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Significance of Bilateral Coactivation Ratio for Analysis of Neuromuscular Fatigue of Selected Knee Extensor Muscles during Isometric Contractions at 0º in Sportspersons

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Abstract Muscle coactivation is the activation of two or more muscles simultaneously around a joint. Coactivation of knee muscles especially quadriceps is considered to be an important phenomenon for the stabilization of patellofemoral joint. The purpose of this study was to investigate the Coactivation ratio of selected knee extensor muscles as measure of neuromuscular fatigue in relation to gender, performance and side (right and left) of male (n1=19) and female (n2=8) during isometric contraction. The isometric contraction consisted of performing knee extension with an angle between 0º to 10º with a load of 30 repetition maximum (RM) on the CYBEX exerciser. The statistical analysis applied were ANOVA with post hoc analysis to determine the influence of fatigue in terms of gender, performance and side (right and left). The results showed significant decrease in the coactivation ratio of the selected muscles pair during isometric contraction with progression of fatigue (time). It also showed male dominance behavior over females in coactivation of Vastus Medialis (VM) and Vastus Lateralis (VL) muscles.. The results of this study would help to better understand the changes in activation strategies that can provide valuable information regarding the mechanisms that alter neuromuscular activity.

Keywords: *coactivation, ratio, fatigue, gender, isometric, bilateral*

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1. Introduction

Coactivation or cocontraction is the activation of two or more things simultaneously. The simultaneous activity of the muscles acting around a joint is known as muscle coactivation [1]. It is an important phenomenon considered for joint stabilization that minimizes the effects of potential internal and external disturbances and helps in regulating joint load thereby preventing injury [2]. Fatigue is basically the inability of the muscle to undergo sustained muscle contraction over a period of time [3]. Missenard et. al. (2008) reported that various neuromuscular factors of fatigue results in the decrease of muscle force and affect the pattern of motor control during exercise [4]. This change in the pattern of motor control leads to decreased coactivation levels that alter the joint stability. Semmler et. al. (2013) explained that the muscle fatigue cause changes in central nervous system (CNS) regulations that in turn reduce muscular coactivation [5]. Silva et al. (2014) proposed that the neuromuscular fatigue does not alter muscle cocontraction between Vastus medialis and Vastus lateralis in maximum voluntary contraction tests [6].

The purpose of this study was to investigate the coactivation ratio of Vastus Medialis (VM) and Vastus Lateralis (VL) muscles as a measure of neuromuscular fatigue in male(s) and female(s) sportsperson during isometric contractions. The measurement of coactivation is done by the analysis of EMG activity of VM and VL muscles because EMG parameters demonstrated significant changes during the onset of fatigue condition in muscles during task performance [2,7]. EMG is widely used by researchers to assess the quality of motor coordination, motor learning stage and the joint stability level [7,8]. In this study, cocontraction of VM and VL muscles were considered because quadriceps especially Vastus Medialis (VM) and Vastus Lateralis (VL) muscles coactivation are important for stabilization of patellofemoral joint and responsible for coordinated pattern of knee extension [9,10]. The angle selected for isometric contraction was between 0º to 10º in order to emphasize fully extended knee condition. The results of this study would help in better understanding of the significance of the gender, performance and side (right and left) related differences in the coactivation ratio. Such understanding is important for the clinicians to evaluate and manage the rehabilitation related to patellofemoral joint injuries. Changes in activation strategies of muscles can provide valuable information regarding the mechanisms that alter neuromuscular strength of fatigued muscles.

2. Materials and Methods

2.1. Participants

Thirty healthy sportsperson engaged in different sports were recruited in the study. Out of these, three were removed for having past symptoms of knee injury. The study population thus consisted of male (n1=19) and female (n2=8) sportsperson. Male subjects were of age 19(±2) years, height 164 (±5) centimeters and weight 68.6(±6)kg/666.8 (±58.8) Newton. The age of female subjects were 19(±2) years, height 152(±3) centimeters and weight 54(±5)kg/529.5(±49) Newton. EMG activity was recorded simultaneously from the selected muscles of both (right and left) the lower limbs of all subjects during isometric contraction.

The excluding criteria of subjects were any medical conditions/ contractures/ deformities in the knee/ankle joint or suffering from skin problem, 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.

2.2. Instrumentation

Cybex 6000 device (Cybex, Division of Lumex Inc., Ronkonkoma, USA) was used for isometric contractions of selected muscles. EMG signals were acquired using four-channel wireless EMG BIOPAC Inc. (CMRR: 110dB at 50/60 Hz, Maximum Sampling rate: 200K samples/sec and Gain: 5-50,000, Input Impedance: 2 MΩ). The skin was rubbed with cotton containing alcohol to minimize the skin impedance, thereby improving the quality of signal acquisition. Disposable electrodes (44 x 32 x 1 mm) were placed on the subject's selected muscles following standard protocols [11] to acquire EMG simultaneously from both the legs as shown in Figure 1(a). The inter-electrode distance was 20 mm, center to center.

2.3. Data Acquisition

After the subject preparation was done, subject was seated on the end of the Cybex bench (Cybex 6000, Cybex, Division of Lumex Inc., Ronkonkoma, USA) with the padded edge of the bench against the posterior surface of the knee joint, the feet hooked behind the padded rollers and the hands grasping the bench just behind their buttocks shown in Figure 1(b). This was done to achieve comfortable posture of the subject for leg extension during the data acquisition. Each selected subjects were then assigned to 30 RM load and they were asked to sustain it for maximum duration of time (recorded in seconds) independently for males and females. 30 RM was opted for the study because 25-30 RM is the most recommended training and testing load for developing and measuring muscular endurance in athletes [12]. Isometric contractions of knee extensor muscles VM and VL were performed at an angle between 0º to 10º to emphasize full extension of legs taking in regard the comfort of subjects as well. 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).

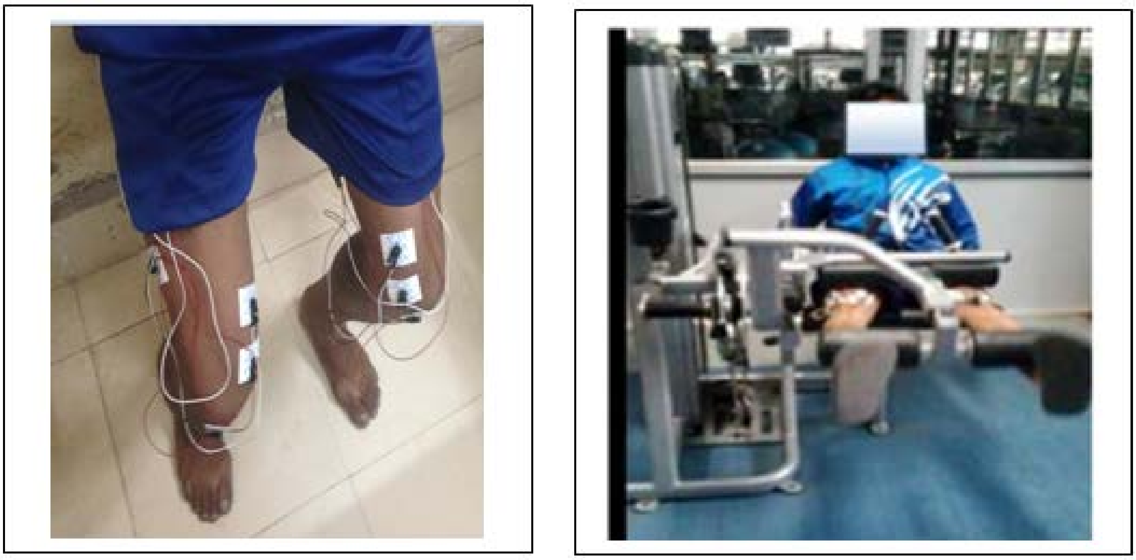

Figure 1. a) Electrode Placement, b) Experimental Setup

2.4. Data Segmentation

The raw EMG data is further segmented into 30, 60 and 90 seconds for each subject, as all subjects were able to perform minimum of 90 seconds isometric contraction. Further the subjects were divided into high and low performance group based on median split method. Median split method was applied on the score (time/duration) the subjects performed isometric knee extension activity. This was done to better understand influence of fatigue with progression of time with regard to their gender, performance level (high and low) as well as side (right and left).

2.5. Data Processing

The raw EMG signals acquired from the subjects were quantified with the help of MATLAB. For processing of EMG signal, notch filter was applied to remove 50 Hz noise interference from the signal. Cascaded low-pass (20 Hz) and a high-pass filter (450 Hz) were subsequently applied in order to remove other noise sources from the signal. The filtered EMG signals were rectified in order to calculate the RMS values. 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:

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

where, X_t is the rectified signal and T, t are 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 [11].

2.6. Determination of Coactivation Ratio

The cocontraction between VM and VL muscles as indicated by the surface EMG signal was calculated as shown in equation 2.

$$\text{VM}:\text{VL} = \frac{\text{Normalized value of VM}}{\text{Normalized value of VL}} \quad (2)$$

$$\left(\begin{array}{l}\text{Winter, 2009; Begalle, Distefano,}\\ \text{Blackburn \& Padua, 2012}\end{array}\right).$$

Table 1. Descriptive Statistics related to Muscle Coactivation Ratio of Selected Variables

Variable		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
R30	FLP	3	1.877	0.198	0.114	1.386	2.368	1.650	2.009
	FHP	5	1.744	0.331	0.148	1.333	2.156	1.374	2.178
	MLP	10	2.355	0.807	0.255	1.778	2.932	1.453	4.190
	MHP	9	1.817	0.296	0.099	1.590	2.044	1.429	2.328
	Total	27	2.010	0.588	0.113	1.777	2.243	1.374	4.190
R60	FLP	3	1.768	0.319	0.184	0.977	2.560	1.410	2.020
	FHP	5	1.628	0.136	0.061	1.459	1.797	1.523	1.843
	MLP	10	2.122	0.597	0.189	1.695	2.549	1.528	3.524
	MHP	9	1.684	0.247	0.082	1.494	1.874	1.386	2.200
	Total	27	1.845	0.448	0.086	1.668	2.022	1.386	3.524
R90	FLP	3	1.838	0.272	0.157	1.162	2.513	1.527	2.033
	FHP	5	1.649	0.068	0.030	1.565	1.734	1.540	1.718
	MLP	10	2.055	0.643	0.203	1.595	2.515	1.548	3.671
	MHP	9	1.655	0.134	0.045	1.552	1.759	1.502	1.903
	Total	27	1.823	0.438	0.084	1.649	1.996	1.502	3.671
L30	FLP	3	0.980	0.108	0.062	0.711	1.249	0.859	1.067
	FHP	5	1.047	0.095	0.043	0.929	1.166	0.954	1.198
	MLP	10	1.200	0.327	0.103	0.966	1.434	0.944	1.802
	MHP	9	1.081	0.105	0.035	1.000	1.162	0.984	1.288
	Total	27	1.108	0.221	0.042	1.020	1.195	0.859	1.802
L60	FLP	3	0.997	0.057	0.033	0.856	1.139	0.964	1.063
	FHP	5	1.010	0.066	0.030	0.928	1.092	0.954	1.118
	MLP	10	1.089	0.160	0.051	0.974	1.204	0.935	1.438
	MHP	9	1.022	0.068	0.023	0.970	1.074	0.948	1.154
	Total	27	1.042	0.112	0.022	0.998	1.086	0.935	1.438
L90	FLP	3	1.035	0.024	0.014	0.974	1.095	1.008	1.056
	FHP	5	0.996	0.047	0.021	0.937	1.054	0.951	1.063
	MLP	10	1.078	0.174	0.055	0.953	1.202	0.947	1.525
	MHP	9	1.017	0.052	0.017	0.978	1.057	0.950	1.097
	Total	27	1.038	0.113	0.022	0.993	1.082	0.947	1.525

Note-FLP=Female Low Performance, FHP=Female High Performance, MLP =Male Low Performance and MHP=Male High Performance.

2.7. Statistical Analysis

SPSS software (IBM) was used for statistical analysis. A One-Way ANOVA with Least Significant differences (LSD) were carried out to determine the differences between the gender, performance and side (right and left) on cocontraction ratio with progression of time related to VM:VL ratio. The findings have been shown in Table 1 and Table 2. The level of significance was set at $p < 0.05$.

Table 2. Least Significant Differences (LSD) Applied on Right and Left Leg with Progression of Time

Dependent Variable			Mean Difference (I-J)	Std. Error	Probability
R30	FLP	FHP	.133	.405	.746
		MLP	-.478	.365	.203
		MHP	.060	.370	.872
	FHP	MLP	-.611	.304	.056
		MHP	-.073	.309	.816
	MLP	MHP	.538*	.255	.046
R60	FLP	FHP	.140	.303	.648
		MLP	-.354	.273	.209
		MHP	.085	.277	.763
	FHP	MLP	-.494	.228	.040
		MHP	-.056	.232	.812
	MLP	MHP	.438*	.191	.031
R90	FLP	FHP	.188	.306	.544
		MLP	-.218	.276	.438
		MHP	.182	.279	.520
	FHP	MLP	-.406	.229	.090
		MHP	-.006	.234	.979
	MLP	MHP	.400*	.192	.049
L30	FLP	FHP	-.067	.160	.680
		MLP	-.220	.145	.142
		MHP	-.101	.146	.498
	FHP	MLP	-.153	.120	.217
		MHP	-.034	.122	.786
	MLP	MHP	.119	.101	.251
L60	FLP	FHP	-.013	.082	.877
		MLP	-.092	.074	.228
		MHP	-.025	.075	.744
	FHP	MLP	-.079	.062	.214
		MHP	-.012	.063	.851
	MLP	MHP	.067	.052	.209
L90	FLP	FHP	.039	.084	.646
		MLP	-.043	.076	.573
		MHP	.017	.077	.823
	FHP	MLP	-.082	.063	.204
		MHP	-.022	.064	.738
	MLP	MHP	.061	.053	.264

* Significant at 0.05 level. FLP=Female Low Performance, FHP=Female High Performance, MLP =Male Low Performance and MHP=Male High Performance.

3. Results

The summary of statistical findings from Table 2 is as follows:

1) During first 30 seconds (0 to 30 seconds), statistically significant difference ($p<0.046$) was found in coactivation ratio between male low and high performance sportspersons in right leg.

2) During second 30 seconds (30 to 60 seconds), statistically significant difference ($p<0.031$) was found in coactivation ratio between male low and high performance sportspersons in right leg.

3) During third 30 seconds (60 to 90 seconds), statistically significant difference ($p<0.049$) was found in coactivation ratio between male low and high performance sportspersons in right leg.

4) At any point of time there were no sex differences.

5) Significant differences between male low and high performance at were found only in the right side of leg.

6) Overall there was male dominating phenomenon

Further analysis of gender related differences in the VM:VL ratio with progression of fatigue (time) during isometric contraction in right and left leg is shown in Figure 2 through the results of descriptive statistics. Trace titles in Figure referred to as FLP=Female Low Performance, FHP=Female High Performance, MLP=Male Low Performance and MHP=Male High Performance. It clearly demonstrated that during isometric contraction, coactivation ratio of males dominated females. For both males and females, the ratio decreases with progression of fatigue (time). It is also depicted that the male low performance sportspersons have higher values of coactivation ratio followed by female low performance sportspersons.

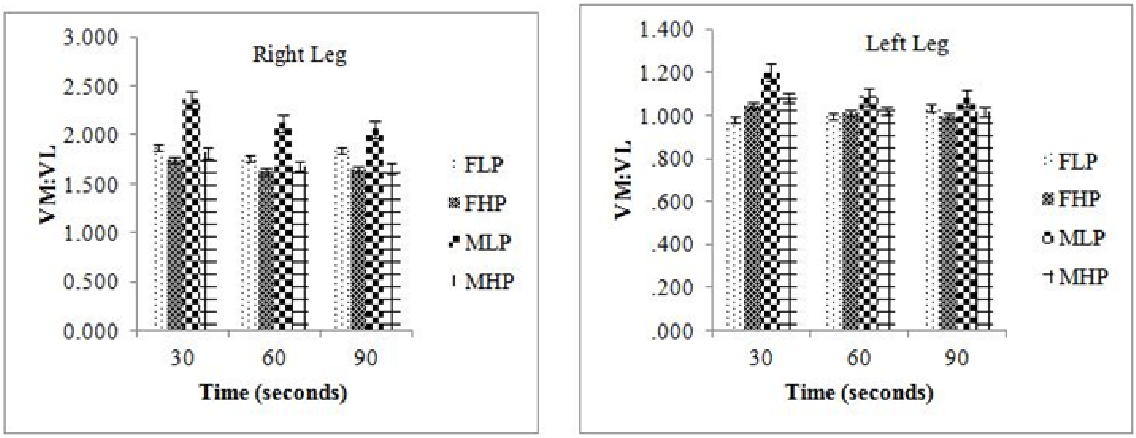

Figure 2. Gender related difference in VM:VL ratio of Right and Left Leg

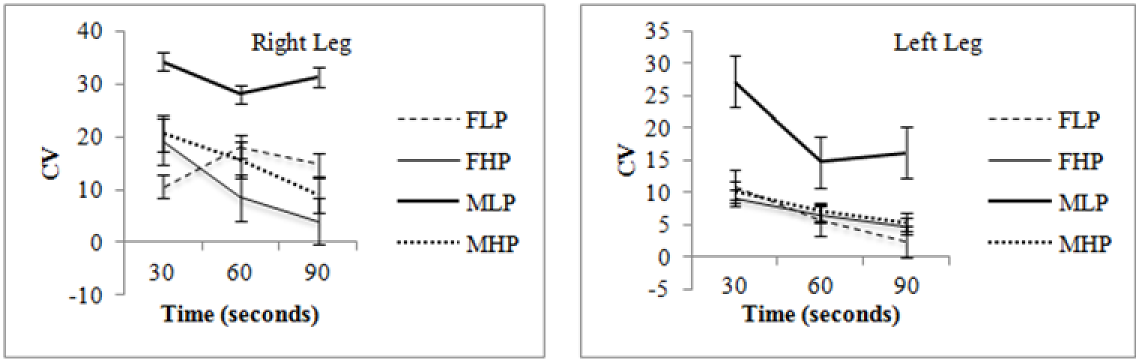

Figure 3. Coefficient of variation of VM:VL ratio of Right and Left Leg

Table 3. Coefficient of Variation of Right and Left Leg with Progression of Time

Variable	R30	R60	R90	L30	L60	L90
FLP	10.5148071	18.04285	14.8042	11.02866	5.687853	2.368313
FHP	19.00625896	8.37408	4.125389	9.129929	6.529956	4.728885
MLP	34.24987881	28.11297	31.30116	27.22564	14.69783	16.14713
MHP	20.68966837	15.67236	8.953088	10.23939	6.981432	5.418507

Note-FLP=Female Low Performance, FHP=Female High Performance, MLP =Male Low Performance and MHP=Male High Performance.

The coefficient of variation in both right and left leg is demonstrated in Table 3. From the findings of Table 3 as illustrated in Figure 3 it is evident that Male Low Performance (MLP) has higher coactivation ratio of VM and VL muscles than that of Female Low Performance (FLP), Male High Performance (MHP) and Female High Performance (FHP) at both right and left legs. This implied that MLP having higher chances of injuries. Attribution factor may be higher muscular development asymmetry in MLP. Cocontraction variations are superior at right leg, as it is the dominant leg.

The following points are evident from the results of coefficient of variation:

1) There is higher asymmetricity in MLP group because of lack of training.

2) There is less asymmetricity in MHP group because of training adaptation.

3) In FLP group because of lack of strength development in the muscles of both legs, asymmetricity is comparatively lower than that in males.

4) In FHP group, training improved the strength in both muscles equally, thus asymmetricity is less.

4. Discussion of Findings

Muscle coactivation is an important phenomenon for regulation of joint load that minimizes the external and internal disturbances around the joint thus preventing injury. Our results demonstrated the decrease in the ratio with progression of fatigue (time) which is in concordance with the results reported by researchers related to fatigue [4,9]. The decrease in co-contraction ratio with progression of fatigue can be understood as the criterion measure of muscles fatigue along with progression of time, their pattern of motor control is affected significantly [6]. The interpretation of the results also depicted that initially VM has higher activation along with progression of time, VM activation decreases while VL activation increases. This shows that fatigue changes the level of coactivation of VM and VL muscles. The findings of the study collectively demonstrated gender, performance and side (right and left) related differences in cocontraction ratio. It has been found that male sportspersons have higher VM:VL ratio than that of female sportspersons during isometric contraction. It is also demonstrated that low performance sportspersons have higher values of cocontraction than that of high performance sportspersons. This indicates that male low performance sportspersons followed by female low performance sportspersons are prone to the higher risks of picking up patellofemoral injuries than compared to male and female of high performance sportspersons. The findings suggested that the isometric exercises employed by clinicians for rehabilitation of sportsperson from patellofemoral injuries must be designed according to gender, performance and side (right and left) rather than common strategies normally followed for both the genders. These results would provide important inputs in prevention of possible training related injuries in patellofemoral joint. It would also provide crucial information that would help in adjusting training protocol of sportspersons by their trainers.

5. Conclusions

The following are the conclusive remarks from the study:

1) The study found gender related differences with regard to cocontraction ratio of VM and VL muscles during isometric contraction in sportspersons.

2) Cocontraction of males is found to be superior in comparison to female sportspersons across the experimental protocol.

3) Performance related differences are found with regards to Cocontraction ratio of VM and VL muscles during isometric contraction in sportspersons.

4) Predominance of right leg over left leg was found across the protocol.

5) Decrease in coactivation ratio is found with progression of fatigue (time).

These results would help in the understanding the significance of the gender, performance and side (right and left) related differences in the co activation ratio and its relation to individual member of the muscular group. Such understanding is important for the clinicians and trainers to evaluate and manage the rehabilitation related to patellofemoral joint injuries. Changes in activation strategies of muscles can provide valuable information regarding the mechanisms that alter neuromuscular strength of fatigued muscles.

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