The Effects of Lower Extremity Static Muscle Fatigue on Balance Components

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Research Article

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Abstract

Background: The body exhibits dynamic and static movements in response to the changes in the center of gravity in some positions. Balance plays a key role in all sports branches and daily life because it can control the lowest energy consumption and muscle activation.

Objectives: This study investigated the effects of lower extremity static muscle fatigue on static and dynamic balance components. Design/Methods: The sample consisted of 40 healthy volunteers aged 18-24 years. Participants took part in an isometric fatigue protocol for lower extremity muscles. A squat position was used for static fatigue for lower extremity muscles. Measurements were performed in a squat press for 25 seconds, with the knee at a 90-degree angle and a load of about 30% of the participant's weight isometrically. The protocol was repeated five times. The participant was allowed to rest for two minutes between each repetition. The muscles and their antagonists that contracted most actively during the squat press exercise were *vastus lateralis obliquus*, *rectus femoris*, *tibialis anterior*, *biceps femoris*, *semi tendineus*, and *lateral gastrocnemius*. Electromyography (EMG) measurements were conducted on these muscles bilaterally and motion analysis system was used to standardize the 90-degree angle of the knee joint.

Results: There was a significant difference between pre-test and post-test Eyes Open (EO) static balance scores, pre- and post-exercise posttest dynamic balance scores between non-athletes and athletes, pre- and post-exercise posttest dominant leg EO, and pretest non-dominant leg between non-athletes and athletes ($p<.05$). There was a significant difference in the MF (Hz) values of the dominant leg agonist *rectus femoris* ($p<.05$) and the antagonist muscle *semi tendineus* ($p<.05$) scores during isometric squat press between athletes and non-athletes. There were statistically significant differences in the co-fatigue (coordinated fatigue) scores of the dominant leg agonist and antagonist muscle groups between non-athletes and athletes during isometric squat press ($p<.05$).

Conclusions: we need different applications to understand the mechanisms underlying balance and discover athletes' potential. Lower extremity proprioception exercises have positive effects on static body balance parameters, and a co-fatigue index can help us investigate co-fatigue, especially during isometric effort at different knee joint angles and different joints.

1. Introduction

Cells communicate through electrical currents in millivolts or microvolts. We obtain and interpret the activations of electrical currents in the central nervous system and peripheral regions. These data provide important clues in terms of facilitating, developing, and explaining human life. Electrophysiological developments have gained importance to determine the chronic effects during exercise. In this context, new perspectives have been developed to measure electrical activations in muscles during sports activities and to analyze and interpret them correctly through appropriate methods. The brain perceives and interprets technical skills that differ across different types of exercises or sports. Responses to any sporting activity, exercise, or performance occur in muscles in line with the information sent from the brain. The examination of these responses in muscles is also of great importance [1].

Most movements become automatic after they are consciously learned, and therefore, it is hard to correct motor skills that are incorrectly automated. Athletes or non-athletes who take measures at a young age are more likely to learn motor skills correctly. We need to define and practice each motor skill required for each activity, formation, and technical movement. Superficial Electromyography (sEMG) is the most common method to achieve that [2]. Superficial electromyography is used for different purposes in rehabilitation, sports medicine, kinesiology, and sports sciences thanks to advances in electronics, electricity, computer science, and biomedicine. It is generally used to determine the physical load of muscle contraction, to identify muscle activation times, to define contraction profiles, and to describe fatigue formation in muscles [1]. It can be used alone or with different devices (isokinetic dynamometer, force platforms, image analysis, and balance platforms) [2].

The word “isometric” literally means “same length.” Static contraction and isometric contraction are used interchangeably. In isometric contraction, the internal tension produced by the muscle is less than the external resistance, and therefore, there is no change in the joint angle and muscle length. However, the muscle tension, that is, the tone, increases. Muscles always contribute directly to the formation of the relevant joint movement. Muscles can cause or prevent movement. Standing upright and arm wrestling despite gravity are the best examples for this situation [3].

Balance detects and regulates sensory stimuli and plans movements for upright posture. Balance is the ability to control the body with minimal energy consumption and minimal muscle activation in dynamic and static positions in response to possible changes in the center of gravity. The primary balance mechanism is to minimize the forces acting on the body and preserve its alignment in response to internal and external forces [4, 5]. The balance mechanism requires the skeletal and neural systems to work regularly. This rhythmic action is provided by the transmission, collection, evaluation, and rhythmic execution of vestibular, visual, and proprioceptive senses in the central nervous system [6]. There are two types of balance: static and dynamic. Static balance ensures that the body remains stable on a surface or position and remains in the desired position in the face of external forces or interventions. Hip stabilization plays a crucial role in providing and maintaining static balance. Stabilization and muscle coordination of all joints are necessary for balance and proper alignment [7]. All moving objects have dynamic balance [8]. Dynamic balance involves adjusting body position while performing activities (slowing down, accelerating, turning, etc.). The control of balance is dynamic when one is in motion [9, 10]. The base support surface refers to the surface between the feet and the ground that we need in order to have the desired posture. If the base support surface is uneven or smaller than the object, the support is reduced. Therefore, if the base support surface is uneven or narrow, the balance shows a negative trend [11, 12]. The stability limit refers to the angular area in which the center of gravity oscillates. In other words, it moves [13]. The limit of this area depends on the base support surface position and the position of the feet. When an average person is in a relaxed standing position, the limit of stability is elliptical. The body must be able to continuously regulate the displacements of the center of gravity in response to internal and external forces and keep it within the limits of stability for balance. One performs oscillations in various directions in order to maintain balance. Any oscillation, voluntarily or otherwise, made by the center of gravity is called the oscillation limit. Sensory state and its relationship with the support surface are effective in this case [14].

The main task of the balance system is to maintain the vertical projection of the body's center of gravity within the base support area. This is the case because the body is not rigid, but it experiences constant oscillations on its vertical projection [15]. Stable balance depends on a feedback control mechanism, which is a complex system governed by receptors of the visual, vestibular, and somatosensory systems that receive various stimuli [16].

This study examined the effects of static fatigue on static and dynamic balance components in lower extremity muscle groups.

2. Methods

2.1 Study design

The sample consisted of 40 healthy volunteers (ten male athletes, ten female athletes, ten non-athlete men, and ten non-athlete females) aged 18–24 years. Table 4.1 shows the participants' body analysis results. Body composition was analyzed using an X-SCAN PLUS II device (Jawon Medical, Co, Kyungsan City, Korea). All participants filled out a health screening questionnaire and signed an informed consent form. The study was conducted in the Performance Laboratory of the School of Physical Education and Sports of Ordu University. Each participant visited the laboratory once. The study was approved by the Clinical Research Ethics Committee of Ordu University (KAEK-216). The study was supported by the Scientific Research Projects Coordination Unit of Ordu University (B-1906).

2.2. Data collection

Participants took part in an isometric fatigue protocol for lower extremity muscles. A squat position was used for static fatigue for lower extremity muscles. Measurements were performed in a squat press for 25 seconds, with the knee at a 90-degree angle and a load of about 30% of the participant's weight isometrically. The protocol was repeated five times. The participant was allowed to rest for two minutes between each repetition. The muscles and their antagonists that contracted most actively during the squat press exercise were *vastus lateralis obliquus*, *rectus femoris*, *tibialis anterior*, *biceps femoris*, *semi tendineus*, and *lateral gastrocnemius*. Electromyography (EMG) measurements were conducted on these muscles bilaterally. Electromyography data were recorded during each exercise protocol using wireless surface Ag/AgCl electrodes and a Noraxon device (myoMUSCLE, Noraxon, Scottsdale, AZ, USA). Noraxon (myoMOTION, Noraxon, Scottsdale, AZ, USA) motion analysis system was used to standardize the 90-degree angle of the knee joint. All muscle electrode locations were selected in accordance with the SENIAM criteria.

Figure 1 about here

Electromyography Analysis.

Electromyography data were passed through a 20 Hz high-pass Butterworth filter, and then, the median frequency was calculated (Hz) between 5 and 20 seconds of motion. Muscle fatigue studies using EMG signals focus on median frequency to calculate the fatigue index. The median frequency divides two equal parts of the total power spectral area. The more fatigued the muscle, the lower the MF during isometric contraction [17].

The coordinated-fatigue (co-fatigue) index is calculated by the mathematical ratio of the median frequency of the agonist and antagonist muscles (If the agonist and antagonist muscle groups have a median frequency of 80 and 50 Hz, then the co-fatigue index is 80/50 = 1.6) [18].

Balance Measurements.

The static and dynamic balance were measured before and after the fatigue protocol. The static and dynamic balance were measured using a CSI TecnoBody (PK-252) balance system, which provides objective and measurable data. The system is run by servo motors (air pistons) and measures the dynamic balance at an operating angle of 15 degrees in all directions of the platform. Dynamic balance results can be monitored and recorded live on a screen on the device. The balance of the moving platform is automatically adjusted by the weight applied to each point of the platform and the coefficient of instability. Therefore, the platform applies different resistance to everyone. In other words, everyone encounters resistance according to their weight. This feature allows us to compare measurement outcomes regardless of weight. The automatic motor locking function allows the device to switch from dynamic measurement to static measurement instantly.

Static Balance Measurements.

Static test balance measurements were performed in two ways: eyes open (EO) and eyes closed (EC). They were made on a flat surface and a stable platform on two legs. The participant's feet were shoulder-width apart. The feet were positioned in such a way that the x and y axes on the platform were equidistant from the origin point determined as a reference to the lines indicating the oscillation zones. The test lasted 30 minutes. The participant was asked to maintain his/her position during the test. The static balance measurement protocol was started by clicking the start button on the device screen. The device automatically terminated the test.

Static EO, EC, dominant leg, and non-dominant leg balance scores were the sum of the right-left standard deviation and the forward-backward standard deviation. Higher balance scores indicated poorer balance, whereas lower balance scores indicated better balance.

Dynamic Balance Measurements.

Dynamic test balance measurements were performed on a flat surface and a stable platform on two legs. The participant's feet were shoulder-width apart. The feet were positioned in such a way that the x and y axes on the platform were equidistant from the origin point determined as a result of reference to the lines indicating the oscillation zones. The circular oscillating movements of the body were followed clockwise. The specific route on the circular shape on the device screen was completed by turning five rounds for 60 seconds, provided that the feet remained on the floor. The device automatically terminated the test at the end of the fifth round. Some participants could not complete the test in 60 seconds. Their balance scores were the scores they obtained until the moment the test was over.

Dynamic balance data is referred to as Average Track Error (ATE). The resulting values show the amount of deviation or exceedance of the limits of the path that the participant should follow. Higher ATE scores indicated poorer dynamic balance, while lower ATE scores indicated better dynamic balance.

2.3. Statistical analysis

The data were analyzed using the Statistical Package for Social Sciences (SPSS, v. 22.0) at a significance level of 0.05. Arithmetic mean (X) and standard deviation (SD) were used for descriptive statistics. The Shapiro-Wilk test was used for normality testing, and the results showed that the data were normally distributed. Therefore, an independent samples t-test was used to determine co-fatigue levels in the agonist and antagonist muscles involved in the static squat movement applied to the lower extremity muscles and to compare the median frequency scores of the effects of fatigue levels on the static and dynamic balance between groups (athletes- non-athletes; males-females). A paired-samples t-test was used to compare pretest and posttest static and dynamic balance sores.

3. Results

Table 1
Body Analysis

Variable	Group	n	X	Sd	t	p
Age (year)	Athletes	20	21.45	3.37	1.034	0.308
	Non-athletes	20	20.40	3.03		
Body Height (cm)	Athletes	20	171.00	6.84	-0.572	0.571
	Non-athletes	20	172.40	8.53		
Body Weight (kg)	Athletes	20	61.81	14.43	-0.836	0.408
	Non-athletes	20	65.09	9.94		
Body Mass Index (kg/m^2)	Athletes	20	21.56	2.84	-0.279	0.782
	Non-athletes	20	21.76	1.65		
Body Fat Percentage	Athletes	20	18.00	6.23	-1.150	0.257
	Non-athletes	20	20.00	4.65		
Lean Body Mass	Athletes	20	51.85	9.45	-0.137	0.892
	Non-athletes	20	52.26	9.54		
Soft Lean Mass	Athletes	20	48.18	8.86	-0.120	0.905
	Non-athletes	20	48.52	8.98		
Skeletal Muscle Mass	Athletes	20	24.97	7.42	0.706	0.484
	Non-athletes	20	23.47	5.92		
Total Body Water	Athletes	20	37.33	6.80	-0.146	0.885
	Non-athletes	20	37.65	6.87		
Protein	Athletes	20	10.84	2.06	-0.038	0.970
	Non-athletes	20	10.87	2.11		

There was no significant difference in body height, body weight, age, Body Mass Index, body fat percentage, lean body mass, soft lean mass, skeletal muscle mass, total body water, and protein levels between non-athletes and athletes ($p > 0.05$). This result indicated that the two groups were homogenous.

Table 2
Pre- and Post-Exercise Dynamic Balance Scores

Variable	Group	n	X	Sd	t	p
ATE	Pretest	40	42.80	13.22	-1.278	0.209
	Posttest		44.85	12.51		
*p < 0.05						

There was no significant difference between pretest and posttest ATE scores ($p > 0.05$).

Table 3
Pre- and Post-Exercise Static Balance Scores

Variable	Group	n	X	Sd	t	p
EO	Pre-test	40	7.97	3.04	2.075	0.045*
	Post-test		7.07	1.71		
EC	Pre-test	40	9.92	2.36	1.041	0.304
	Post-test		9.50	2.01		
Dominant EO	Pre-test	40	10.15	2.24	-0.373	0.711
	Post-test		10.40	4.12		
Non-dominant EO	Pre-test	40	15.70	6.58	1.699	0.097
	Post-test		13.70	4.14		
*p < 0.05						

There was a significant difference between pretest and posttest static balance EO scores ($p < 0.05$). However, there was no significant difference between pretest and posttest Static EC, dominant single leg, and non-dominant single leg static balance scores ($p > 0.05$). These results showed differences only in the static EO balance scores after exercise, indicating improvements in static EO balance values after exercise.

Table 4
Comparison of Pre- and Post-Exercise Dynamic Balance Scores in Athletes and Non-athletes

Test	Variable	Group	n	X	Sd	t	p
Pre-test	ATE	Athletes	20	45.55	14.75	1.328	0.192
		Non-athletes	20	40.05	11.18		
Post-test	ATE	Athletes	20	49.05	9.26	2.228	0.032*
		Non-athletes	20	40.65	14.08		
*p < 0.05							

There was a significant difference in the posttest ATE scores between athletes and non-athletes (p<0.05). Non-athletes had a higher posttest ATE score than pretest ATE score, indicating poorer dynamic balance after exercise. Athletes had a significantly higher posttest ATE score than pretest ATE score, indicating poorer dynamic balance after exercise. There was no significant difference in pretest balance components between athletes and non-athletes (p>0.05).

Table 5
Comparison of Pre- and Post-Exercise Static Balance Scores in Male and Female Participants

Test	Variable	Group	n	X	Sd	t	p
Pre-test	EO	Athletes	20	8.65	2.97	1.421	0.163
		Non-athletes	20	7.30	3.02		
	EC	Athletes	20	10.55	2.37	1.710	0.095
		Non-athletes	20	9.30	2.25		
	Dominant EO	Athletes	20	10.60	2.16	1.276	0.210
		Non-athletes	20	9.70	2.29		
	Non-dominant EO	Athletes	20	18.00	8.20	2.332	0.025*
		Non-athletes	20	13.40	3.23		
Post-test	EO	Athletes	20	7.35	2.08	1.014	0.317
		Non-athletes	20	6.80	1.23		
	EC	Athletes	20	9.80	2.04	0.941	0.353
		Non-athletes	20	9.20	1.98		
	Dominant EO	Athletes	20	12.00	4.95	2.633	0.012*
		Non-athletes	20	8.80	2.23		
	Non-dominant EO	Athletes	20	15.20	4.57	2.427	0.020*
		Non-athletes	20	12.20	3.10		

*$p < 0.05$

There was a significant difference in the pretest non-dominant leg EO scores between athletes and non-athletes ($p < 0.05$). Athletes had a significantly higher pretest non-dominant leg EO score than non-athletes. Athletes had significantly higher posttest dominant leg EO and non-dominant EO static balance scores than non-athletes ($p < 0.05$). There was no significant difference in the other static balance components between athletes and non-athletes ($p > 0.05$).

Table 6
Comparison of Pre- and Post-Exercise Dynamic Balance Scores in Male and Female Participants

Test	Variable	Group	n	X	Sd	t	p
Pre-test	ATE	Female	20	13.05	2.91	4.877	0.000**
		Male	20	7.08	1.58		
Post-test	ATE	Female	20	13.63	3.04	2.109	0.042*
		Male	20	10.09	2.25		

*p < 0.05. **p < 0.01

Male participants had significantly lower pretest and posttest ATE scores than female participants ($p < 0.05$). The difference in the pretest dynamic balance components was significantly high ($p < 0.01$). The posttest dynamic balance scores showed that male participants had poorer dynamic balance after exercise but that their scores were better compared to female participants' scores.

Table 7
Comparison of Pre- and Post-Exercise Static Balance Scores in Male and Female Participants

Test	Variable	Group	n	X	Sd	t	p
Pre-test	EO	Female	20	7.50	2.32	-0.987	0.330
		Male	20	8.45	3.61		
	EC	Female	20	9.30	2.12	-1.710	0.095
		Male	20	10.55	2.48		
	Dominant EO	Female	20	10.05	2.18	-0.278	0.783
		Male	20	10.25	2.35		
	Non-dominant EO	Female Male	20	12.80	3.48	-3.073	0.004*
			20	18.60	7.68		
Post-test	EO	Female	20	7.25	2.14	0.640	0.526
		Male	20	6.90	1.16		
	EC	Female Male	20	9.25	1.86	-0.782	0.439
			20	9.75	2.17		
	Dominant EO	Female	20	9.10	2.84	-2.076	0.045*
		Male	20	11.70	4.82		
	Non-dominant EO	Female	20	14.30	4.57	0.913	0.367
		Male	20	13.10	3.68		
*p < 0.05							

Female participants had a significantly lower mean pretest non-dominant leg EO score than male participants ($p < 0.05$). However, there was no significant difference in the posttest non-dominant leg EO scores between male and female participants. Female participants also had a significantly lower mean posttest dominant leg EO score than their male counterparts ($p < 0.05$). There were no significant differences in the other static balance scores between male and female participants ($p > 0.05$).

Table 8
Comparison of the MF (Hz) scores of the dominant leg agonist and antagonist muscles in Athletes and Non-athletes during isometric squat press (average of five repetitions)

Muscle Group		Group	n	X	Sd	t	p
Agonist	Vastus Lateralis Obliquus	Athletes	20	62.03	10.25	-0.661	0.513
		Non-athletes	20	66.93	31.53		
	Rectus Femoris	Athletes	20	76.82	10.76	2.765	0.009*
		Non-athletes	20	67.95	9.48		
	Tibialis Anterior	Athletes	20	90.26	20.09	-1.322	0.194
		Non-athletes	20	101.14	30.81		
Antagonist	Biceps Femoris	Athletes	20	64.78	11.20	1.804	0.079
		Non-athletes	20	57.11	15.35		
	Semi Tendineus	Athletes	20	49.66	8.23	2.785	0.008*
		Non-athletes	20	42.40	8.24		
	Lateral Gastrocnemius	Athletes	20	80.22	15.06	1.265	0.214
		Non-athletes	20	73.88	16.63		
*p < 0.05							

This study compared the MF (Hz) scores of the dominant leg agonist and antagonist muscles in athletes and non-athletes during isometric squat press (average of five repetitions). When we focused on the muscles involved in the exercise, we saw a significant difference in the *rectus femoris*, an agonist muscle ($p < 0.05$). Non-athletes had a significantly lower agonist *rectus femoris* MF score than athletes. This result showed that non-athletes experienced more fatigue than athletes during exercise. Of the antagonist muscles, we observed a significant difference only in *semi tendineus* ($p < 0.05$). Non-athletes had a significantly lower agonist *semi tendineus* MF score than athletes. This result also showed that non-athletes experienced more fatigue than athletes during exercise. There were no significant differences in the MF scores of the other dominant leg agonist and antagonist muscles ($p > 0.05$).

Table 9
Comparison of the MF (Hz) scores of non-dominant leg agonist and antagonist muscles in athletes and non-athletes during isometric squat press (average of five repetitions)

Muscle Group		Group	n	X	Sd	t	p
Agonist	Vastus Lateralis Obliquus	Athletes	20	59.89	8.09	1.194	0.240
		Non-athletes	20	57.37	4.87		
	Rectus Femoris	Athletes	20	79.24	9.26	4.011	0.000**
		Non-athletes	20	67.78	8.80		
	Tibialis Anterior	Athletes	20	85.64	18.97	-0.295	0.769
		Non-athletes	20	87.65	23.77		
Antagonist	Biceps Femoris	Athletes	20	61.55	12.47	-0.187	0.852
		Non-athletes	20	62.29	12.54		
	Semi Tendineus	Athletes	20	48.87	7.26	0.995	0.326
		Non-athletes	20	46.56	7.46		
	Lateral Gastrocnemius	Athletes	20	84.42	19.26	0.387	0.701
		Non-athletes	20	82.16	17.50		
**$p < 0.01$							

This study compared the MF (Hz) scores of the non-dominant leg agonist and antagonist muscles in athletes and non-athletes during isometric squat press (average of five repetitions). When we focused on the muscles involved in the exercise, we saw a significant difference in the *rectus femoris*, an agonist muscle ($p < 0.01$). Non-athletes had a significantly lower agonist *rectus femoris* MF score than athletes. This result showed that non-athletes experienced more fatigue than athletes during exercise. There were no significant differences in the MF scores of the other non-dominant leg agonist and antagonist muscles ($p > 0.05$).

Table 10

Comparison of the mean MF (Hz) scores of dominant leg agonist and antagonist muscles in athletes and non-athletes during isometric squat press exercise

Muscle Group	Group	n	X	Sd	t	p
Agonist	Athletes	20	76.37	10.83	-0.517	0.608
	Non-athletes	20	78.67	16.69		
Antagonist	Athletes	20	64.89	8.95	2.591	0.014*
	Non-athletes	20	57.80	8.34		
*p < 0.05						

Table 10 compares the mean MF (Hz) scores of the dominant leg agonist and antagonist muscles in athletes and non-athletes during isometric squat press exercise. Non-athletes had significantly lower mean antagonist muscle MF (Hz) scores than athletes ($p < 0.05$). This result showed that non-athletes experienced more fatigue than athletes during exercise. There was no significant difference in the mean MF scores of the muscle groups between athletes and non-athletes ($p > 0.05$).

Table 11

Comparison of the mean MF (Hz) scores of non-dominant leg agonist and antagonist muscles in athletes and non-athletes during isometric squat press exercise

Muscle Group	Group	n	X	Sd	t	P
Agonist	Athletes	20	74.92	8.71	1.440	0.158
	Non-athletes	20	70.93	8.81		
Antagonist	Athletes	20	64.95	10.37	0.457	0.650
	Non-athletes	20	63.67	6.97		
*p < 0.05						

There was no significant difference in the mean MF (Hz) scores of the non-dominant leg agonist and antagonist muscles during isometric squat press between athletes and non-athletes ($p > 0.05$).

Table 12
Comparison of the mean co-fatigue (agonist/antagonist) scores of dominant leg agonist and antagonist muscle groups in athletes and non-athletes during isometric squat press exercise

Muscle Group	Group	n	X	Sd	t	P
Co-fatigue	Athletes	20	1.19	0.19	-2.379	0.022*
	Non-athletes	20	1.37	0.28		
*p < 0.05						

Athletes had a significantly lower mean dominant leg agonist and antagonist muscle group co-fatigue score than non-athletes ($p < 0.05$). This result showed that the agonist and antagonist muscles of the athletes were fatigued at a similar rate during exercise compared to non-athletes.

Table 13
Comparison of the mean Co-fatigue (agonist/antagonist) scores of non-dominant leg agonist and antagonist muscle groups in athletes and non-athletes during isometric squat press exercise

Muscle Group	Group	n	X	Sd	t	P
Co-fatigue	Athletes	20	1.16	0.14	0.917	0.365
	Non-athletes	20	1.12	0.16		

There was no significant difference in the mean co-fatigue scores of the non-dominant leg agonist and antagonist muscle groups during isometric squat press between athletes and non-athletes ($p > 0.05$).

Table 14
Comparison of the mean MF (Hz) scores of dominant leg agonist and antagonist muscle groups in male and female participants during isometric squat press exercise

Muscle Group	Group	n	X	Sd	t	p
Agonist	Female	20	72.81	8.94	-2.247	0.031*
	Male	20	82.24	16.49		
Antagonist	Female	20	58.78	7.67	-1.800	0.080
	Male	20	63.91	10.17		
*p < 0.05						

Table 14 compares the mean dominant leg agonist and antagonist muscle MF (Hz) scores in male and female participants during isometric squat press exercise. Female participants had significantly lower mean dominant leg agonist muscle MF (Hz) scores than male participants ($p < 0.05$). This result showed that female participants experienced more fatigue in their agonist muscle groups than their male counterparts during isometric squat press exercise. Female participants also had lower mean dominant leg antagonist muscle MF (Hz) scores than male participants ($p = 0.080$), but the difference was statistically insignificant ($p > 0.05$).

Table 15
Comparison of the mean MF (Hz) scores of non-dominant leg agonist and antagonist muscle groups in male and female participants during isometric squat press exercise

Muscle Group	Group	n	X	Sd	t	P
Agonist	Female	20	71.31	9.40	-1.157	0.255
	Male	20	74.54	8.25		
Antagonist	Female	20	61.69	9.22	-1.960	0.057
	Male	20	66.93	7.58		

Table 15 compares the mean non-dominant leg agonist and antagonist muscle MF (Hz) scores in male and female participants during isometric squat press exercise. There was no significant difference in agonist muscle MF (Hz) scores between male and female participants during isometric squat press exercise ($p > 0.05$). Although female participants had lower mean non-dominant leg antagonist muscle MF (Hz) scores than male participants ($p = 0.057$), the difference was statistically insignificant ($p > 0.05$).

Table 16
Comparison of the mean co-fatigue (agonist/antagonist) scores of dominant leg agonist and antagonist muscle groups in male and female participants during isometric squat press exercise

Muscle Group	Group	n	X	Sd	t	P
Co-fatigue	Female	20	1.25	0.22	-0.623	0.537
	Male	20	1.30	0.28		

There was no significant difference in the mean dominant leg agonist and antagonist muscle co-fatigue scores between male and female participants during isometric squat press ($p > 0.05$).

Table 17
Comparison of the mean co-fatigue (agonist/antagonist) scores of non-dominant leg agonist and antagonist muscle groups in male and female participants during isometric squat press exercise

Muscle Group	Group	n	X	Sd	t	P
Co-fatigue	Athletes	20	1.16	0.15	0.911	0.368
	Non-athletes	20	1.12	0.15		

There was no significant difference in the mean non-dominant leg agonist and antagonist muscle co-fatigue scores between male and female participants during isometric squat press ($p > 0.05$).

4. Discussion

Balance is the ability of the body to maintain its position on a support surface with as little movement as possible. Joint positions required to perform the desired function, muscles working in harmony, and the conservation of the center of gravity are also the ability of the body to maintain physical adaptation in response to changing situations. Balance plays an important role in maintaining physical performance and daily life under desired conditions. People with poor balance are more likely to have difficulty performing desired movements, whereas those with good balance are more likely to succeed in physical performance and have a high quality of life. Balance functions highly in relation to skeletal muscles and neural mechanisms. People with dysfunctions or disabilities in those systems must go through rehabilitation to perform activities of daily living, to restore mobility and coordination, and to return to sports. Therefore, we learn about balance by specifying dynamic or static balance, determining the transition from dynamic to static state, and identifying differences between using dominant and non-dominant feet. These data allow us to find out whether the balance is at the desired level. With this information, we can identify exercises or rehabilitation processes, choose the right methods, and decide in what order to implement those methods in cases of dysfunctions or disabilities in balance. We can also use this information to help people with good balance to maintain their balance. If we use the right tests and devices to obtain data on balance, we can help athletes improve their performance or undergo rehabilitation in cases of dysfunctions or disabilities.

Muscle fatigue is a complex chain of events involving different causes and mechanisms. Fatigue results from metabolic and structural changes in the muscles due to insufficient oxygen and malnutrition and the changes in the efficiency of the nervous system. Merletti and Farina et al. [19] group the sites of fatigue under the headings of (1) central fatigue, (2) fatigue of the neuromuscular junction, and (3) muscle fatigue. The term "muscle fatigue," which means "local muscle fatigue," is also expressed or equivalent to "neuromuscular" fatigue [20].

This study investigated the effects of lower extremity static muscle fatigue on balance components. The athletes and non-athletes in this study had similar physiological characteristics. Therefore, the groups were homogenous, suggesting that similar physiological characteristics would not affect physiological responses.

This study focused on Average Track Error (ATE) as a dynamic balance component to investigate pre-test and post-test dynamic balance scores. There was no significant difference between pre-test and post-test dynamic balance scores. There was a significant difference between pre-test and post-test static balance EO scores. However, there was no significant difference between pre-test and post-test Static EC, dominant single leg, and non-dominant single leg static balance scores. These results showed only significant differences in static EO balance scores after exercise. This difference indicated improvements in static EO balance scores after exercise. There was a significant difference in ATE scores between athletes and non-athletes. Non-athletes had a higher posttest ATE score than pretest ATE score, but the difference was statistically insignificant. On the other hand, athletes had a significantly higher post-test ATE score than pre-test ATE score, indicating that their dynamic balance components worsened more after exercise. There was no significant difference in pre-test balance components between athletes and non-athletes. Non-athletes had a significantly lower mean pre-test non-dominant leg EO score than athletes. Non-athletes also had significantly lower mean dominant leg EO and non-dominant EO static balance scores than athletes. There was no significant difference in EO and EC scores between athletes and non-athletes. Male participants had significantly lower pre-test and post-test ATE scores than female participants. The difference in pre-test ATE scores between male and female participants was significantly high. These results showed that although male participants had worse dynamic balance scores after exercise, they had better scores than their female counterparts. Female participants had a significantly lower mean pre-test non-dominant leg EO score than male participants. However, there was no significant difference in post-test non-dominant leg EO scores between male and female participants. Female participants also had a significantly lower mean post-test dominant leg EO score than male participants. There was no significant difference in the other static balance scores between male and female participants. Kwon et al. [21] investigated the effects of lower extremity isokinetic muscle fatigue on static balance and reported static balance deterioration after muscle fatigue. Rozzi et al. [22] used electromyography to determine fatigue in six muscle groups responsible for knee joint stability. They reported reductions in stability index and proprioceptive abilities in both sexes. Fatahi et al. [23] compared the electromyography activity of the lower extremity muscle groups before and after fatigue. They reported increases in electromyography activations in the muscle groups close to the knee joint after fatigue. They concluded that muscle fatigue increased the sensitivity of the joints and thus made postural control difficult. Research shows that athletes who participate in training programs to improve balance performance have better balance components than non-athletes [24, 25, 26, 27].

Decreases in mean frequency (MF) in surface EMG profiles are used to determine fatigue (high frequency) in an isometric muscle movement. Methods used to generate MF data often rely on fixed waveforms and high sampling rates [28]. This study examined the mean differences in the MF (Hz) scores of the dominant leg agonist and antagonist muscles in athletes and non-athletes during a five-repetition isometric squat press exercise. Considering the muscles involved in the exercise, we observed a statistical difference in the *rectus femoris*, an agonist muscle. This result showed that non-athletes had a lower MF score in the *rectus femoris* than athletes, indicating that non-athletes experienced more fatigue during exercise. Of the antagonist muscles, the only difference was observed in the *semi tendineus*. Non-athletes had a lower MF score in the *semi tendineus* than athletes, indicating that non-athletes experienced more fatigue during exercise. There was no significant difference in the MF scores in the other dominant leg agonist and antagonist muscles. This study examined the mean differences in the MF (Hz) scores of the non-dominant leg agonist and antagonist muscles in athletes and non-athletes during the five-repetition isometric squat press exercise. Considering the muscles involved in the exercise, we observed a statistical difference in the *rectus femoris*. This result showed that non-athletes had a lower

MF score in the *rectus femoris* than athletes, indicating that non-athletes experienced more fatigue during exercise. There was no significant difference in MF scores in the other non-dominant leg agonist and antagonist muscles. This study examined the mean differences in MF (Hz) scores of the dominant leg agonist and antagonist muscles in athletes and non-athletes during isometric squat press. Non-athletes had significantly lower mean scores in antagonist muscle groups than athletes, indicating that non-athletes experienced more fatigue in the antagonist muscle groups during exercise than athletes. There was no significant difference in the MF scores of the agonist muscle groups between athletes and non-athletes. This study examined the mean differences in the MF (Hz) scores of the non-dominant leg agonist and antagonist muscles in athletes and non-athletes during isometric squat press. There was no significant difference in the MF (Hz) scores of the non-dominant leg agonist and antagonist muscles between athletes and non-athletes. This study looked into the mean differences in the MF (Hz) scores of the non-dominant leg agonist and antagonist muscles in male and female participants during isometric squat press. Female participants had a significantly lower MF (Hz) score in the agonist muscle groups than male participants. This result showed that female participants experienced more fatigue in the agonist muscle groups than male participants during exercise. Female participants had a lower MF (Hz) score in the antagonist muscle groups than male participants, but the difference was statistically insignificant. This study investigated the mean differences in the MF (Hz) scores in the non-dominant leg agonist and antagonist muscles in male and female participants during isometric squat press exercise. There was no significant difference in the MF (Hz) scores in the non-dominant leg agonist muscles between male and female participants during isometric squat press exercise. Female participants had lower MF (Hz) scores in the antagonist muscle groups than male participants, but the difference was statistically insignificant. Mademli and Arampatzis [29] used EMG to investigate the fatigue level of the *gastrocnemius medialis* in isometric plantar flexion angle. They found that changes in fascicle length and pennation angle of *gastrocnemius medialis* during contraction affected the strength potential of the muscle due to the force-length relationship and the transfer of force to the tendon. They presented evidence that this might contribute to the increase in the EMG activity of the *gastrocnemius medailis* during submaximal isometric sustained contractions. These results are similar to ours. Our result also showed that the decrease in the fascicle length of the muscles involved in the continuous isometric contraction increased muscle fatigue. This was observed with an increase in the EMG activity of the muscles and a decrease in the MF scores. EMG activity usually increases gradually for a given force during a submaximal isometric contraction [30, 31, 32, 33]. This increase suggests that the body involves more motor units to make up for the inability of the currently active muscle fibers to maintain force generation [30, 31]. Some of the mechanisms that contribute to changes in muscle force generation during fatigue are metabolite accumulation [33, 34, 35], inhomogeneous activation [36], and changes in Ca^{2+} concentration and sensitivity [37, 38]. In addition, an increase in antagonist muscle activity during sustained isometric contraction may exacerbate fatigue in the agonist muscles [39]. Changes in ankle angle during an isometric contraction [40, 41] may affect the fascicle length [42], and thus, the force potential of the muscle due to force. The pennation angle is a component of the force that acts through muscle fibers horizontally and orthogonally to the tendon. Changes in the pennation angle are regarded as an increase in this angle during isometric contraction, which leads to a reduction in force transmission to the tendon.

There was a significant difference in the mean co-fatigue scores of the dominant leg agonist and antagonist muscle groups between athletes and non-athletes during isometric squat press exercise. This result showed that athletes experienced more similar fatigue in the agonist and antagonist muscles during exercise than non-athletes. There was no significant difference in the mean co-fatigue scores of the non-dominant leg agonist and antagonist muscle groups between athletes and non-athletes during isometric squat press exercise. There was no significant difference in the mean co-fatigue scores of the dominant leg agonist and antagonist muscle groups between male and female participants during isometric squat press exercise. There was no significant difference in the mean co-fatigue scores of the non-dominant leg agonist and antagonist muscle groups between male and female participants during isometric squat press exercise. Agonist and antagonist co-fatigue play an important role in stabilizing the knee joint after fatigue. However, it is still unclear whether selective fatigue of agonist or antagonist muscles causes changes in muscle activation patterns. Determining the co-fatigue levels of agonist and antagonist muscles indirectly affects muscle activation, which is an important factor affecting exercise efficiency because it depends on muscle activation levels at the moment of maximum contraction during voluntary contraction [18].

5. Conclusions

Above all, we should ensure that motor skills are fully and harmoniously developed at every stage to turn non-athletes into well-trained athletes. Some researchers focus on possible strategies to improve athletes' static and dynamic balance and the impact of different sports activities on postural strategies at an early age. Balance is a complex composition. Therefore, we need different applications to understand the mechanisms underlying balance and discover athletes' potential. Lower extremity proprioception exercises have positive effects on static body balance parameters.

Surface EMG is a non-invasive source of information regarding the status of skeletal muscle fatigue. Numerous practical biomechanical methods show that interdisciplinary bioengineering approaches are successful in providing quantitative EMG-based information on the fatigue state of skeletal muscles. If we integrate advanced measurement techniques with sophisticated mathematical methods and digital signal processing techniques, we can establish a solid foundation for standardizing methods suitable for biomechanical situations. We foresee those biomechanical methods will be improved, standardized, and implemented in the future. Modern methods in a new muscle fatigue monitoring device have not yet been standardized in clinical diagnostic practice both in sports and medical rehabilitation processes.

A co-fatigue index can help us determine efficiency in sports branches. It is important to identify co-fatigue, especially during isometric contractions. A co-fatigue index can help us investigate co-fatigue, especially during isometric effort at different knee joint angles and different joints.

Declarations

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Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Ethics Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Clinical Research Ethics Committee of Ordu University (KAEK-216).

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Authors’ contribution

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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Figures

Figure 1

Squat Position for Lower extremity Static Fatigue