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**ORIGINAL ARTICLE**



# Determination of Electromyography-Based Coordinated Fatigue Levels in Agonist and Antagonist Muscles of the Thigh during Squat Press Exercise

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## ABSTRACT

**Background.** Simultaneous tiredness of two or more muscles around a joint can be defined as coordinated fatigue (co-fatigue) and might occur between agonist and antagonist muscles, and vary according to the level of sporting activity levels or gender. **Objectives.** The aim of this study was to determine the levels of coordinated fatigue in agonist and antagonist muscles during squat-press exercise. **Methods.** Twenty athletes and twenty sedentary subjects participated in the study. Surface electromyography signals of the rectus femoris, vastus lateralis obliquus, biceps femoris and semitendinosus muscles were recorded at the squat press position for 15 seconds during isometric contraction. Measurements were repeated five times and a 2-minute rest period was allowed between repetitions. After erroneous EMG elimination, movement artefacts were removed by using a 20 Hz high-pass Butterworth filter. Then, as a well-recognized fatigue index, the median frequency (MF) of each filtered middle part of the EMG signal (5 to 10 s. of contraction) was calculated, given that it is known that the MF decreases during isometric contractions. Finally, each MF-based co-fatigue index was calculated by dividing the mean RF and VLO median frequencies by the mean ST and BF median frequencies. The cumulative co-fatigue values of "male vs. female" and "sedentary vs. athlete" comparisons were performed by using a two-sided Student t-test with a Bonferroni correction. **Results.** There was a statistically significant (Bonferroni corrected p-value $< 0.05$) difference between the mean female ($1.57 \pm 0.53$) and the mean male ($1.23 \pm 0.17$) co-fatigue values, while there was no statistically significant difference between the mean co-fatigue values of sedentary ($1.51 \pm 0.52$) and athlete ($1.29 \pm 0.27$) subjects. **Conclusion.** The offered co-fatigue indices might be useful for other sports, physiotherapy and related areas if sufficient scientific proof is accumulated.

**KEY WORDS:** ***Electromyography, Muscle Fatigue, Co-Fatigue, Agonist, Antagonist, Squat Press***

## INTRODUCTION

Muscle fatigue from high-intensity contractile activity is thought to be due in large part to 1) the accumulation of metabolic by products acting to directly inhibit contraction and 2) a reduction in intracellular calcium (Ca2+), levels acting to limit activation of the myofilaments. Ultimately, both of these intracellular changes contribute to fatigue by either directly or indirectly reducing the force- and motion-generating capacity of a myosin cross-bridge (1). Fatigue can alter overt performance, such that the task is performed more slowly or clumsily or even cannot be performed successfully, or it can alter the neuromuscular activity required to perform the task and this may be evident as increased electrical activity of the muscle. Additionally, there are sensations that

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accompany muscle fatigue, such as muscle pain or discomfort and perception of increased effort (2). The development of muscle fatigue during exercise has a consistent effect on performance. Numerous studies have shown that the underlying physiological traits of muscle fatigue range from CNS to myofilaments (3). A decrease in the power generation capacity of muscles affects their ability to act as dynamic stabilizers of joints (4) Muscle co-activation is the simultaneous activation of muscles around a joint and can be measured using surface electromyography (EMG) during isometric contraction (5-8). It is generally calculated by dividing the normalized EMG of agonist muscles by the normalized EMG of antagonist muscles (or vice versa) during isometric contraction. In this way it is possible to determine which muscle group (or groups) is more active, and the result can be used for treatment and exercise purposes. The hypothesis of our study was that we can calculate an index based on fatigue (we refer to muscle-coordinated fatigue as co-fatigue throughout) by dividing EMG-based fatigue indices (median frequency) of a muscle group during isometric contraction, similar to muscle co-activation. The advantage of such an index would be that it could provide us with a single number that could be used as a measure of which muscle group or groups are fatigued with respect to other or others (for example agonist w.r.t. antagonist). Learning muscle-specific movement patterns causes reductions in muscle co-activation (5, 9). Therefore, learning muscle-specific movement patterns may also cause changes in muscle co-fatigue levels. EMG-based co-fatigue may occur in terms of agonist and antagonist muscles, and also vary according to the level of sporting activity levels or gender.

Agonist and antagonist co-fatigue can plays an important role for stabilizing the knee joint, especially after fatigue. However, whether selective fatigue of agonist or antagonist muscles would cause different changes in muscle activation patterns is unknown. Determine of coordinated fatigue levels of agonist and antagonist muscles may indirectly affect muscle activation levels which is an important factor effecting training efficiency. Because it is well known that the maximal moment during voluntary contraction depends on the voluntary activation levels of muscles. The presence of an index that determines coordinated fatigue levels can help determine efficiency in sports branches especially isometric contractions are important. Co-fatigue index may help investigate the co-fatigue during isometric effort, especially at different knee joint angles and different joints.

The aim of this study was to test the EMG-based co-fatigue hypothesis by comparing agonist and antagonist muscles (leg flexors and extensors) of sedentary subjects and athletes during squat-press exercise.

## MATERIALS AND METHODS

**Participants.** The study group consists of a total of 40 participants; 20 athletes (10 male: age 19.7 ± 0.94 years; weight 74.3 ± 5.0 kg; height 178.9 ± 3.5 cm; BMI 23.24 ±1.8 and 10 female: 20.2 ± 1.5 years; weight 58.8 ± 6.1 kg; height 168.2 ± 4.3 cm; BMI 20.7 ±1.7) and 20 sedentary subjects (10 male: age 20.5 ± 1.5 years; weight 77.1 ± 5.6 kg; height 180.4 ± 2.4 cm; BMI 23.6 ±1.4, 10 female: age 19.8 ± 0.7 years; weight 59.9 ± 3.9 kg; height 168.9 ± 3.7cm; BMI 21.0 ±1.4) from the School of Physical Education and Sports at Ordu University. There were no significant differences between groups in terms of age, weight, height, or BMI. All procedures were in accordance with the Helsinki declaration, all participants provided written informed consent, and the study protocol has been approved by the local ethical committees (2018-01).

**Measures.** EMG measurements of the rectus femoris (RF), vastus lateralis obliquus (VLO), biceps femoris (BF) and semitendinosus (ST) muscles were recorded during isometric squat press position (knee angle of 45 degrees with a 30% body weight load). Measurements were repeated five times and a 2-minute rest period was allowed between repetitions. EMG signals of both legs were recorded. A Noraxon DTS wireless system (Noraxon, USA) was used for EMG recordings. Dual Ag/AgCl EMG electrodes (spacing - 2.0 cm) were placed according to SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscle) recommendations.

After erroneous EMG elimination, movement artefacts were removed by using a 20 Hz high-pass Butterworth filter. Then, as a well-recognized fatigue index, the median frequency (MF) of each filtered middle part of the EMG signal (5 to 10 s. of contraction) was calculated. Each MF-based co-fatigue index was calculated by dividing the mean RF and the VLO median frequencies by the mean ST and BF median frequencies (i.e. (RF+VLO) / (ST+BF)). Finally, left and right knee co-fatigues were averaged as a single co-fatigue index for each subject. Cumulative co-fatigue comparisons of the values of "male vs. female" and "sedentary vs. athlete" were performed using a two-sided Student t-test with a Bonferroni correction. EMG studies for muscle fatigue often use the median frequency as a fatigue index. Median frequency (MF) is the frequency that divides the power spectrum into two equal regions. Although there is still some suspicion about its merits (10). It is commonly accepted that muscle fatigue shows a decrease in EMG MF during isometric contractions (11-15). The resultant decrease in EMG spectral variables, such as the median or mean frequency, has provided investigators with a non-invasive and localized method of monitoring electrophysiological fatigue processes (16, 17).

The biggest advantage of using median or mean frequency values obtained by using EMG as fatigue index is giving us information about local fatigue levels. The mathematical ratio of the median frequency of agonist and antagonist muscles was used for the calculation of the co-fatigue index that we propose as a hypothesis (if the mean MF of agonist and antagonist muscle groups are 60 and 50 Hz respectively, then the co-fatigue index is 60.50 = 1.2).

**Figure 1. Sample EMG Measurement**

**Statistical Analysis.** The two-sided Student-t test was used for comparisons and the significance level was set as 0.05. Cumulative comparisons of the co-fatigue values of "male vs. female" and "sedentary vs. athlete" were performed using a two-sided Student t-test with a Bonferroni correction. Mean MF comparisons ("female vs. male" and "sedentary vs. athlete") were performed similarly (without Bonferroni correction) for the five repetitions. The interclass correlation coefficient (ICC) was also calculated.

## RESULTS

The ICC of five repeats in MF were 0.981 (95% CI: 0.970, 0.989), 0.980 (95% CI: 0.967, 0.988), 0.969 (95% CI: 0.950, 0.982), 0.957 (95% CI: 0.931, 0.975), 0.980 (95% CI: 0.969, 0.989), 0.882 (95% CI: 0.812, 0.931), 0.969 (95% CI: 0.950, 0.982) and 0.899 (95% CI: 0.840, 0.941) for RRF, RVLO, LRF, LVLO, RBF, RST, LBF and LST, respectively. The interclass correlation coefficient of five repeats in terms of co-fatigue was 0.966 (95% CI: 0.946, 0.980) (Table 1).

**Table 1. Differences in MF (Hz) between agonist and antagonist muscles of athletes and sedentary subjects during isometric squat press (1st repeat)**

| Group | n | X | SD | t | p |
|---|---|---|---|---|---|
| | | | **Agonist** | | |
| **RRF** | | | | .821 | 0.417 |
| Athlete | 20 | 80.24 | 15.81 | | |
| Sedentary | 20 | 75.89 | 17.63 | | |
| **RVLO** | | | | 2.712 | 0.010* |
| Athlete | 20 | 64.00 | 7.49 | | |
| Sedentary | 20 | 57.13 | 8.49 | | |
| **LRF** | | | | 3.689 | 0.001* |
| Athlete | 20 | 83.89 | 15.10 | | |
| Sedentary | 20 | 68.24 | 11.48 | | |
| **LVLO** | | | | 2.972 | 0.005* |
| Athlete | 20 | 65.75 | 10.61 | | |
| Sedentary | 20 | 56.66 | 8.62 | | |
| | | | **Antagonist** | | |
| **RBF** | | | | 2.420 | 0.020* |
| Athlete | 20 | 65.60 | 21.06 | | |
| Sedentary | 20 | 49.29 | 21.54 | | |
| **RST** | | | | 2.421 | 0.020* |
| Athlete | 20 | 52.87 | 12.07 | | |
| Sedentary | 20 | 41.36 | 17.49 | | |
| **LBF** | | | | 3.245 | 0.002* |
| Athlete | 20 | 64.15 | 12.75 | | |
| Sedentary | 20 | 50.41 | 13.99 | | |
| **LST** | | | | 2.959 | 0.005* |
| Athlete | 20 | 55.03 | 11.71 | | |
| Sedentary | 20 | 42.59 | 14.70 | | |

*$p < 0.05$

**Table 2. Differences in MF (Hz) between agonist and antagonist muscles of athletes and sedentary subjects during isometric squat press (2nd repeat)**

| Group | n | X | SD | t | p |
|---|---|---|---|---|---|
| | | | **Agonist** | | |
| **RRF** | | | | 0.915 | 0.366 |
| Athlete | 20 | 81.87 | 14.61 | | |
| Sedentary | 20 | 76.84 | 19.72 | | |
| **RVLO** | | | | 2.112 | 0.041* |
| Athlete | 20 | 62.54 | 8.92 | | |
| Sedentary | 20 | 56.74 | 8.42 | | |
| **LRF** | | | | 3.370 | 0.002* |
| Athlete | 20 | 85.11 | 14.87 | | |
| Sedentary | 20 | 70.24 | 12.96 | | |
| **LVLO** | | | | 2.743 | 0.009* |
| Athlete | 20 | 63.41 | 8.32 | | |
| Sedentary | 20 | 56.13 | 8.46 | | |
| | | | **Antagonist** | | |
| **RBF** | | | | 2.512 | 0.016* |
| Athlete | 20 | 63.91 | 15.74 | | |
| Sedentary | 20 | 49.76 | 19.67 | | |
| **RST** | | | | 2.651 | 0.012* |
| Athlete | 20 | 50.61 | 11.20 | | |
| Sedentary | 20 | 39.38 | 15.28 | | |
| **LBF** | | | | 2.327 | 0.025* |
| Athlete | 20 | 63.74 | 13.12 | | |
| Sedentary | 20 | 54.46 | 12.07 | | |
| **LST** | | | | 2.460 | 0.019* |
| Athlete | 20 | 50.99 | 8.42 | | |
| Sedentary | 20 | 41.48 | 15.09 | | |

*$p < 0.05$

**Table 3. Differences in MF (Hz) between agonist and antagonist muscles of athletes and sedentary subjects during isometric squat press (3rd repeat)**

| Group | n | X | SD | t | p |
|---|---|---|---|---|---|
| | | **Agonist** | | | |
| **RRF** | | | | 1.374 | 0.177 |
| Athlete | 20 | 81.80 | 15.38 | | |
| Sedentary | 20 | 74.16 | 19.53 | | |
| **RVLO** | | | | 2.700 | 0.010* |
| Athlete | 20 | 62.93 | 7.96 | | |
| Sedentary | 20 | 56.33 | 7.48 | | |
| **LRF** | | | | 1.903 | 0.065 |
| Athlete | 20 | 80.65 | 15.58 | | |
| Sedentary | 20 | 71.79 | 13.78 | | |
| **LVLO** | | | | 3.228 | 0.003* |
| Athlete | 20 | 67.44 | 13.16 | | |
| Sedentary | 20 | 56.20 | 8.30 | | |
| | | **Antagonist** | | | |
| **RBF** | | | | 2.721 | 0.010* |
| Athlete | 20 | 64.19 | 18.01 | | |
| Sedentary | 20 | 47.60 | 20.46 | | |
| **RST** | | | | 2.032 | 0.049* |
| Athlete | 20 | 50.68 | 15.55 | | |
| Sedentary | 20 | 41.01 | 14.50 | | |
| **LBF** | | | | 2.190 | 0.035* |
| Athlete | 20 | 62.29 | 11.69 | | |
| Sedentary | 20 | 52.46 | 16.29 | | |
| **LST** | | | | 3.316 | 0.002* |
| Athlete | 20 | 52.97 | 10.99 | | |
| Sedentary | 20 | 39.08 | 15.17 | | |

*$p < 0.05$

**Table 4. Differences in MF (Hz) between agonist and antagonist muscles of athletes and sedentary subjects during isometric squat press (4th repeat)**

| Group | n | X | SD | t | p |
|---|---|---|---|---|---|
| | | **Agonist** | | | |
| **RRF** | | | | 0.476 | 0.637 |
| Athlete | 20 | 80.42 | 14.90 | | |
| Sedentary | 20 | 77.30 | 25.31 | | |
| **RVLO** | | | | 3.126 | 0.003* |
| Athlete | 20 | 62.59 | 7.26 | | |
| Sedentary | 20 | 55.50 | 7.07 | | |
| **LRF** | | | | 1.993 | 0.053 |
| Athlete | 20 | 83.21 | 15.72 | | |
| Sedentary | 20 | 73.08 | 16.39 | | |
| **LVLO** | | | | 3.071 | 0.004* |
| Athlete | 20 | 64.80 | 9.59 | | |
| Sedentary | 20 | 54.53 | 11.48 | | |
| | | **Antagonist** | | | |
| **RBF** | | | | 2.363 | 0.023* |
| Athlete | 20 | 62.97 | 19.46 | | |
| Sedentary | 20 | 48.69 | 18.74 | | |
| **RST** | | | | 2.187 | 0.035* |
| Athlete | 20 | 52.76 | 17.13 | | |
| Sedentary | 20 | 40.85 | 17.31 | | |
| **LBF** | | | | 2.121 | 0.040* |
| Athlete | 20 | 62.27 | 11.86 | | |
| Sedentary | 20 | 52.75 | 16.18 | | |
| **LST** | | | | 1.251 | 0.219 |
| Athlete | 20 | 52.58 | 12.25 | | |
| Sedentary | 20 | 45.07 | 23.89 | | |

*$p < 0.05$

There were statistically significant differences in the MF between agonist and antagonist muscles of athletes and sedentary subjects during isometric squat press at the first repeat ($p < 0.05$), with the exception of the right RF muscle ($p > 0.05$) (Table 2).

There were statistically significant differences in the MF between agonist and antagonist muscles of athletes and sedentary subjects during isometric squat press at the second repeat ($p < 0.05$), with the exception of the right RF muscle ($p > 0.05$) (Table 3).

There were statistically significant differences in the MF between agonist and antagonist muscles of athletes and sedentary subjects during isometric squat press at the third repeat ($p < 0.05$), with the exception of the right and left RF muscles ($p > 0.05$) (Table 4).

There were statistically significant differences in the MF between agonist and antagonist muscles of athletes and sedentary subjects during isometric squat press at the fourth repeat ($p < 0.05$), with the exception of the right and left RF muscles and left ST muscles ($p > 0.05$) (Table 5).

There were statistically significant differences in the MF between agonist and antagonist muscles of athletes and sedentary subjects during isometric squat press at the fifth repeat ($p < 0.05$), with the exception of the right RF muscle, and right and left ST muscles ($p > 0.05$) (Table 6).

The averages of all repeats shows that there were statistically significant differences in the MF between agonist and antagonist muscles of athletes and sedentary subjects during isometric squat press ($p < 0.05$), with the exception of the right RF muscle ($p > 0.05$) (Table 7).

Differences in the mean values of agonist and antagonist MF (Hz) between agonist and antagonist muscles of athletes and sedentary subjects during isometric squat press show that median frequency values of sedentary during isometric squat press are statistically lower than those of athletes ($p < 0.05$) (Table 8).

There was no statistically significant difference in the ratio of agonist and antagonist MF (Hz) between agonist and antagonist muscles of athletes and sedentary during isometric squat press ($p > 0.05$) (Table 9).

**Table 5. Differences in MF (Hz) between agonist and antagonist muscles of athletes and sedentary subjects during isometric squat press (5th repeat)**

| Group | n | X | SD | t | p |
|---|---|---|---|---|---|
| | | | **Agonist** | | |
| **RRF** | | | | 1.019 | 0.315 |
| Athlete | 20 | 80.99 | 15.95 | | |
| Sedentary | 20 | 75.24 | 19.56 | | |
| **RVLO** | | | | 2.128 | 0.040* |
| Athlete | 20 | 61.83 | 8.24 | | |
| Sedentary | 20 | 56.41 | 7.86 | | |
| **LRF** | | | | 2.865 | 0.007* |
| Athlete | 20 | 84.44 | 13.93 | | |
| Sedentary | 20 | 71.44 | 14.76 | | |
| **LVLO** | | | | 2.929 | 0.006* |
| Athlete | 20 | 65.85 | 10.96 | | |
| Sedentary | 20 | 56.25 | 9.71 | | |
| | | | **Antagonist** | | |
| **RBF** | | | | 2.305 | 0.027* |
| Athlete | 20 | 62.86 | 18.56 | | |
| Sedentary | 20 | 48.49 | 20.79 | | |
| **RST** | | | | 1.181 | 0.245 |
| Athlete | 20 | 53.09 | 24.38 | | |
| Sedentary | 20 | 45.47 | 15.45 | | |
| **LBF** | | | | 2.193 | 0.034* |
| Athlete | 20 | 63.19 | 13.05 | | |
| Sedentary | 20 | 53.69 | 14.31 | | |
| **LST** | | | | 1.103 | 0.277 |
| Athlete | 20 | 53.17 | 19.83 | | |
| Sedentary | 20 | 45.81 | 22.29 | | |

*$p < 0.05$

**Table 6. Differences in MF (Hz) between agonist and antagonist muscles of athletes and sedentary subjects during isometric squat press (average).**

| Group | n | X | SD | t | p |
|---|---|---|---|---|---|
| | | Agonist | | | |
| **RRF** | | | | 0.937 | 0.355 |
| Athlete | 20 | 81.06 | 14.78 | | |
| Sedentary | 20 | 75.88 | 19.79 | | |
| **RVLO** | | | | 2.647 | 0.012* |
| Athlete | 20 | 62.77 | 7.60 | | |
| Sedentary | 20 | 56.42 | 7.58 | | |
| **LRF** | | | | 2.910 | 0.006* |
| Athlete | 20 | 83.46 | 13.87 | | |
| Sedentary | 20 | 70.96 | 13.28 | | |
| **LVLO** | | | | 3.297 | 0.002* |
| Athlete | 20 | 65.45 | 9.17 | | |
| Sedentary | 20 | 55.95 | 9.03 | | |
| | | Antagonist | | | |
| **RBF** | | | | 2.568 | 0.014* |
| Athlete | 20 | 63.90 | 17.91 | | |
| Sedentary | 20 | 48.77 | 19.33 | | |
| **RST** | | | | 2.490 | 0.017* |
| Athlete | 20 | 52.00 | 12.33 | | |
| Sedentary | 20 | 41.61 | 14.00 | | |
| **LBF** | | | | 2.573 | 0.014* |
| Athlete | 20 | 63.12 | 11.86 | | |
| Sedentary | 20 | 52.75 | 13.57 | | |
| **LST** | | | | 2.392 | 0.022* |
| Athlete | 20 | 52.95 | 10.35 | | |
| Sedentary | 20 | 42.80 | 15.89 | | |

*p < 0.05

**Table 7. Differences in mean values of agonist and antagonist MF (Hz) between agonist and antagonist muscles of athletes and sedentary subjects during squat press**

| Group | n | X | SD | t | P |
|---|---|---|---|---|---|
| **Agonist** | | | | 2.704 | 0.010* |
| Athlete | 20 | 73.19 | 9.74 | | |
| Sedentary | 20 | 64.81 | 9.86 | | |
| **Antagonist** | | | | 3.102 | 0.004* |
| Athlete | 20 | 58.00 | 8.80 | | |
| Sedentary | 20 | 46.49 | 14.06 | | |

*p < 0.05

**Table 8. Differences in ratio (co-fatigue = agonist/antagonist) of agonist and antagonist MF (Hz) between agonist and antagonist muscles of athletes and sedentary during isometric squat press (unitless)**

| Group | n | X | SD | t | p |
|---|---|---|---|---|---|
| **Agonist/Antagonist** | | | | -1.676 | 0.102 |
| Athlete | 20 | 1.29 | 0.27 | | |
| Sedentary | 20 | 1.51 | 0.52 | | |

*p < 0.05

**Table 9.** Differences in median MF (Hz) between agonist and antagonist muscles of men and women at the moment of an isometric squat press

| Group | n | X | SD | t | p |
|---|---|---|---|---|---|
| **Agonist** | | | | 1.377 | 0.177 |
| Female | 20 | 66.72 | 11.94 | | |
| Male | 20 | 71.27 | 8.69 | | |
| **Antagonist** | | | | -3.473 | 0.001* |
| Female | 20 | 45.96 | 14.03 | | |
| Male | 20 | 58.53 | 8.06 | | |

*p < 0.05

**Table 10. Differences in ratio of agonist and antagonist MF (Hz) between agonist and antagonist muscles of men and women during isometric squat press (unitless)**

| Group | n | X | SD | t | p |
|---|---|---|---|---|---|
| **Agonist/Antagonist** | | | | 2.700 | 0.010* |
| Female | 20 | 1.57 | 0.53 | | |
| Male | 20 | 1.23 | 0.17 | | |

*p < 0.05



There was no statistically significant difference in the MF between agonist muscles of men and during isometric squat press ($p > 0.05$) while there was a statistically significant difference in the median frequency between antagonists muscles ($p < 0.05$).

There is a statistically significant difference in the agonist/antagonist MF (Hz) ratio (co-fatigue = agonist/antagonist) between men and women at the moment of an isometric squat press ($p < 0.05$).

## DISCUSSION

Repeated, intense use of muscles leads to a decline in performance known as muscle fatigue also in isometric contraction. Many muscle properties change during fatigue including the action potential, extracellular and intracellular ions, and many intracellular metabolites. A range of mechanisms have been identified that contribute to the decline of performance (18). Although the agonist and antagonist muscles show the same mechanical properties during isometric contractions, they are fatigued at different rates. In this study, there were no statistically significant age, height, weight and BMI differences between athlete and sedentary co-fatigue values. In fact, the statistical analysis of co-fatigue values during isometric squat press exercise showed lower results in favour of athletes (1.29 ± 0.27) w.r.t. sedentary (1.51 ± 0.52). However, the difference was not statistically significant. Maybe there is no difference because similar age and physical characteristics can be revealed by similar biological mechanism responses. Although there were no statistically significant age, height, weight and BMI differences between male and female co-fatigue values, the cumulative male (1.23 ± 0.17) vs. female (1.57 ± 0.53) mean co-fatigue comparison showed a statistically significant difference (Bonferroni corrected p-value < 0.05). In addition, very high ICC values of MF and co-fatigue suggests that the difference is not random.

There is a difference in the antagonist muscles of females and males, i.e. in auxiliary muscles, indicating that antagonist muscles assist in the function of primary muscles more in males than in females. The difference in the median frequency of agonist muscles between male and female is in favour of men. However, the difference is not statistically significant.

The analysis shows a difference in the co-fatigue index between male and female, indicating that male fatigue in agonist and antagonist muscles is more coordinated than in those of females. When the co-fatigue index values of men and women are examined, women's antagonist muscles show more fatigue than men's antagonist muscles to ensure joint stability. This increases the recruitment of antagonists, especially secondary muscles. Although there are similar physiological responses in fatigue, gender differences affect the rate of these physiological responses.

The interclass correlation coefficient reveals high reliability for repetitive median frequency and co-fatigue measurements, indicating that the measurements are reliable and accurate.

Muscle co-contraction is important for minimizing the effects of internal and external disturbances, and adjusting the joint strength in terms of joint stabilization (5, 9, 19-21). The muscle co-fatigue index also might play an important role in maintaining joint stabilization, such as in the case of co-contraction or co-activation. This is because changes in muscle co-fatigue affect the motor control model, which may result in a reduction in muscle co-contraction.

A number of studies have reported similar correlation values despite using different fatigue protocols (22-25). These results indicate that muscle cooperation continues, even in non-physical working conditions. With the development of muscle co-fatigue, the simultaneous fatigue of muscles around a joint may provide more contact between the joint surfaces, and improve the ability to withstand external loads.

Silva et al. (2014) performed a submaximal isometric leg extension test and reported that neuromuscular fatigue applied to the vastus medialis and vastus lateralis muscles did not cause any change in muscle co-contraction values (25). Using the co-fatigue index in such a study may yield better results for the scaling of neuromuscular fatigue. The primary and auxiliary muscles involved in stabilizing muscle co-activation, that is, in maintaining stability, may exhibit specific and coordinated fatigue, which might result in changes in the muscle co-fatigue index.

## CONCLUSIONS

We propose that the co-fatigue index can be employed in studies of different exercise and load levels, different muscles, different levels of activity, and different fatigue indices (for example, other indices such as mean frequency instead of median frequency, median frequency to normal, and slope median frequencies) and can also contribute to the field of sports and physical therapy. Co-fatigue values vary according to sporting habits, age and sex. Therefore, further studies with larger sample sizes could offer more insight into the variables associated with athletic performance and muscle activities. This approach might have potential to contribute to sports science, to rehabilitation, and to the exercise of healthy athletes and sedentary individuals, especially with respect to exercise conditions that promote the physiological process of joint stabilization.

## APPLICABLE REMARKS

- Simultaneous tiredness of two or more muscles around a joint can be defined as coordinated fatigue (co-fatigue) and might occur between agonist and antagonist muscles, and vary according to the level of sporting activity levels or gender.

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