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Does Acute Fatigue Affect Lumbar Proprioception and Balance?

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Abstract

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ABSTRACT
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Keywords: fatigue, proprioception, balance, muscles

INTRODUCTION

Fatigue is a symptom that is commonly seen in primary care. Fatigue varies in duration and intensity, reduces the ability to perform activities of daily living, and is a common symptom with a frequency of 4% to 45%.[1] Muscle fatigue is defined as any decrease in the neuromuscular ability to generate force. It is commonly seen after vigorous sports and daily activities. The onset of voluntary muscle activity involves various processes that begin with cortical control in the brain and end with cross-bridges within the muscle fiber. Therefore, muscle fatigue can be the result of failure in any exercise-related process, particularly involving concentric muscle contractions.[2] Muscle fatigue is also an important factor in the development of musculoskeletal injuries. In particular, the imbalance in force production around the joint due to fatigue can cause abnormal joint load, which is a precursor to musculoskeletal injury.

More than 20% of the world's population works in hazardous working conditions, causing fatigue, unreasonably heavy work, and physically hazardous conditions. These fatigue-inducing work conditions can cause chronic low back pain, one of the most common occupational injuries.[3] Fatigue can not only cause work injuries, but also increases the risk of sports injuries by increasing the internal rotation of the knee and stiffness during running, for example. This leads to the progression of asymmetry between the extremities and the change of lumbar region kinematics.[4] For this reason, it is important to examine the effects of acute fatigue to reduce and prevent the risk of injury in primary care.

Using the correct posture and being aware of the trunk position to reduce the load on the vertebral column in activities of daily living is important to stabilize the core region.[5] Trunk stability requires integrating core muscle strength, endurance, neuromuscular control, and proprioception. Proprioception describes the ability to sense joint position and movement based on afferent sensory input from joints, tendons, and proprioceptors in deep tissue. Viscoelastic structures and muscles in the trunk provide mechanoreceptors that sense lumbar region position and movement.[6] Inadequate lumbar proprioception can impair dynamic joint stability and cause changing movement patterns, creating a risk factor for low back pain and musculoskeletal problems that may occur in the low back and extremities.[7,8]

Balance is defined as the central nervous system input resulting from the integration of proprioceptive, vestibular, and visual afferent nerve signals.[9] It is also defined as the ability to respond quickly and effectively to external perturbation before, during, and after voluntary movement to maintain postural stability by centering body mass above the base of support in a gravitational field.[10] Postural control is considered a complex motor skill derived from the interaction of many sensorimotor processes such as biomechanical constraints (eg: degrees of freedom, strength, stability limits), movement strategies (eg: reactive, anticipatory, voluntary), sensory strategies (eg: sensory integration, sensory reweighting), spatial orientation (eg: visual perception of verticality, postural verticality), control of dynamics (for example walking), cognitive processing (for example attention, learning, reaction time), experience, and practice.[11]

Postural control is a multisensory process, and proprioception acts as a sensory system that provides information about the maintenance of postural balance and the level of motor activities in the central nervous system.[12] Muscle fatigue is an important condition that impairs sensorimotor integration, proprioception, and thus postural control. Muscle fibers and Golgi tendon organ activity decrease with fatigue, resulting in changes in joint proprioception and afferent output from joint and muscle receptors. Fatigue of postural muscles such as lumbar extensor and abdominal muscles impairs postural control and may form the basis for injuries. Fatigue can also impair the proprioceptive and kinesthetic properties of the joints. The muscle spindle, which disrupts afferent feedback and subsequently alters joint awareness, increases the discharge threshold. When a muscle is fatigued, fewer motor units work during muscle contractions, resulting in fatigue and biomechanical adaptations, thus damaging lumbar proprioception.[13,14] In addition, muscle fatigue leads to increased joint laxity and indirect changes in joint movement and position sense. Fatigue creates an interruption in the chain of events from the central nervous system to the muscle fiber, thus reducing the contraction activities of the muscles against the neural stimulus.[15]

Although there are studies in the literature examining the effect of lower extremity and trunk muscle fatigue on balance and joint position sense, studies examining the effect of localized muscle fatigue on balance and proprioception are insufficient.[16,17] This study was designed to prevent musculoskeletal injury in healthy individuals in primary care and to contribute to preventive rehabilitation by investigating the effects of acute fatigue. Accordingly, the study aimed to investigate the acute effects of trunk extensor, abdominal, and calf muscle fatigue and the effect of muscle contraction type during fatigue protocols on lumbar proprioception and balance.

METHODS

Participants

Seventy (70) healthy individuals, aged between 18-25, without pain in the low back and lower extremities, with right dominant lower extremities, and who signed the voluntary consent form were included in the study. The recruitment was carried out in the

Neuromuscular Laboratory of the Faculty of Health Sciences at the Eastern Mediterranean University between February and April 2022. This study was approved by the Eastern Mediterranean University Research and Publication Ethics Board with the decision numbered ETK00-2022-0025.

The pain intensity in the low back and lower extremities of the individuals in the last 6 months was determined with a 10 cm visual analog scale (VAS). The pain felt during rest and activity was requested to be indicated with an 'X' sign on a 10 cm scale. According to this scale, the value of '0' indicates no pain, and the value of '10' indicates the most severe pain. The distance between the marked point and the starting point was measured with a ruler.[18] Individuals with a pain intensity of 2 cm or more on the VAS, those with disc herniation, spondylolisthesis, degenerative arthritis, those who had a surgical operation related to the low back, and those with systemic problems such as diabetes and rheumatoid arthritis were not included in the study.

Outcome Measures

Age, gender, height, weight, and body mass index (BMI) of the individuals were recorded. International Physical Activity Questionnaire- Short Form (IPAQ-SF) was used in this study to determine the level of physical fitness in all individuals. It consists of seven questions designed to determine the average daily time spent sitting, walking, and participating in moderate and vigorous physical activity over the last 7 days. In calculating the total score, Metabolic Equivalents of Task (MET) values given to the activities (vigorous= 8 METs, moderate= 4 METs, walking= 3.3 METs) the duration of the activities (min), and the frequency (the number of days) are multiplied and (MET)-minutes per week of the individuals are obtained. According to the result scores obtained, the physical activity levels of the individuals are classified into three categories "inactive," "minimally active," and "very active". Saglam et al. performed the validity and reliability study of a Turkish version of the IPAQ–SF with university students. The criterion validity correlation coefficient for total weekly time spent in physical activity from the IPAQ and result from the accelerometer was 0.49. The test-retest reliability coefficient of the Turkish IPAQ-SF was 0.69.[19]

Dynamic balance was evaluated with the Y-balance Test (YBT) which consists of lower extremity reaching tasks in the anterior (ANT), 135° posteromedial (PM), and 135° posterolateral (PL) directions and requires a combination of strength, flexibility, and neuromuscular control.[20] The inter-rater and intra-rater reliability of the YBT was found to be high (ICC: 0.85 -0.99).[21] During the test, individuals warmed up by reaching in 3 directions 6 times while standing on a platform with one leg and using the other extremity. Then, the test was performed in 3 repetitions and the average value was recorded. The test was canceled and repeated if the stance on one leg was not maintained throughout the entire movement, if the support was taken, and if the participant could not return to the starting position because of losing balance.[22,23]

Lumbar region proprioception sense was assessed with the application of IOS software (Goniometer Pro version 2.7, 5fuf5 Co., Bloomfield, NJ, USA) due to the presence of a built-in accelerometer and gyroscope in iPhones that allow measurement of joint motion with moderate to excellent reliability (ICC = 0.65-0.85).[24] The phone was placed in the armband with a transparent front and fixed to the lumbar region with the tape extended with velcro so that the upper edge of the phone was at the L1 level. To reduce the foot position difference between the first and last evaluation, the initial foot location was marked on a piece of paper on the floor. Participants performed 30°, 45°, and 60˚ lumbar flexion randomly, 4 times, with verbal commands and with eyes opened as a trial. Afterward, the subject was expected to perform lumbar flexion with eyes closed, and the difference between the randomly selected angle and the angle made by the participant was recorded in degrees (˚).[25]

Interventions

Dynamic balance, lumbar proprioception sense, and fatigue level were evaluated before and immediately after the back extensor, abdominal, and calf muscle fatigue protocols. Because 48-72 hours are needed to completely resolve fatigue after activities that require maximum effort, a 72-hour washout period was given to ensure adequate recovery between each protocol.[26] The Biering-Sørensen test position (prone position) was used for trunk extensor muscle fatigue and the modified reverse Biering-Sørensen test (supine position) position was applied for abdominal muscle fatigue. The hands were placed on the ears with the elbows pointing outward, the head in a neutral position, the body at the T12 level, and on the edge of the bed, and participants were expected to stay in this position until fatigue occurs. Fatigue duration was evaluated with a stopwatch, and its severity was evaluated with the 6-20 Borg Scale.[27,28] In the calf fatigue protocol, the subject was asked to perform toe lifts by placing a sandbag equal to 10% of their body weight on their shoulders. The fatigue level was reached and evaluated when subjects were no longer able to perform toe lifts. The number of repetitions during this period was also recorded and the severity of fatigue was evaluated with the 6-20 Borg Scale.[29]

Statistical analysis

The Statistical Package for Social Science (SPSS) 26.0 statistical data analysis package software was used to analyze the data. Descriptive statistics were given as mean ± standard deviation (X ± SD) or percentage (%). The significance level for all statistical analyzes was determined as $p < .05$. According to Kolmogorov-Smirnov and Shapiro-Wilk test results for normality, it was determined that the values were not normally distributed. Due to the skewed distribution of the data, the authors choose to apply non-parametric analyses (Wilcoxon Signed Ranks Test) to examine the changes in proprioception and balance parameters before and after the fatigue protocols. In the study by Wattananon et al, a correlation between time pairs was .50 and the effect size was 0.362 from the pre (6.83±.85) and post (7.12±.74) values of the 30˚ lumbar flexion proprioception measurement (18). The total sample size was determined to be 65 with a Type I error rate of 5% and a Type II error rate of 20% by using G.Power 3.1.9.6 software. The study was completed with 70 participants, and the effect size was calculated as 0.363 with 30˚ lumbar flexion error angle values before and after calf muscle fatigue, and .83 power was obtained as a result of post hoc power analysis.

RESULTS

A total of 70 healthy individuals between the ages of 18-25 were included in the study. The mean age, height, weight, and BMI of the participants were 21±2 years, 171±9 cm, 68±14 kg, and 22.96±3.75 kg/cm2, respectively. 55.7% of the individuals were male and 44.3% were female. While 22.9% (16 people) were inactive, 64.3% (45 people) were minimally active, and 12.9% (9 people) had an active physical activity level, the mean physical activity intensity was 5984.4 ± 3565 MET-min/week. The mean pain intensity of individuals was 0.34 ± 0.54 cm during rest and 0.50 ± 0.69 cm during activity on VAS. As shown in Table 1, it was determined that the mean fatigue severity increased statistically significantly as a result of the fatigue protocols applied ($p<0.05$). The mean time for trunk flexor, extensor, and calf muscle fatigue to occur was 88 ± 37 seconds, 93.98 ± 41.04 seconds, and 96 ± 30 seconds, respectively, while the average number of toe-up repetitions performed by individuals during calf fatigue was 61 ± 33.

Table 1. Variation of fatigue severity according to the Borg Scale

	Pre-Fatigue (X ± SD)	**Post- Fatigue (X ± SD)**	**p value**
Abdominal Muscles Fatigue	7.71 ± 1.83	14 ± 3	<.001**
Trunk Extensors Fatigue	8.00 ± 1.98	13.16 ± 3.08	<.001**
Calf Muscles Fatigue	8.04 ± 2.10	13.31 ± 3.14	<.001**

X: Mean; SD: Standard Deviation; **:p<.001; Wilcoxon Signed Ranks Test

As stated in Table 2, after all fatigue protocols, the error angle in 30˚ lumbar flexion was found to increase statistically significantly ($p<0.05$). After abdominal muscle fatigue, the error angle in 45˚ lumbar flexion proprioception also increased statistically significantly ($p<0.05$), while no significant change was found in other proprioception parameters ($p>0.05$).

Table 2. Change in lumbar proprioception sense with fatigue protocols

	Pre-Fatigue (X ± SD)	**Post- Fatigue (X ± SD)**	**p value**
Abdominal Muscle Fatigue			
30˚ Trunk Flexion (˚)	3.45 ± 3.19	4.10 ± 3.15	.002*
45˚ Trunk Flexion (˚)	3.36 ± 2.51	4.03 ± 2.79	.009*
60˚ Trunk Flexion (˚)	3.39 ± 2.90	3.86 ± 2.71	.053
Trunk Extensors Fatigue			
30˚ Trunk Flexion (˚)	2.63 ± 1.91	3.23 ± 2.18	.006*
45˚ Trunk Flexion (˚)	2.55 ± 1.61	2.90 ± 2.02	.172
60˚ Trunk Flexion (˚)	3.26 ± 2.86	3.16 ± 2.09	.592
Calf Muscles Fatigue			
30˚ Trunk Flexion (˚)	2.18 ± 1.92	2.95 ± 2.28	<.001**
45˚ Trunk Flexion (˚)	2.79 ± 2.04	3.09 ± 2.24	.470
60˚ Trunk Flexion (˚)	3.59 ± 2.59	2.90 ± 2.03	.062

X: Mean; SD: Standard Deviation; ˚:degree; *: p<.05;**:p<.001; Wilcoxon Signed Ranks Test.

It was observed that abdominal muscle fatigue caused a significant change in the ANT reaching the dominant and non-dominant extremities ($p<0.05$). Trunk extensor fatigue caused a significant change in the reaching of the dominant extremity (DE) in the PL direction, and after calf fatigue, a significant change was observed in the non-dominant extremity (NDE) reaching in the ANT direction ($p<0.05$). No significant difference was found in other dynamic balance parameters ($p>0.05$) (Table 3).

Table 3. Change in balance with fatigue protocols

	Pre-Fatigue (X ± SD)	**Post- Fatigue (X ± SD)**	**p value**
Abdominal Muscles Fatigue			
NDE Anterior Reach (cm)	78.47 ± 12.24	78.24 ± 12.89	.001**
NDE Posteromedial Reach (cm)	82.91 ± 13.56	84.91 ± 13.53	.055
NDE Posterolateral Reach (cm)	87.02 ± 13.49	87.46 ± 15.21	.737
DE Anterior Reach (cm)	78.01 ± 10.87	76.04 ± 9.67	.003*
DE Posteromedial Reach (cm)	82.47 ± 15.03	83.84 ± 14.6	.153
DE Posterolateral Reach (cm)	87.73 ± 14.00	86.9 ± 14.4	.261
Trunk Extensors Fatigue			
NDE Anterior Reach (cm)	78.46 ± 11.46	72.22 ± 11.62	.258
NDE Posteromedial Reach (cm)	83.56 ± 14.32	83.62 ± 15.33	.774
NDE Posterolateral Reach (cm)	87.29 ± 14.66	87.78 ± 16.22	.501
DE Anterior Reach (cm)	78.01 ± 10.91	78.25 ± 11.38	.820
DE Posteromedial Reach (cm)	82.7 ± 15.11	83.61 ± 15.81	.610
DE Posterolateral Reach (cm)	88.07 ± 14.35	87.42 ± 14.97	.046*
Calf Muscles Fatigue			
NDE Anterior Reach (cm)	78.78 ± 10.71	77.44 ± 11.34	.027*
NDE Posteromedial Reach (cm)	83.83 ± 14.76	85.14 ± 15	.251
NDE Posterolateral Reach (cm)	87.65 ± 14.26	88.02 ± 16.08	.904
DE Anterior Reach (cm)	79.14 ± 10.73	78.63 ± 10.85	.363
DE Posteromedial Reach (cm)	82.96 ± 15.30	83.16 ± 15.42	.488
DE Posterolateral Reach (cm)	88.6 ± 14.42	87.68 ± 14.99	.059

NDE: Non-dominant extremity; DE: Dominant extremity; X: Mean; SD: Standard Deviation;˚:degree; *: p<.05;**:p<.001; Wilcoxon Signed Ranks Test

DISCUSSION

The results of the study demonstrated that the acute fatigue of the trunk extensor, abdominal, and calf muscles showed a decrease in the sense of lumbar proprioception, especially at 30˚, abdominal and calf fatigue decreased the dynamic balance ability in the anterior (ANT) direction, and the trunk extensor muscles change balance ability in the posterolateral (PL) direction.

In general, "fatigue" is a term used to describe a decrease in physical performance associated with an increase in actual and/or perceived exertion of a task or exercise. Fatigue during exercise involving muscle activation is defined as the inability to maintain the required power level.[30] Apart from the Biering-Sørensen test fatigue protocol, it is also used to evaluate the endurance of the back extensor muscles, and performance is divided into 3 categories as a result of the time obtained in the literature (< 58 s: poor; 58-104 s: medium; 104-240 s: good).[31] As a result of the extensor muscle fatigue time we obtained in our study (93.98 ± 41.04 s), we suggest that individuals have moderate performance. The fatigue protocol for the abdominal muscles resulted in a shorter time and more perceived fatigue severity than the extensor muscles. The fact that the majority of the individuals participating in our study were inactive or minimally active may be the reason for these results.

Proprioception is important for effective sensorimotor control over muscle contraction, which is essential for motion smoothness, joint stability, coordination, and balance. Proprioception, which includes both peripheral and central pathophysiological changes in the nervous system as a result of fatigue, can cause sudden sensorimotor control disorders and cause musculoskeletal disorders in the long term.[31] Performing muscle contractions such as isometric, concentric, and eccentric at the level of fatigue may impair the sense of proprioception. Especially in eccentric contraction, metabolic fatigue is not only accompanied by other types of exercise, but also a component of strength loss resulting in muscle damage.[33] The extensor fatigue protocol we apply also includes eccentric contraction in the flexor muscles. It is seen that the longer the protocol for the extensor muscles causes more eccentric contraction of the flexor muscles, affecting the proprioception at 30˚ and 45˚.

The calf fatigue protocol is for the triceps surae muscle, and fatigue of this muscle can affect proprioception and gait, as well as increase biceps femoris and rectus femoris muscle activation.[34] In addition, co-contraction of the rectus femoris and biceps femoris muscles provides postural stability with effective control of the body's center of gravity in the frontal and sagittal planes.[35] It suggests that decreased proprioception as a result of muscle fatigue in the triceps surae, an antigravity muscle, may increase the risk of injury for younger individuals. For this reason, care should be taken to plan the exercise or activities of daily living in a way that does not cause excessive fatigue.

As the muscle spindles, which are sensitive to tension, get longer, the afferent discharge rate increases. Therefore, the sense of lumbar proprioception can be perceived more easily at high degrees of flexion.[24] In our study, the effect of fatigue was observed especially at 30˚, and we think that it is easier to perceive since the ligament structures in the lumbar region begin to give more information about the position sense at 45˚ and 60˚. In addition, with an average of 2 minutes of fatigue protocols, the effect of acute fatigue may not be fully reflected. For this reason, it is necessary to examine the longer effect with long-term fatigue protocols.

Local muscle fatigue can disrupt the afferent feedback system and change conscious joint awareness. Muscle fatigue may impair neuromuscular control with the increase in joint lacticity, which directly leads to the deterioration of the expected learning in joint position sense or indirectly to changes in kinesthesia and position sense. It is not yet clear how localized muscle fatigue affects balance.[16] Kand et al found that ankle dorsiflexion and hip flexion were the best predictors of ANT and PM reaching, respectively, during the Y-balance test. In addition, with balanced body kinematics, dynamic balance performance increases. It has been shown that the contribution of trunk movements during the test is less than that of the lower extremity, but the combination of ankle dorsiflexion and trunk extension results in 15% more reach in ANT.[36] In our study, a significant decrease was found only in ANT reach, especially after abdominal and calf muscle fatigue.

Considering that the change in the sensorimotor is more in the eccentrically contracted muscle than in the other types of contraction,[33] the performance in the ANT reach may have decreased by creating eccentric contractions in the trunk extensors muscles during the abdominal muscle fatigue protocol and especially in the NDE dorsi flexors during the calf fatigue protocol. Unlike ANT reaching created in the sagittal plane, PM and PL reaching occur in diagonal planes, and therefore more trunk movements are needed. In the study by Johnson et al, they examined the effect of anaerobic fatigue on dynamic postural control, which they evaluated with YDT. It was found that fatigue had a negative effect in all reaching directions and the change in PL direction was the last to improve.[37]

Detection of change in DE only during the fatigue of trunk extensor muscles in PM reach suggests that the applied protocol is insufficient to examine the effect on balance and that there are compensatory mechanisms thought to be involved. The fatigued muscle group can create compensation by working with other muscle groups to perform the function. In addition, using DE more in occupational and daily life activities may change the effect of fatigue, and the protocols may not have had an equal effect on both extremities. Previous studies have shown that changes in dynamic postural balance performance depend on the characteristics of the fatigue protocol. It was determined that the effect of localized fatigue on static balance and general fatigue on dynamic postural control were more pronounced.[16,37,38] In the study by Lin et al, it was found that acute fatigue created by an isokinetic dynamometer in the ankle, knee, shoulder, and lumbar region showed different postural control changes on each joint.[39] Since fatigue protocols can cause changes in various joints, proprioception and balance parameters should be evaluated as joint-specific and fatigue protocol-specific in future studies.

Many factors contribute to the onset and maintenance of fatigue. In line with the results obtained, when planning a training or rehabilitation program for healthy individuals, fatigue should be taken into account. Fatigue not only damages the muscles and joints, but also can affect postural control and occupational injuries in young adults and increase the risk of falling in older adults. In addition, it can affect physical fitness parameters such as balance, strength, and agility, which affect performance in athletes. The results obtained from the study indicate that the exercises to be selected in rehabilitation programs should be designed in a way that does not cause fatigue, by guiding the evaluations made about proprioception and balance in both young and older populations.

Limitations

Although the Borg scale provides us with the effort perceived by the individuals against the formed trunk extensor, abdominal, and calf muscle fatigue, it is necessary to use the assessment that measures the severity of fatigue by giving direct and objective results. The effect of fatigue on dynamic and static postural control is still controversial in the literature, and another limitation is that we only measure dynamic balance.

CONCLUSION

The results of the study demonstrated that acute fatigue negatively affects proprioceptive sense and dynamic postural control in the ANT direction. The trunk is the center of the kinetic chain for the movements of the limb. Understanding how the trunk extensor, abdominal, and ankle plantar flexor muscles respond to a fatigue-inducing exercise, especially concerning postural control and trunk proprioception, is important for understanding and preventing injury and lowering risk.

Conflict of Interest

The authors declare no conflict of interest.

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