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THE EFFECT OF TRUNK EXTENSORS AND ABDOMINAL MUSCLE FATIGUE ON STATIC AND DYNAMIC BALANCE

VPLIV UTRUJENOSTI MIŠIC IZTEGOVALK TRUPA IN TREBUŠNIH MIŠIC NA STATIČNO IN DINAMIČNO RAVNOTEŽJE

ABSTRACT

The aim of this study was to investigate the effect of static fatigue of trunk extensor and abdominal muscle groups on static and dynamic balance components. The study sample consisted of 40 healthy volunteers. Lumbar erector spinae, multifidus, and latissimus dorsi, external oblique, rectus abdominis and internal oblique muscles were measured on the dominant side. Dynamic and static balances were measured before and after the test protocol following EMG analysis. Pre-test and post-test static and dynamic balance scores showed that there was a statistically significant difference in OE (open-eyed) static balance values between the experimental and control groups (p<.01). There was a statistically significant difference in ATE (Average track error) scores between male and female participants (p<.05). There was a statistically significant difference in mean coordinated fatigue values of agonist and antagonist muscle groups in the Biering-Sørensen position between male and female participants (p<.05). Deterioration was observed in participants' OE static balance, indicating that OE static balance deterioration occurred again in the OE position. There was a statistically significant difference in co-fatigue values of abdominal muscles between the two groups.

Keywords: trunk extensor muscles, abdominal muscles, EMG, static balance, dynamic balance, fatigue, co-fatigue

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IZVLEČEK

Namen te študije je bil raziskati vpliv statične utrujenosti mišic iztegovalk trupa in trebušnih mišic na statične in dinamične komponente ravnotežja. V študiji je sodelovalo 40 zdravih prostovoljcev. Na dominantni strani so bile izmerjene mišice erector spinae, multifidus, latissimus dorsi, zunanje poševne mišice, rectus abdominis in notranje poševne mišice. Dinamično in statično ravnotežje je bilo izmerjeno pred testnim protokolom in po njem, prav tako EMG. Rezultati statičnega in dinamičnega ravnotežja pred testom in po njem so pokazali, da obstaja statistično pomembna razlika v vrednostih statičnega ravnotežja OE (z odprtimi očmi) med eksperimentalno in kontrolno skupino (p<0.01). Med udeleženci moškega in ženskega spola je obstajala statistično pomembna razlika v vrednostih ATE (povprečna napaka sledenja) (p<0.05). Med udeleženci moškega in ženskega spola je obstajala statistično pomembna razlika v povprečnih vrednostih koordinirane utrujenosti agonističnih in antagonističnih mišičnih skupin v položaju Biering-Sørensenovega testa (p<0.05). Pri udeležencih je bilo opaženo poslabšanje statičnega ravnotežja v položaju OE, kar kaže na to, da se je poslabšanje statičnega ravnotežja v položaju OE ponovilo. Med obema skupinama je bila ugotovljena statistično pomembna razlika v vrednostih sočasne utrujenosti trebušnih mišic.

Ključne besede: mišice iztegovalke trupa, trebušne mišice, EMG, statično ravnotežje, dinamično ravnotežje, utrujenost, sočasna utrujenost

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INTRODUCTION

Fatigue is usually described as an inability of muscle groups to generate the desired force during continuous or intermittent contraction. Muscular fatigue is the inability of muscles to generate or sustain sufficient force through contraction (Nikolić & Ilić, 1992; Gandevia, 2001). Muscle fatigue might be caused by lactic acid accumulation, depletion of phosgene stores, depletion of muscle glycogen stores, inappropriate blood supply and lack of oxygen etc.

Balance is the ability to correctly positioning the vertical projection of the center of gravity on the support surface during rest or activity. Balance is achieved by assessment of vestibular, visual and somatosensory stimuli by the central nervous system and generation of proper responses in the musculoskeletal system (Kılıç, Börü, Bayrakçı, Aksoy & Ergun, 2018). Balance can also be defined as the ability of the body to resist gravity and internal and external forces, which is achieved by voluntary of reflex muscle activation. . The skeletal system and the muscular system should collaborate to resist gravity (Lazar, 1998). The vestibular system is a balance system which is responsible for accelerating the head and transmitting gravitational forces to higher centers as biological signals. The control centers in the brain perceive the subjective position of the head and develop reflexes to achieve and sustain balance by orienting the body according to its surroundings. There are two different balances: dynamic and static. Performance-enhancing training methods include posture control and balance exercises to minimize the risk of injury. Balance is a general term encompassing dynamics that prevent body mass from falling and is also a high-quality conditioning in many sports. Training methods focus not only on increasing specific fitness characteristics but also on reducing the risk of postural balance injury (Bressel, Yonker, Kras & Heath, 2007). Balance components can be associated with muscle fatigue in the center of the body in all sports involving body movements. Moreover, the visual system provides information regarding flow movement of the environment, changes in retinal disparity, imagine size and position (Elliot, Patla, Flanagan, Spaulding, Rietdyk, Strong & Brown, 1995).

There are some sports in which static and/or dynamic balance limits performance. Not only does low balance affect performance, but also increases the risk of injury. Balance components, therefore, play a key role in quickly readjusting to baseline after sport-specific training (Zemková, 2014). Postural balance and oculomotor control are influenced by neck kinaesthetic functions in elite ice hockey players (Rosker, Kristjansson, Vodicar & Rosker, 2021). To that end, such stabilographic parameters as sway area and velocity or path length are analyzed. A stabilogram displays the pressure center coordinates as a function of time. Medio-lateral and antero-posterior sways define the x and y coordinates, respectively. Changes can be observed in these parameters during and after training. For example, dominant pressure center coordinates on one of the axes may shift during sport-specific training (e.g. throwing). We can also draw a sway velocity-time curve to analyze the magnitude and readjustment of balance after sport-specific training (e.g., biathlon) (Zemková, 2014). Sports-specific training can lead to sports-specific balance adaptation (Rosker & Vodicar, 2020). Less precise monitor of the center of mass might affect performance in weightlifting, powerlifting, golf and throwing. Trauma caused by such exercises may affect balance in fencing, boxing, karate, taekwondo, judo, and wrestling. The capacity of regional muscle systems (e.g., fatiguing hip muscles, fatiguing neck muscles) to withstand fatigue can affect balance performance (Schieppati, Nardone & Schmid,2003; Sarabon, Hirsch, & Majcen, 2016). Determining what type of balance is of importance in a sport helps us to improve that sport-specific performance and minimize the risk of injury. Moreover, three systems (proprioception, vision and vestibular) should provide information regarding performance to achieve optimal balance (Hammami, Behm, Chtara, Othman & Chaouachi, 2014).

It is easier to record sEMG signals during isometric contractions than during dynamic contractions. Isometric contractions involve no movements and, hence, less motion interaction than do dynamic contractions. However, some other factors may affect sEMG signals during static contractions and make their interpretation difficult (Farina, Merletti & Enoka, 2004). For example, subcutaneous tissue layers of different thicknesses (hypodermis) or electrode configuration (proximity to tendons) can change the intensity of sEMG signals. It is the electrical activity of muscles that are close enough to be recorded using surface electrodes. This input signal can be recorded even if the muscle is relaxed. Placing electrodes correctly may reduce this unwanted effect (Gonzalez-Izal, Malanda, Gorostiaga & Izquierdo, 2012). A main characteristic of sEMG signals during isometric contractions is the change in spectral sEMG signals that last for several seconds. The mean value of sEMG signals and the correlation between samples is, therefore, not time dependent, which leads us to the assumption that sEMG signals are stationary (Farina, 2006). Since an EMG signal recorded during an isometric contraction is assumed to be constant, conventional frequency-based techniques such as discrete Fourier transform can be used to determine changes in the power spectral content of EMG signals. It is easier to interpret an sEMG signal recorded during an isometric contraction than that recorded during a dynamic contraction (Cairns, Knicker, Thompson & Sjogaard, 2005). Neural activation pattern, however, varies across static and dynamic contractions, and it is questionable to assume that fatigue-induced changes recorded during isometric contractions are the same as those recorded during dynamic contractions (Cheng & Rice, 2005).

The association of balance components, which are critical in all sports involving movement, with the fatigue of the muscles in the body center leads training programs to focus on the trunk extensor and abdominal muscle groups. In this context, it is important to study the subject. There are limited number of studies on this subject in the literature (Sarabon, Hirsch & Majcen, 2016). Identifying the effect of the muscles in the body center on static or dynamic balance can highlight the significance of the relevant muscle groups for the balance component needed. Maintaining postural control requires coordination between muscle and movement patterns and precise monitoring of all body movements. Balance components, which are critical in all sports involving movement, can be associated with the fatigue of the muscles in the body center. The aim of this study was, therefore, to explore the effect of static fatigue levels on the static and dynamic balance components of the trunk extensor and abdominal muscle groups. The study also focused on examining the EMG-based computational co-fatigue index and differences in individual sporting skill levels between the agonist and/or antagonist muscles and genders and on comparing the EMG-based co-fatigue indices of the experimental and control groups in terms of the agonist and antagonist muscles involved in the static exercise of the trunk extensor and abdominal muscle groups.

METHODS

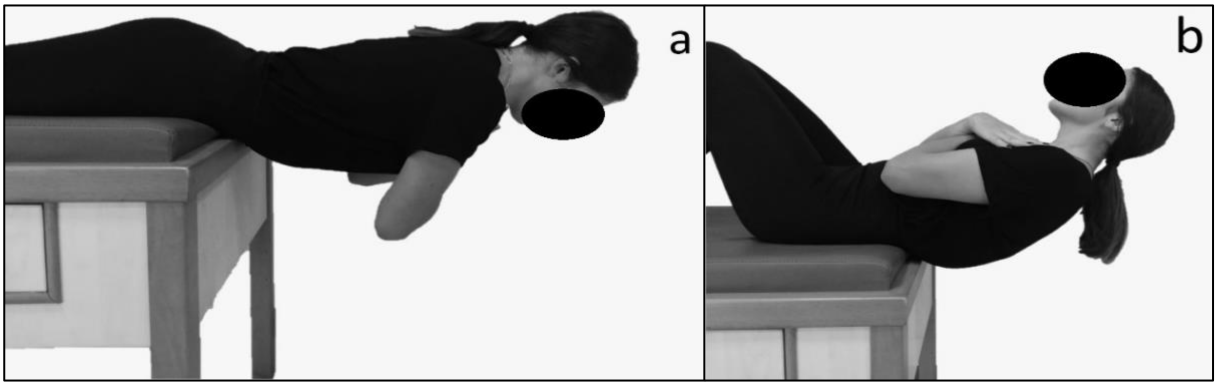
Participants

The study sample consisted of 40 healthy athletes (10 female athletes: age 20.50 ±1.08; 10 male athletes age 21.00 ±1.24; 10 female sedentary controls age 21.10 ±1.969; 10 male sedentary controls age 21.70 ±1.88) between the ages of 18 and 24 years with normal BMI. Power analysis was performed to ascertain whether the number of participants is sufficient to detect significant differences. The exclusion criteria were acute/chronic abdominal or low back pain/injury and history of musculoskeletal or skin diseases. All participants completed 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. The study was approved by the Health Research Ethics Committee of the university (No: 2018-147).

Data Collection

Participants first completed an isometric fatigue protocol for the trunk extensor or abdominal muscles and then a fatigue protocol for the opposite muscle groups. The Biering-Sørensen position was used to test the fatigue of the trunk extensor muscles (Figure 1) (McGill, Childs & Liebenson, 1999). The Biering-Sørensen position was used in reverse to determine the fatigue of the abdominal muscles. Participants were adjusted to the edge of the test table at the level of T12 spinal cord and were asked to maintain the isometric position until they were exhausted at both fatigue stage.

Figure 1. A representative participant shown in the Biering-Sørensen position (a) for trunk extensor fatigue and in a modified reserve Biering-Sørensen position (b) for abdominal muscle fatigue.



Lumbar erector spinae (LE), *multifidus* (ML) and *latissimus dorsi* (LD) muscles, which are the trunk extensors that contract most, and *external oblique* (EO), rectus *abdominis* (RA) and *internal oblique* (IO) muscles in the reverse Biering-Sørensen position modified for abdominal muscle fatigue was measured on the dominant side using a Noraxon device (myoMUSCLE, Noraxon, Scottsdale, AZ, USA) with wireless superficial Ag / AgCl electrodes. Electrodes were placed at the locations defined by SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscle).

EMG Analysis

After EMG data were filtered through a 20 Hz high pass Butterworth filter, median frequency (MF) (Hz) was calculated at the interval of 5 and 20 sec. MF is commonly used to calculate fatigue index in muscle fatigue studies performed with EMG signals. MF is the frequency that divides the power spectrum into two regions with equal power. The more fatigue the muscle, the lower the MF during isometric contraction (De Luca, 1984).

Co-fatigue index is the ratio of the MF of the agonist muscle group to that of the antagonist muscle group (Sözen, Erdoğan, İnce & Soylu, 2019). As an example, if the MF values of the agonist and antagonist muscle groups are 60 and 50 Hz, respectively, then the co-fatigue index is 60/50 = 1.2.

Balance Measurements

Following EMG analysis, Dynamic and static balance were measured before and after the test protocol using a CSMI TecnoBody PK-252 isokinetic stability system, which provides objectively measurable balance data (Ince, Ulupinar & Özbay 2020). The movable balance platform of the system runs on air piston servo motors and does measurements with an operating angle of 15 degrees in every direction. Results can be viewed on screen and recorded at the same time.

The system is a precise isokinetic balance system because it automatically adjusts the balance of the platform to the weight of the person and the coefficient of steadiness at each point. The platform applies different resistance to everyone, and therefore, everyone measures on a platform that applies resistance according to their weight. This allows us to make a weight-independent comparison of results. The automatic motor locking function allows the system to instantly switch from dynamic to static measurement.

Static Balance Measurement

Static test was performed on a stationary platform under open-eyed (OE) and closed eye (CE) conditions. Participants stood with both feet positioned shoulder width apart and equidistant from the point of origin, with reference to the lines on the x and y axes of the platform. Participants were asked to maintain the position during the test, which lasted 30 seconds. The test was started with the pressing of the start button on a computer and was automatically terminated by the computer after 30 sec. The static balance score of each individual was obtained by summing the forward-backward standard deviation and the right-left standard deviation. The greater the balance score, the worse the balance of the participant.

Dynamic Balance Measurement

During the dynamic test, participants stood on both feet positioned shoulder width apart and equidistant from the point of origin, with reference to the lines on the x and y axes of the platform. The 60-sec dynamic test involved five rounds of clockwise rotation of the platform following a circular path on the screen. Whenever a participant failed, his/her score at the time of failure was recorded as his/her data. Dynamic balance measurement data is referred to as average track error (ATE), which indicates the amount of exceeding the boundaries of the track one should follow. The lower the ATE, the better the dynamic balance.

Statistical Analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS), version 22. Descriptive statistical methods such as arithmetic mean (X) and standard deviation (SD) were used. A Shapiro–Wilk W-test showed that the data were normally distributed. Differences in MF values of different groups (athletes-sedentary; female-male) were analyzed using independent samples t-test. Static and dynamic balance pretest and posttest data were compared using paired samples t-test.

RESULTS

Table 1. Participants' pre- and post-exercise static and dynamic balance values.

Variable	**Group**	**n**	**X**	**SD**	**t**	**p**
ATE	Pre-test	40	47.75	15.01	-1.004	0.322
	Post-test		49.77	15.67		
Static OE	Pre-test	40	6.40	1.93	-6.569	0.000
	Post-test		8.55	2.21		
Static CE	Pre-test	40	10.50	3.45	-1.353	0.184
	Post-test		11.55	4.91		

There was no statistically significant difference between participants' pre-test and post-test ATE and CE static balance values. However, there was a statistically significant difference between their pre-test and post-test OE static balance values, indicating deterioration in participants' OE static balance after the exercise.

Table 2. Athletes' and sedentary controls' pre- and post-exercise static and dynamic balance values.

Test	**Variable**	**Group**	**n**	**X**	**SD**	**t**	**p**
Pre-test	ATE	Athlete	20	50.50	17.48	1.164	0.252
		Sedentary	20	45.00	11.87		
	Static OE	Athlete	20	6.60	2.23	0.650	0.520
		Sedentary	20	6.20	1.60		
	Static CE	Athlete	20	11.00	3.46	0.913	0.367
		Sedentary	20	10.00	3.46		
Post-test	ATE	Athlete	20	52.90	17.42	1.271	0.211
		Sedentary	20	46.65	13.40		
	Static OE	Athlete	20	8.35	2.00	-0.565	0.575
		Sedentary	20	8.75	2.44		
	Static CE	Athlete	20	11.00	2.82	-0.702	0.487
		Sedentary	20	12.10	6.40		

There was no statistically significant difference in pre-test and post-test dynamic, OE static and CE static balance values between athletes and sedentary controls.

Table 3. Men's and women's pre- and post-exercise static and dynamic balance values.

Test	**Variable**	**Group**	**n**	**X**	**SD**	**t**	**p**
Pre-test	ATE	Female	20	52.40	15.85	2.036	0.049
		Male	20	43.10	12.87		
	Static OE	Female	20	6.40	2.28	0.000	1.000
		Male	20	6.40	1.56		
	Static CE	Female	20	10.55	3.94	0.090	0.929
		Male	20	10.45	2.99		
Post-test	ATE	Female	20	55.25	18.53	2.332	0.025
		Male	20	44.30	9.86		
	Static OE	Female	20	8.40	2.77	-0.423	0.675
		Male	20	8.70	1.52		
	Static CE	Female	20	10.10	2.40	-1.928	0.061
		Male	20	13.00	6.28		

There was a statistically significant difference in ATE values between male and female participants. However, there was no statistically significant difference in static balance scores between the two.

Table 4. Differences in MF values of agonist and antagonist muscle groups during isometric contraction of trunk extensor muscles between athletes and sedentary controls.

Muscle	**Group**	**n**	**X**	**SD**	**t**	**p**
Agonist	Athlete	20	70.03	8.98	0.460	0.648
	Sedentary	20	68.56	11.16		
Antagonist	Athlete	20	36.80	11.30	0.493	0.625
	Sedentary	20	35.25	8.38		

There was no statistically significant difference in the mean MF values of the agonist and antagonist muscle groups during the Biering-Sorensen position applied for the fatigue of the trunk extensor muscles between athletes and sedentary controls.

Table 5. Mean differences in MF (Hz) values of agonist and antagonist muscle groups during isometric contraction of abdominal muscles between athletes and sedentary controls.

Muscle	**Group**	**n**	**X**	**SD**	**t**	**p**
Agonist	Athlete	20	51.88	7.98	1.560	0.127
	Sedentary	20	48.00	7.73		
Antagonist	Athlete	20	24.08	5.31	-1.923	0.062
	Sedentary	20	27.16	4.81		

There was no statistically significant difference in the mean MF values of the agonist and antagonist muscle groups during the Biering-Sorensen position applied for the fatigue of the abdominal muscles between athletes and sedentary controls.

Table 6. Mean differences in co-fatigue values of agonist and antagonist muscle groups during isometric contraction of trunk extensor muscles between athletes and sedentary controls.

	Group	**n**	**X**	**SD**	**t**	**p**
Co-fatigue	Athlete	20	2.10	0.79	0.284	0.778
	Sedentary	20	2.04	0.57		

There was no statistically significant difference in the mean co-fatigue values of the agonist and antagonist muscle groups during the Biering-Sorensen position applied for the fatigue of the trunk extensor muscles between athletes and sedentary controls.

Table 7. Mean differences in co-fatigue values of agonist and antagonist muscle groups during isometric contraction of abdominal muscles between athletes and sedentary controls.

	Group	**n**	**X**	**SD**	**t**	**p**
Co-fatigue	Athlete	20	2.24	0.61	2.45	0.019
	Sedentary	20	1.82	0.45		

There was a statistically significant difference in the mean co-fatigue values of the agonist and antagonist muscle groups during the Biering-Sorensen position applied for the fatigue of the abdominal muscles between athletes and sedentary controls.

Table 8. Mean differences in co-fatigue values of agonist and antagonist muscle groups during isometric contraction of trunk extensor muscles between male and female participants.

	Group	**n**	**X**	**SD**	**t**	**p**
Co-fatigue	Female	20	2.35	0.76	2.762	0.009
	Male	20	1.80	0.45		

There was a statistically significant difference in the mean co-fatigue values of the agonist and antagonist muscle groups during the Biering-Sorensen position applied for the fatigue of the trunk extensor muscles between male and female participants.

Table 9. Mean differences in co-fatigue values of agonist and antagonist muscle groups during isometric contraction of abdominal muscles between male and female participants.

	Group	**n**	**X**	**SD**	**t**	**p**
Co-fatigue	Female	20	1.96	0.61	-0.802	0.428
	Male	20	2.10	0.52		

There was no statistically significant difference in the mean co-fatigue values of the agonist and antagonist muscle groups during the Biering-Sorensen position applied for the fatigue of the abdominal muscles between male and female participants.

DISCUSSION

In this section, the results obtained from our study are discussed with different studies in the literature. According to Helbostad et al. (Helbostad, Sturnieks, Menant, Delbaere, Lord & Pijnappels, 2010) muscle fatigue reduces muscle strength and balance. Static trunk muscle fatigue increased our participants' ATE, which is a pre-test and post-test dynamic balance component, however, it was not statistically significant. Static trunk muscle fatigue caused a significant change in pre-test and post-test static OE balance components. Static fatigue negatively affects OE balance. However, static trunk muscle fatigue did not cause a significant change in pre-test and post-test static CE balance components.

Dieen et al. (Dieen, Luger & Eb, 2012) reported that the fatigue caused by the isotonic contraction of muscles disrupted the static and dynamic trunk balance and those participants mostly obtained OE static balance scores, which is like our result. Daneshjoo et al. (Daneshjoo, Mokhtar, Rahnama & Yusof, 2012) reported that pre-exercise warm-up protocols improved static and dynamic balance components. If a warm-up protocol does not cause muscle fatigue, it does not deteriorate the balance components. Several mechanisms highlight the observed effects of fatigue. Activation levels should be elevated to maintain agonistic muscle fatigue and force output, which increases the instability of muscle strength (Missenard, Mottet & Perrey, 2009), which results in increased sway. Given that variable muscle strength does not limit the kinematic variability in the trunk and that it may lead to a further increase in sway amplitude, an increase in antagonistic contraction increases the variability in muscle strength (Selen, Beek & Dieen, 2005). Fatigue slows down muscle responses due to increased proprioceptive thresholds (Taimela, Kankaanpaa & Luoto, 1999) and slower force development in the fatigued muscles (Perrey, Racinais, Saimouaa & Girard, 2010). Slower responses to balance deterioration increase the sway amplitude (Radebold, Cholewicki, Polzhofer & Greene, 2001) and possibly reduce the intact sway frequency. This also increases the amplitude, and thus, prevents movement distortion (Reeves, Cholewicki & Narendra, 2009). Lastly, fatigue is associated with an increased respiratory difficulty that affects trunk stability (Janssens, Brumagne, Polspoel, Troosters & McConnell, 2010). The most prominent respiratory effect is expected to be observed in the sagittal plane. Our results showed no statistically significant difference in the static trunk muscle fatigue pre-test and post-test dynamic balance, static OE and static CE scores between athletes and sedentary controls. Some studies reported that sedentary individuals had lower static and dynamic balance scores than athletes (Davlin, 2004; Gökdemir, Ciğerci, Er, Suveren & Sever, 2012). This difference might be due to the fact that those researchers used different static and dynamic balance test protocols. Research also shows that balance plays a key role in many athletic activities and sport-specific postural control and can improve performance despite the weak relationship between the two (Alderton, Moritz & Moe-Nilssen, 2003; Hrysomallis, 2011). Numerous studies have examined the coordination of movement of the eyes, head, body, and limbs during a locomotor task to analyze various motor controls and orientations (Cremieux & Mesure, 1994; Imai, Moore, Raphan & Cohen, 2001; Paillard, Noe, Riviere, Marion, Montoya & Dupui, 2006). However, whether elite athletes use different postural control strategies (OE or CE and single or double legged posture) from other athletes is still up for debate. There is little evidence to support that CE balance assessment is more effective than OE balance assessment. Paillard et al. (Paillard, Costes Salon, Lafont & Dupui, 2002) showed that elite judoists were more dependent on visual information for posture control. Moreover, experienced athletes use specific sensory information to regulate posture and balance depending on the requirements of the sport (Perrin, Schneider, Deviterne, Perrot & Constantinescu, 1998; Vuillerme, Nougier & Prieur, 2001). For example, not only should rugby players control their posture but also obtain visual information about their teammates and opponents in order to perform various skills (for example, high-speed sprints and change direction to intercept the ball or kick it for a throw) (Brault, Bideau, Craig & Kulp, 2010). Rugby training, therefore, involves strong visual dependence on the teammates, the ball and the opponent team. Romero-Franco et al. (Romero-Franco, Martínez-López, Lomas-Vega, Hita-Contreras & Martínez-Amat, 2012) investigated the effect of a proprioceptive training program on the control of center of gravity in sprinters and reported that OE exercises improved balance. This dependence on vision also exists in surfing (Chapman, Needham, Allison, Lay & Edwards, 2008) and soccer (Burfield & Fischman, 1990). Surfers performed better in anterior-posterior balance than subjects without training and partially transferred static postural control functions and developed specific balance models (Chapman, Needham, Allison, Lay & Edwards, 2008). However, different results have also been reported. For example, there are studies that report that judoists and triathletes are less dependent on OE posture (Williams, Weigelt, Harris & Scott, 2002; Nagy, Toth, Janositz, Kovacs, Faherkiss, Angyan & Horvath, 2004; Simmons, 2005). These results indicate that the importance of OE and CE posture varies across sports and can be improved by sport-specific training. Male participants had better dynamic balance than female participants, which was observed in both pre-test and post-test scores. However, there was no statistically significant difference in the pre-test and post-test static balance scores between male and female participants.

Regional muscle fatigue is a complex process due to various physiological and psychological events. In general, low frequency band amplitude increases while high frequencies, referred to as the compression of EMG signals, relatively decrease during a continuous isometric contraction. Therefore, MF is often used to monitor muscle changes in fatigue during isometric contraction (Duchene & Goubel, 1993). MF values obtained from superficial EMG signals are an important index for regional muscle fatigue (Xie & Wang, 2006). Our results showed no statistically significant difference in the MF values of the agonist and antagonist muscles during the isometric contraction of the trunk extensor muscles between athletes and sedentary controls. Similarly, Santos et al. found no significant difference in MF values of lower extremity isometric muscle fatigue between athletes and sedentary individuals (Santos, Semeghuini, Azevedo, Colugnati, Filho, Alves & Arida, 2008). Our results showed no statistically significant difference in the MF values of the agonist and antagonist muscles during the isometric contraction of the trunk extensor and abdominal muscles between athletes and sedentary controls. We also used the MF values to calculate the fatigue index and then the co-fatigue index. Muscle co-contraction plays a key role in achieving joint stabilization, minimizing the impact of potential internal and external disturbances, and adjusting joint load (Choi, 2003; Harput, Soylu, Ertan, Ergun & Mattacola, 2014). Muscle co-fatigue index plays as important a role as co-contraction or co-activation in maintaining joint stabilization because a change in the muscle co-fatigue process affects the motor control model, which may result in a reduction in muscle co-contraction (Sözen, Erdoğan, İnce & Soylu, 2019). Muscle specific movement patterns might lead to a change in muscle co-fatigue levels, just like the way specific movement patterns lead to a reduction in muscle co-activation (Şimşek & Ertan, 2014). Our results showed no significant difference in the co-fatigue values of the trunk extensor muscles between athletes (2.10) and sedentary controls (2.04). There was, however, a significant difference in the co-fatigue values of the abdominal muscles between athletes (2.24) and sedentary controls (1.82). These results suggest that sedentary individuals had similar antagonist and agonist group muscle fatigue values and that athletes' antagonistic muscle fatigue values differed from their agonist muscle fatigue values. This result indicates that the agonist muscles of the athletes generated adequate force to maintain joint stability during the isometric contraction of the abdominal muscles and that their antagonist muscles were not involved much in the process. The fatigue indices of the two groups differed. However, both the agonist and antagonist muscle groups of the sedentary individuals were involved in the process during the same contraction. Our results showed no statistically significant difference in the agonist and antagonist muscle fatigue values of the extensor and abdominal muscle groups between male and female participants, suggesting that both groups had similar fatigue levels during the contraction. There was, however, a statistically significant difference in the co-fatigue values during the isometric contraction of the trunk extensor muscles between male (1.80) and female participants (2.35), suggesting that the agonist and antagonist muscles of male participants had similar fatigue values compared to those of female participants. This indicates that the agonist muscles of women are durable enough to maintain joint stability during the isometric contraction of the trunk extensor. Studies show that women have greater muscle endurance than men during isometric exercises (Fulco, Rock, Muza, Lammi & Cymerman, 1999; Clark, Manini, Thé, Doldo & Ploutz-Snyder, 2003; Russ & Kent-Braun, 2003; Hunter, Critchlow, Shin & Enoka, 2004; Hunter, Butler, Todd, Gandevia & Taylor, 2006), which is similar to our results on abdominal isometric muscle fatigue. Our results showed no statistically significant difference in the co-fatigue values during the isometric contraction of the abdominal muscles between male (2.10) and female participants (1.96). As the co-fatigue index approaches 1, both the antagonist and agonist muscles are involved in maintaining joint stability during their isometric contraction.

In addition to the inclusion and exclusion criteria of the volunteers from the methods section, previous surgery of the lumbar region of the volunteers was also considered because lumbar region surgery is one of the criteria affecting the balance performance of the individual (Rosker, Rosker & Sarabon, 2020). Moreover, inclusion and exclusion criteria are limited not checking for other musculoskeletal disorders that could influence postural balance (Han, Anson, Waddington, Adams, & Liu 2015; Majcen, Vodicar & Kristjansson, 2022).

CONCLUSION

It is unclear to what extent loss of trunk stability affects sporting performance. However, balance and trunk stability are hard pressed in many sports. Moreover, fatigue-induced deterioration of trunk stability and resulting loss of balance may reduce performance and increase the risk of injury. Although trunk stability is adversely affected by a series of fatigue exercises that reflect training and competition intensity, it yields a few practical results. When planning the sequence of exercises, trainers may have to consider studies focusing on preventing potential post-fatigue loss of balance. It should also be kept in mind that muscle fatigue caused by warm-up protocols may result in deterioration, especially in the OE trunk position. Not only the primary agonist muscles involved in the process but also the antagonist muscles should be improved during the endurance training of the trunk muscles.

We think that the co-fatigue index that we propose might be useful for further studies on different exercise and load levels, different muscles, different athletes and sedentary individuals, and different fatigue indices (mean frequency, normalized median frequency or slope of consecutive median frequencies instead of median frequency). We also believe that this approach will contribute to the sports sciences and rehabilitation field and training of healthy athletes and sedentary in terms of exercise conditions that promote the physiological process of joint stabilization.

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Ethical Considerations

The study was approved by the Health Research Ethics Committee of University of Ordu (No: 2018-147).

Declaration of Concflicting Interests

Authors have declared that no competing interest exists.

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REFERENCES

Alderton AK, Moritz U, Moe-Nilssen R. (2003). Force plate and accelerometer measures for evaluating the effect of muscle fatigue on postural control during one legged stance. *Physiotherapy Research International,* 8:187-199.

Brault S, Bideau B, Craig C, Kulp R. (2010). Balancing deceit and disguise: How to successfully fool the defender in a 1 vs. 1 situation in rugby. *Human Movement Science,* 29:412-425.

Bressel E, Yonker JC, Kras J, Heath EM. (2007). Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. *Journal Athletic Training,* 42:42–46.

Burfield B, Fischman M. (1990). Control of a ground-level ball as a function of skill level and sight of the foot. *Journal of Human Movement Studies,* 12:181-188.

Cairns SP, Knicker AJ, Thompson MW, Sjogaard G. (2005). Evaluation of models used to study neuromuscular fatigue. *Exercise and Sport Sciences Reviews*, 33(1):9-16.

Chapman DW, Needham KJ, Allison GT, Lay B, Edwards DJ. (2008). Effects of experience within a dynamic environment on postural control. *British Journal of Sports Medicine*, 42:16-21.

Cheng AJ, Rice CL. (2005). Fatigue and recovery of power and isometric torque following isotonic knee extensions. *Journal Applied Physiology,* 99(4):1446-1452.

Choi H. (2003). Quantitative assessment of co-contraction in cervical musculature. *Medical Engineering & Physics,* 25(2):133-140.

Clark BC, Manini T M, Thé DJ, Doldo NA, Ploutz-Snyder LL. (2003). Gender differences in skeletal muscle fatigability are related to contraction type and EMG spectral compression. *Journal of Applied Physiology,* 94:2263–2272.

Cremieux J, Mesure S. (1994). Differential sensivity to static visual cues in the control of postural equilibrium in man. *Perceptual and Motor Skills,* 78: 67-74.

Daneshjoo A, Mokhtar AH, Rahnama N, Yusof A. (2012). The effects of comprehensive warm-up prgrams on proprioception, static and dynamic balance on male soccer players. *PLOS ONE,* 7(12): e51568.

Davlin CD. (2004). Dynamic balance in high level athletes. *Perceptual and Motor Skills,* 98(3):1171-1176.

De Luca, C. J. (1984). Myoelectrical Manifestations of Localized Muscular Fatigue in Humans. *Critical Reviews in Biomedical Engineering,* 11(4):251-279.

Dieen JH, Luger T, Eb JVD. (2012). Effects of fatigue on trunk stability in elite gymnasts. *European Journal of Applied Physiolgy*, 112:1307-1313.

Duchene J, Goubel F. (1993). Surface electromyogram during voluntary contraction: processing tools and relation to physiological events. *Critical Reviews in Biomedical Engineering,* 21:313-397.

Elliot DB, Patla AE, Flanagan JG, Spaulding S, Rietdyk S, Strong G, Brown S. (1995). The Waterloo Vision and Mobility Study: postural control strategies in subjects with ARM. *Ophthalmic and physiological Optics*, *15*(6), 553-559.

Farina D, Merletti R, Enoka RM. (2004). The extraction of neural strategies from the surface EMG. *Journal of Applied Physiology*, 96(4):1486-1495.

Farina D. (2006). Interpretation of the surface electromyogram in dynamic contractions. *Exercise and Sport Sciences Reviews,* 34:121 – 127.

Fulco CS, Rock PB, Muza SR, Lammi E., Cymerman A., Butterfield G., Moore LG., Braun B., Lewis SF. (1999). Slower fatigue and faster recovery of the adductor pollicis muscle in women matched for strength with men. *Acta Physiologica Scandinavica,* 167:233–9.

Gandevia SC. (2001). Spinal and supraspinal factors in human muscle fatigue. *Physiological reviews*.

Gonzalez-Izal M, Malanda A, Gorostiaga E, Izquierdo M. (2012). Electromyographic models to assess muscle fatigue. *Journal of Electromyography and Kinesiology,* 22(4):501-512.

Gökdemir K, Ciğerci AE, Er F, Suveren C, Sever O. (2012). The comparison of dynamic and static balance performance of sedentary and different branches athletes. *World Applied Sciences Journal,* 17(9):1079-1082.

Hammami R., Behm DG., Chtara M., Othman AB., Chaouachi A. (2014). Comparison of static balance and the role of vision in elite athletes. *Journal of Human Kinetics,* 40:33-41.

Han J, Anson J, Waddington G, Adams R, Liu Y. (2015). The Role of Ankle Proprioception for Balance Control in relation to Sports Performance and Injury. *BioMed Research International*, *2015*, 842804. https://doi.org/10.1155/2015/842804

Harput G., Soylu AR., Ertan H., Ergun N., Mattacola CG. (2014). Effect of gender on the quadriceps-to-hamstrings coactivation ratio during different exercises. *Journal of Sport Rehabilitation,* 23:36-43.

Helbostad JL, Sturnieks DL, Menant J, Delbaere K, Lord SR, Pijnappels M. (2010). Consequences of lower extremity and trunk muscle fatigue on balance and functional tasks in older people: A systematic literatüre review. *BMC Geriatrics,* 10(56):1-8.

Hrysomallis C. (2011). Balance ability and athletic performance. *Sports Medicine,* 41:221-232.

Hunter SK, Critchlow A, Shin I-S, Enoka RM. (2004). Men are more fatigable than strength-matched women when performing intermittent submaximal contractions. *Journal of Applied Physiology,* 96:2125–32.

Hunter SK, Butler JE, Todd G, Gandevia SC., Taylor JL. (2006). Supraspinal fatigue does not explain the sex difference in muscle fatigue of maximal contractions. *Journal of Applied Physiology,* 101(4):1036–1044.

Imai T, Moore ST, Raphan T, Cohen B. (2001). Interaction of the body, head and eyes during walking and turning. *Experimental Brain Research,* 136:1-18.

Ince I, Ulupinar S, Özbay, S. (2020). Body composition isokinetic knee extensor strength and balance as predictors of competition performance in junior weightlifters. *Isokinetics and Exercise Science,* 28(2), 215-222.

Janssens L, Brumagne S, Polspoel K, Troosters T, McConnell A. (2010). The effect of inspiratory muscles fatigue on postural control in people with and without recurrent low back pain. *Spine*, 35:1088–1094.

Kılıç RT, Börü A, Bayrakçı T.V., Aksoy S, Ergun N. (2018). Farklı branşlardaki sporcuların denge kararlılık sınırlarının karşılaştırılması. *Journal of Exercise Therapy and Rehabilitation,* 5(2):106-115.

Lazar RB. (1998). *Principles of Neurologic Rehabilitation*. New York, NY, Mc Graw Hill.

McGill SM, Childs A, Liebenson C. (1999). Endurance time for low back stabilization exercises: clinical targets for testing and training from a normal database. *Archives Physical Medicine Rehabilitation,* 80:941-944.

Majcen RZ, Vodicar M, Kristjansson E. (2022). Relationship between Cervicocephalic Kinesthetic Sensibility Measured during Dynamic Unpredictable Head Movements and Eye Movement Control or Postural Balance in Neck Pain Patients. *International Journal of Environmental Research and Public Health*, *19*(14), 8405. https://doi.org/10.3390/ijerph19148405

Missenard O, Mottet D, Perrey S. (2009). Factors responsible for force steadiness impairment with fatigue. *Muscle Nerve,* 40:1019–1032.

Nagy E, Toth K, Janositz G, Kovacs G, Faherkiss A, Angyan L, Horvath G. (2004). Postural control in athletes participating in an ironman triathlon. *European Journal Applied Physiology,* 92:407-413.

Nikolić Z, Ilić N. (1992). Maximal oxygen uptake in trained and untrained 15-year-old boys. *British Journal of Sports Medicine,* 26(1):36-38.

Paillard T, Costes Salon C, Lafont C, Dupui P. (2002). Are there differences in postural regulation according to the level of competition in judoists? *British Journal of Sports Medicine,* 36:304- 305.

Paillard T, Noe F, Riviere T, Marion V, Montoya R, Dupui P. (2006). Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. *Journal of Athletic Training,* 41:172-176.

Perrey S, Racinais S, Saimouaa K, Girard O. (2010). Neural and muscular adjustments following repeated running sprints. *European Journal of Applied Physiolgy*, 109:1027–1036.

Perrin P, Schneider D, Deviterne D, Perrot C, Constantinescu L. (1998). Training improves the adaptation to changing visual conditions in maintaining human posture control in a test of sinusoidal oscillation of the support. *Neuroscience Letters,* 245:155-158.

Radebold A, Cholewicki J, Polzhofer GK, Greene HS. (2001). Impaired postural control of the lumbar spine is associated with delayed muscle response times in patients with chronic idiopathic low back pain. *Spine*, 26:724–730.

Reeves NP, Cholewicki J, Narendra KS. (2009). Effects of reflex delays on postural control during unstable seated balance. *Journal of Biomechanics*, 42:164–170.

Romero-Franco N, Martínez-López E, Lomas-Vega R, Hita-Contreras F, Martínez-Amat A. (2012). Effects of proprioceptive training program on core stability and center of gravity control in sprinters. *The Journal of Strength & Conditioning Research*, 26:2071-2077.

Rosker ZM, Rosker J, Sarabon N. (2020). Impairments of Postural Balance in Surgically Treated Lumbar Disc Herniation Patients. *Journal of Applied Biomechanics*, 1–7. https://doi.org/10.1123/jab.2019-0341

Rosker ZM, Vodicar M. (2020). Sport-specific habitual adaptations in neck kinesthetic functions are related to balance controlling mechanisms. Applied Sciences, 10(24), 8965.

Rosker ZM, Kristjansson E, Vodicar M, Rosker J. (2021). Postural balance and oculomotor control are influenced by neck kinaesthetic functions in elite ice hockey players. *Gait & Posture*, *85*, 145-150.

Russ DW, Kent-Braun JA. (2003). Sex differences in human skeletal muscle fatigue are eliminated under ischemic conditions. *Journal of Applied Physiology*, 94:2414–2422.

Santos MCA., Semeghuini TA., Azevedo FMd., Colugnati DB., Filho RdFN., Alves N., Arida RM. (2008). Analysis of localized muscular fatigue in athletes and sedentary subjects through frequency parameters of electromyographic signal. *Revista Brasileira de Medicina do Esporte*, 14(6):509-512.

Sarabon N, Hirsch K, Majcen Z. (2016). The acute effects of hip abductors fatigue on postural balance. *Montenegrin Journal of Sports Science and Medicine*, *5*(1), 5–9.

Schieppati M, Nardone A, Schmid M. (2003). Neck muscle fatigue affects postural control in man. *Neuroscience*, *121*(2), 277–285. https://doi.org/10.1016/s0306-4522(03)00439-1

Selen LPJ, Beek PJ, Diee¨n JHv. (2005). Can co-activation reduce kinematic variability? A simulation study. *Biological Cybernetics*, 93:373–381.

Simmons RW. (2005). Sensory organization determinates of postural stability in trained ballet dancers. *International Journal of Neuroscience*, 115:87-97.

Sözen H, Erdoğan E, İnce A, Soylu AR. (2019). Determination of electromyography-based coordinated fatigue levels in agonist and antagonist muscles of the thigh during squat press exercise. *Annals of Applied Sport Science*, 7(3):e738.

Şimşek D., Ertan H. (2014). Motor beceri öğreniminde kas ko-aktivasyon ve rekürrent inhibisyon aktivitesinin fonksiyonel önemi. *Spormetre Beden Eğitimi ve Spor Bilimleri Dergisi,* 12(1):51-57.

Taimela S, Kankaanpaa M, Luoto S. (1999). The effect of lumbar fatigue on the ability to sense a change in lumbar position—a-controlled study. *Spine*, 24:1322–1327.

Vuillerme N, Nougier V, Prieur JM. (2001). Can vision compensate for a lower limbs muscular fatigue for controlling posture in humans? *Neuroscience Letters*, 308:103-106.

Williams AM, Weigelt C, Harris M, Scott MA. (2002). Age related differences in vision and proprioception in a lower limb interceptive task: the effects of skill level and practice. *Research Quarterly for Exercise and Sport*, 73:386-395.

Xie H, Wang Z. (2006). Mean frequency derived via Hilbert-Huang transform with application to fatigue EMG signal analysis. *Computer Methods and Programs in Biomedicine*, 82(2):114-120.

Zemková E. (2014). Sport-Specific balance. *Sports Medicine*, 44(5):579-590.