tibialis activity is eccentric and Soleus activity is concentric while during ankle dorsiflexion, Tibialis activity is concentric and Soleus activity is eccentric [22]. The angle selected for knee extension was 0º-10º, for knee flexion was 110º-120º, for ankle plantar-flexion 30º-40º and for ankle dorsiflexion 10º-20º in order to emphasize fully extended, flexed knee and ankle conditions. Isometric type of muscle action was used for the MVC.

The results of this study, would help in the understanding the significance of the gender related differences in the energy expenditure of selected muscles during maximum knee and ankle contraction. Such understanding is pivotal for the clinicians and physiotherapists in designing the rehabilitation program strategies on basis of gender by introducing a new method of muscle functional assessment during rehabilitation i.e. muscle mechanical energy expenditure that would also help in the prevention of occupational musculoskeletal injuries in men and women.

2. Materials and Method

A. Participants

Twenty healthy right leg dominant male (n1=10) and female (n2=10) adult volunteers were recruited in the study. Limb dominance was determined according to which leg the individual chooses and relies on to carry out a variety of functional activities. Before starting the study, each subject was asked to perform normal walk, the leg with which they started was considered as the dominant leg. Average Mean (±SD) characteristics of subjects are shown in Table 1.

Inclusion criteria excluded subjects having any medical conditions or deformities in the knee/ankle 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. Written informed consent was obtained from each participant as per ethical requirements before participating in the study.

Table 1. Characteristics of Female and Male Subjects

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

B. Instrumentation

EMG Signals were recorded from the selected ipsilateral and contralateral muscles of both the dominant (DL) and non dominant (NDL) lower limbs of all subjects employing 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 electrodes (44 x 32 x 1 mm) were placed on the subject’s selected muscles based on Seniam: European Recommendations for Surface Electromyography [19].

The subject preparation was carried out following standard protocols [12] for placing electrodes on subject’s pre-identified muscles to acquire EMG simultaneously from both the dominant and non dominant legs.

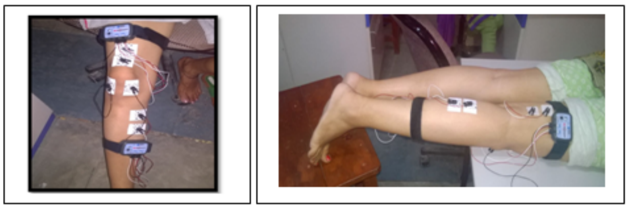

Figure 1. Electrode Placement

The transmitters were tied to the subject’s leg with the help of bands as shown in Figure 1 while the receiver of the system is connected to Laptop using Local Area Network (LAN) wire. Crosstalk was removed by keeping the inter-electrode distance 20 mm, center to center.

C. Data Acquisition

The study was carried out for each subject in a quiet laboratory room. Isometric Maximum voluntary contraction (MVC) values were acquired from the selected muscles of the subject at maximum angle pre-data acquisition. For calculating the MVC, resistance was applied manually. Two sets of voluntary data of 10 seconds each were then acquired by instructing the subject to execute the routinely performed knee and ankle joint positions i.e. knee flexion and extension and ankle plantar-flexion and dorsiflexion being examined without any applied resistance. Knee extension; ankle plantarflexion and dorsiflexion were done while the subject was sitting on a chair whereas knee flexion was done while he/she was lying prone on a table. The angle selected for knee extension was 0º-10º, for knee flexion was 110º-120º, ankle plantarflexion 30º-40º and for ankle dorsiflexion 10º-20º to emphasize maximum movement. The subjects maintained the position for 10 seconds and it was ensured through the stopwatch. Angle was measured with the help of local wooden replica of goniometer available in the laboratory separately for all the angles. Sampling rate during acquisition was set to 2000Hz as per Nyquist criteria. The collected data was stored using AcqKnowledge 4.3 software (BIOPAC Inc., USA) available with the data recording system.

D. Data Processing

The raw EMG signals acquired from the subjects were imported to MATLAB for further processing. The stepwise processing is as follows:

1) Normalization of the EMG signal acquired from each subject with its isometric MVC.

2) Rectification of the normalized signal was done in order to obtain absolute values.

3) The absolute signal was then passed through Butterworth 4th order filter of a passband frequency 20-500 Hz.

4) Envelope of EMG signal obtained in step 2 by employing 6 Hz Butterworth 4th order low pass filter.

Table 2. Least Significant Differences (LSD) applied across various activities performed by subject

Dependent Variable			Sig.	Dependent Variable			Sig.
KFT	FNDL	FDL	0.586	APT	FNDL	FDL	0.373
		MNDL	0.441			MNDL	0.949
		MDL	0.848			MDL	0.823
	FDL	MNDL	0.808		FDL	MNDL	0.352
		MDL	0.734			MDL	0.517
	MNDL	MDL	0.57		MNDL	MDL	0.78
KFS	FNDL	FDL	0.999	APS	FNDL	FDL	0.179
		MNDL	0.296			MNDL	0.189
		MDL	0.301			MDL	0.189
	FDL	MNDL	0.295		FDL	MNDL	0.997
		MDL	0.3			MDL	0.998
	MNDL	MDL	0.991		MNDL	MDL	0.999
KFQ	FNDL	FDL	0.388	APQ	FNDL	FDL	0.362
		MNDL	0.692			MNDL	0.93
		MDL	0.917			MDL	0.719
	FDL	MNDL	0.22		FDL	MNDL	0.33
		MDL	0.461			MDL	0.215
	MNDL	MDL	0.626		MNDL	MDL	0.791
KFH	FNDL	FDL	0.328	APH	FNDL	FDL	0.849
		MNDL	0.76			MNDL	0.538
		MDL	0.575			MDL	0.322
	FDL	MNDL	0.515		FDL	MNDL	0.666
		MDL	0.692			MDL	0.419
	MNDL	MDL	0.803		MNDL	MDL	0.711
KET	FNDL	FDL	0.36	ADT	FNDL	FDL	0.987
		MNDL	0.168			MNDL	0.993
		MDL	0.196			MDL	0.144
	FDL	MNDL	0.617		FDL	MNDL	0.994
		MDL	0.679			MDL	0.148
	MNDL	MDL	0.933		MNDL	MDL	0.156
KES	FNDL	FDL	0.81	ADS	FNDL	FDL	0.196
		MNDL	0.688			MNDL	0.931
		MDL	0.888			MDL	0.678
	FDL	MNDL	0.866		FDL	MNDL	0.179
		MDL	0.708			MDL	0.098*
	MNDL	MDL	0.597		MNDL	MDL	0.748
KEQ	FNDL	FDL	0.368	ADQ	FNDL	FDL	0.197
		MNDL	0.428			MNDL	0.377
		MDL	0.38			MDL	0.525
	FDL	MNDL	0.1		FDL	MNDL	0.703
		MDL	1			MDL	0.063*
	MNDL	MDL	0.109		MNDL	MDL	0.143
KEH	FNDL	FDL	0.275	ADH	FNDL	FDL	0.997
		MNDL	0.256			MNDL	0.999
		MDL	0.204			MDL	0.145
	FDL	MNDL	0.942		FDL	MNDL	0.997
		MDL	0.832			MDL	0.144
	MNDL	MDL	0.892		MNDL	MDL	0.155

* Significant at 0.05 level. KFT= Knee Flexion Tibialis, KFS=Knee Flexion Soleus, KFQ= Knee Flexion Quadriceps, KFH= Knee Flexion Hamstrings, KET= Knee Extension Tibialis, KES=Knee Extension Soleus, KEQ= Knee Extension Quadriceps, KEH= Knee Extension Hamstrings, APT= Ankle Plantarflexion Tibialis, APS=Ankle Plantarflexion Soleus, APQ= Ankle Plantarflexion Quadriceps, APH= Ankle Plantarflexion Hamstrings, ADT= Ankle Dorsiflexion Tibialis, ADS=Ankle Dorsiflexion Soleus, ADQ= Ankle Dorsiflexion Quadriceps, ADH= Ankle Dorsiflexion Hamstrings, FDL= Female Dominated Leg, FNDL= Female Non Dominated Leg, MDL= Male Dominated Leg and MNDL= Male Non Dominated Leg.

5) Across the various activities performed by subject, integral values calculated for each muscle activity with respect to time taken for task completion. The time window of integration was 10 seconds which was kept constant for all the activities.

6) For each activity mean and standard deviation of integrated EMG was calculated for each muscle which gives the value of each muscle's mechanical energy expenditure as shown in equation 1.

$$X_i(t) = \int_0^{10} x_e(t)\,dt \quad (1)$$

where, $x_i(t)$= Integrated signal and $x_e(t)$= Enveloped signal and 0-10 is the time window of integration i.e. 10 seconds.

7) An index which sum the absolute difference of muscles between male and female was then calculated for each activity. It is represented as shown in equation 2:

$$I_x = \sum_{i=1}^{n} fa_x - ma_x \quad (2)$$

Where, I_x= Index of activity x; fa_x=Female muscle during particular activity; ma_x= Male muscle during particular activity and n= Duration of each activity.

E. Statistical Analysis

SPSS version 20.0 (IBM) was employed for statistical analysis. A One-Way ANOVA was carried out to determine whether the influence of gender was statistically significant or not between the four different groups. The four groups were Female Dominant Leg (FDL), Female Non Dominant Leg (FNDL), Male Dominant Leg (MDL) and Male Non Dominant Leg (MNDL). Least significant differences (LSD) among the different groups related to energy expenditure were conducted using post hoc analysis as shown in Table 2. The level of significance was set to α=0.05 for all statistical computation.

3. Result

One-Way ANOVA results depicted no significant gender related differences in muscles mechanical energy expenditure among the different activities performed. The findings from Table 2 of Post hoc analysis suggested significant gender differences in ankle dorsiflexion for dominant leg. Apart from this, no significant gender differences were found in any muscle during the various knee and ankle movements performed. For each activity performed by individuals an index was calculated to determine the activity with maximum and minimum energy expenditure. The results of dominant and non dominant leg are shown in Figure 2.

Figure 2 clearly demonstrated that for the dominant leg, minimum energy expenditure occurs during knee flexion while reverse occurs during knee extension. For the non dominant leg, minimum energy expenditure occurs during knee flexion while ankle dorsiflexion causes maximum energy expenditure.

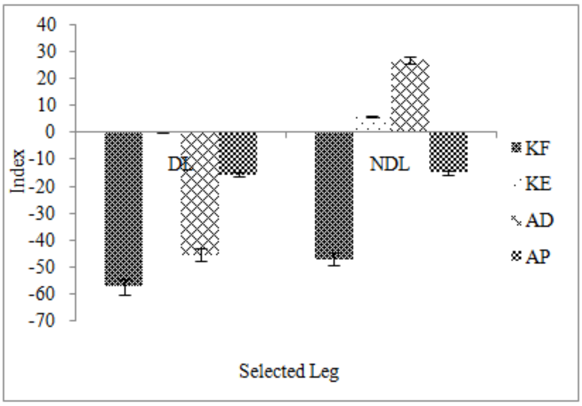

Figure 2. Index of Each Activity for Dominant and Non Dominant Leg DL=Dominant Leg, NDL= Non Dominant Leg, KF= Knee Flexion, KE=Knee Extension, AD= Ankle Dorsiflexion and AP= Ankle Plantarflexion

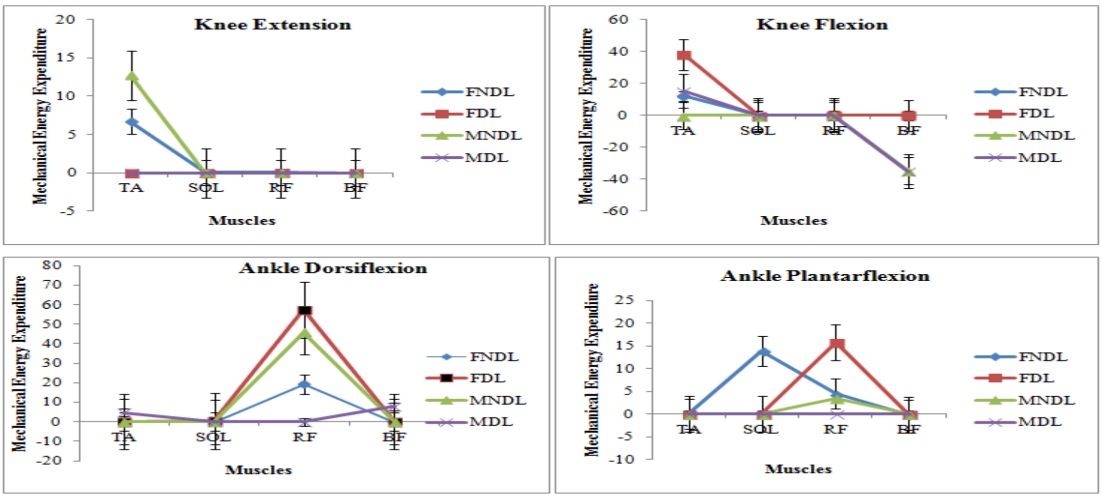

Figure 3. Agonist and Antagonist Muscle Mechanical Energy Expenditure for Dominant and Non Dominant Leg during different knee and ankle contractions FDL=Female Dominant Leg, FNDL= Female Non Dominant Leg, MDL=Male Dominant Leg and MNDL= Male Non Dominant Leg

Further analysis of descriptive statistics results demonstrate the behavior of agonist and antagonist muscles during knee and ankle contractions as shown in Figure 3. It is clearly demonstrated that Tibialis anterior (TA) is having the maximum energy expenditure during knee contractions while the Rectus Femoris (RF) - Biceps Femoris (BF) agonist- antagonist pair considered active during knee contractions show minimum mechanical energy expenditure. During ankle contractions, Rectus Femoris (RF) is having the maximum energy expenditure while the Tibialis Anterior (TA) - Soleus (Sol) agonist-antagonist pair considered active during ankle contractions shows minimum mechanical energy expenditure. This could be inferred from the results of Figure 3 that active agonist-antagonist muscle pair during contractions is shown to have minimum mechanical energy expenditure.

4. Discussion

The findings from the study demonstrated that there is no significant gender related differences in energy expenditure of agonist and antagonist muscles of dominant and non dominant leg. These results are opposite to the findings suggested by Browning et. al. (2005) that gender has significant influence on energy expenditure [7]. These findings are in concordance with the research reported by Morio et. al. (1997) on elderly population that gender has no influence on energy expended during light seated activities, walking, cycling, and sleep [15].

For the dominant leg, knee flexion is the activity found to be with minimum energy expenditure while knee extension is the activity with maximum energy expenditure. For non dominant leg, knee flexion has minimum energy expenditure while ankle dorsiflexion has maximum energy expenditure. This suggests that knee flexion is the most energy efficient technique that is routinely performed in activities of daily living (ADL). Similar observation was inferred by Winter in 2009 that in normal gait, antagonistic muscle pairs at each lower extremity joint contracts in an alternating pattern with low durations of concurrent activity, to generate sufficient joint moment [22].

During ankle contractions, Rectus Femoris (RF) having the maximum energy expenditure can be related to the finding of Gough et. al. (1971) that indicates EMG activity of Vastus Medialis, Vastus Lateralis and Rectus Femoris was higher during ankle dorsiflexion [10]. A similar finding reported by Signorile et. al. (1995) suggested that quadriceps activation was larger with neutral active ankle position [20]. The same phenomenon was observed during knee contraction with Tibialis Anterior (TA) having maximum energy expenditure.

The findings related to gender performance and energy expenditure are limited in literature. The authors found no significant evidence related to this study. This study was an attempt to find the effect of gender only for which EMG was employed. EMG has been vastly employed and is a standardized tool to study muscle activity. We agree that age and dietary assessment are also crucial however we intend to report those effects in our future studies. More research needs to be done to infer if they have significance on the outcomes. The limitation of this study was that we examined muscle activation in a young and healthy control adult population; therefore the results cannot be generalized with an injured or old age population group, which could be considered in future studies.

5. Conclusions

The results of this study, demonstrated no significant influence of gender on agonist-antagonist muscle energy expenditure during maximum knee contraction. For ankle contractions, gender has significant influence on energy expenditure during maximum ankle dorsiflexion. In addition to this, knee flexion is found to be the activity with minimum energy expenditure in healthy males and females. Active agonist-antagonist muscle pairs during knee and ankle contractions i.e. Rectus Femoris (RF) - Biceps Femoris (BF) during knee contraction and Tibialis Anterior (TA) - Soleus (Sol) during ankle contraction was found to have minimum mechanical energy expenditure.

The results of this study, would help in the understanding the significance of the gender related differences in the energy expenditure of selected muscles during maximum knee and ankle contractions. Such understanding is pivotal for the clinicians and physiotherapists in designing the rehabilitation program strategies on basis of gender by introducing a new method of muscle functional assessment during rehabilitation i.e. muscle mechanical energy expenditure that would help in the prevention of occupational musculoskeletal injuries in men and women.

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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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