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*Original Article*

# Comparison of the Effect of Hip, Knee, and Ankle Fatigue on Dynamic Balance of Armed Forces

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**Keywords**
Muscle fatigue; Postural balance; Military personnel

## Abstract

**Background:** Muscles of the lower limbs play a very important role in the control of balance and performance in military activities. Fatigue in these muscles results in a decrease in balance and increase in risk of damage. Thus, it is important to determine the group of muscles in which fatigue has more effect on dynamic balance in the armed forces. Therefore, this study was aimed at the investigation of the effects of fatigue in each group of lower limb muscles on dynamic balance of the armed forces and risk assessment of damage to the military.

**Methods:** The participants of the current study included 15 military personnel with a mean age of 27.00 ± 2.12 years and mean height of 178.1 ± 3.1 cm. This study used star excursion balance test (SEBT) to measure balance and used the ankle plantar flexion system, knee extension system, knee flexion system, thigh abduction system, and thigh adduction system to assess fatigue. First, all the participants were asked to warm up for about 5 minutes. Then, using a annual dynamometer, the maximal voluntary contraction (MVC) for the muscles was measured. A 50% reduction in MVC is associated with fatigue. Nevertheless, if the individual was able to continue exercise after 50 extensions, he was given a 4-minute rest and the measurement was performed again using the dynamometer. If MVC was reduced by 50%, the SEBT was immediately performed. To analyze data, descriptive statistics, paired t-test, and repeated measures analysis of variance (ANOVA) test were used at a significance level of $P \leq 0.05$.

**Results:** Comparison of the total mean of balance in the SEBT before and after fatigue showed that there was a significant decrease in balance after fatigue in all 5 groups of muscles (knee extensor, knee flexor, thigh abductor, thigh adductor, and ankle plantar flexor) ($P \leq 0.05$). The results of ANOVA for the total mean score of muscles did not show a significant statistical difference ($P \geq 0.05$). However, there was a significant difference between the thigh abductor muscles, ankle plantar flexor, and knee extensors in terms of the anterior and anterolateral direction scores ($P \leq 0.05$).

**Conclusion:** The findings of the current study showed an inverse relationship between lower limb fatigue and an individual's balance; an increase in fatigue in the muscles resulted in a decrease in balance.



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## Introduction

Physical fitness of the military personnel has an important role in victory or failure. The main objective of physical exercises is attaining and preserving practical readiness, and among the benefits of participating in military training courses are improvement in muscular strength, cardiac and pulmonary strength, excretion of body waste, obesity management, and decline in vulnerability. These trainings help to reduce daily stress and anxiety.[1] Physical exercise during military training, in addition to having pros for military personnel, might lead to several forms of damage. By increasing physical exercises, risk of occurrence of injuries will increase.[2] Motor activities and physical fitness in the military is inevitable because of the importance of fitness in the performance of the combat unit. Therefore, damages caused by partaking in the training programs of military units are predictable among soldiers and forces. Daily physical exercise and military activities require a combination of capacities of balance maintenance (preserving appropriate body posture and special orientation), and specific motor components (involving muscles and joints in performing the intended movement).

Therefore, balance is considered as an important index of independence in performing daily activities and especially military activities.[1] Maintenance of balance indicates preserving organs and various parts of body in appropriate biomechanical direction, which preserves the body in a specific situation.[3] There are 3 types of balance including static balance, dynamic balance, and automatic postural reaction of static balance, meaning preserving anti-gravity position while standing or sitting. Postural automatic reaction indicates preserving balance in response to unexpected external distortions such as standing in the bus.

Dynamic balance is the manner in which the body and its various parts move throughout walking and running. Body muscles exert a constant force to the body's center of gravity in order to preserve the position.[4] Dynamic balance can be described as an ability to maintain postural stability and orientation in center of mass over the base of support.[5,6] One of the factors that can be affected by muscle fatigue is dynamic balance. Muscle fatigue is muscle inability in preserving the required and expected force.[7] Epidemiologic research showed that during exercise, the most probable time for injury is the end of exercise and physical activity, when the individual is getting tired.[8] Previous investigations have shown that the most commonly injured areas are the ankle, knee, and shank.[9]

The ability to repeat jumping is of utmost importance, and the greatest role in this action is played by the plantar flexor muscles in the ankle joint and fatigue in these muscles can lead to damage in the ankle joint.[10,11] Rapid movements in military exercises and changes in various directions require side movements and hip joint rotation, which leads to internal rotation of the femur that in turn causes valgus force in the knee and increased risk of injury to the medial collateral ligament (MCL); in addition, these lateral movements can lead to strain in the abductor and adductor muscles of the hip.[12] Fatigue in the muscles around the knee causes a change in the rotating forces implemented on the knee during movement, and can cause damages to the ligament and meniscus of the knee.

Given the significant role of the plantar flexor muscles of the ankle and knee extensor and flexors in jumping and the role of the abductor and adductor muscles of the thigh in controlling rotator forces of the knee during military exercise, this study was conducted with the aim to investigate the effect of fatigue in abductor and adductor muscles of the hip, knee flexor and extensor, and plantar flexor of the ankle on dynamic balance in the armed forces.

## Methods

The participants were selected through convenience impossible sampling and based on G-power software. The study participants consisted of 15 healthy military men within the age range of 24-30 years. The participants had no history of lower limb damage in the last 6 months. The characteristics of the study participants including age, height, weight, and leg length (from upper anterior iliac spine to medial malleolus) were recorded. In order to assess dynamic balance in the study, the star excursion balance test (SEBT) was used. According to previous studies, SEBT has good validity (r = 0.746) and reliability (ICC = 0.961). The time duration from fatigue to the end of the test was about 3 minutes. In this test, 1 star with 8 directions was drawn on the ground, the person stood at the center of the star on dominant leg and reached the toe of the other foot in 8 directions. The individual was assessed based on maintaining balance while performing test. The individual was barefooted, and was told not to pick up his dominant toe from the ground and not to put weigh on the other foot. In addition, his arms were required to be on his waist. On the first session, the test was introduced and explained; the test was performed 4 times prior to recording data, since the highest rate of achievement is obtained in the SEBT by performing 4 repetitions prior to recording and measuring.[13]

If the right leg is the dominant leg, the test is performed in counterclockwise direction, and if the left leg is the dominant leg, the test is performed in clockwise direction. The achievement distance was the distance between the location of contact of the free toe and the center of the star. Each test was repeated 3 times in each direction, then, the mean was calculated.[14]

To the normalize data, the achievement distance was divided by leg length in centimeters (from the anterior tibia to internal ankle).[15] The result was multiplied by 100, in order to obtain achievement distance in percentage of leg length.[14] All stages of the test were performed for all the participants at a certain time, since circadian rhythm is effective on balance.[16]

**Fatigue protocol**

First, all the participants were asked to warm up for about 5 minutes (slow running and wrestling exercises). Then, using a manual dynamometer, the maximal voluntary contraction (MVC) of the muscles was measured, and the individual was asked to sit on the knee extension chair, or perform a barbell in the size of 50% 1RM, 50 times in each stage of the knee extension act. If the individual was not able to complete 50 repetitions, maximum muscle strength was measured again using the dynamometer. A 50% reduction in MVC signifies fatigue. However, if he was able to continue the exercise after 50 extensions, he was given a 4-minute rest, and asked to repeat knee extension like the first stage, and the measurement was again performed using the dynamometer. If MVC was reduced up to 50%, the SEBT was performed immediately.[17]

**The dynamometer used for measuring the maximum power for different muscle groups was as follows:**

*Knee Extensor and Flexor Muscles:* The person sat on the edge of the chair with his knees and pelvis at 90 degrees flexion, and a strap was used to secure the person's thighs. To assess the extensor muscles of the knee, a dynamometer was placed under the strut, which was fastened 2 cm proximal to the ankle on the person's leg and attached to a fixed base behind the person's leg. The person was asked to grasp the edge of the chair with his or her hands and straighten his or her knee with maximum force. The person was asked to hold the edge of the chair with his hands, and bend his knee with maximum force.

*For the plantar flexor muscles:* The dynamometer was placed under the strut, which was located proximal to the metatarsophalangeal joints at the plantar surface, and attached to a fixed location behind the individual. The person was asked to lower the ankle with maximum force.

*To assess the thigh abductor muscles:* The individual was asked to lie on their side with the upper lower limb in a neutral position [perpendicular to the line that connects the Anterior Superior Iliac Spine (ASIS)] and the knee joint in extension. The dynamometer was placed under a strap that was placed 2 cm above the outer condyle and fastened under the bed, then, the person was asked to raise the upper leg with maximum force.

*To assess the thigh adductor muscles:* The person was placed in a supine position with the pelvis in neutral position and the knee joint in extension. The dynamometer was placed under the strut, which was 3 cm above the inner condyle of the femur on the lower extremity and was fastened under the bed. The idea was that the lower limb should be lifted off the bed with maximum force.

**Statistical analysis**

The obtained data were analyzed in SPSS software (Version 25; IBM Corp., Armonk, NY, USA). The variables of leg length, total score of dynamic balance, and score of dynamic balance in each direction of the SEBT were computed using central indices (mean) and dispersion (standard deviation and variance and range). The results of the Kolmogorov–Smirnov test for all the data illustrate normal distribution, and therefore, parametric tests were used to analyze the studied quantitative variables.

In order to compare the mean total score of dynamic balance and score of dynamic balance in every direction of the SEBT before and after fatigue induction, paired t-test was used. To compare the mean total score of dynamic balance and score of dynamic balance in each direction of the SEBT among muscular groups, repeated measures analysis of variance (ANOVA) was used. In cases in which there was a significant difference among muscular groups, in order to determine the 2 groups with a significant difference, Scheffe's post hoc test was used. Significance level was considered as 0.05 for all the tests.

## Results

**Determining the effect of fatigue in each muscle group on total score of dynamic balance**

In this section, the effect of fatigue in the knee extensor and flexor muscles, thigh adductor and abductor, and ankle plantar flexors on the total score of balance in the SEBT was determined.

*A) Determining the effect of fatigue in knee extensor and flexor muscles on the total score of dynamic balance:* In table 1, changes in the total score of SEBT following fatigue induction in extensor and flexor muscles of the knee are presented using paired t-test.

As can be observed, paired t-test showed that fatigue in both groups of extensor and flexor muscles of the knee leads to a significant reduction in the total score of the SEBT.

**Table 1.** Results of paired t-test regarding the comparison of changes in the total score of the star excursion balance test after fatigue in extensor and flexor muscles of the knee (n = 15)

| Interpretation | P | T | Mean difference | Muscle group |
|---|---|---|---|---|
| Significant | < 0.001 | 6.59 | 78.42 | Knee extensors |
| Significant | < 0.001 | 6.24 | 62.02 | Knee flexors |

*B) Determination of the effect of fatigue in adductor and abductor muscles of the hip on total score of dynamic balance:* Table 2 presents results related to changes in the total score of the SEBT following fatigue induction in adductor and abductor muscles of the thigh, using paired t-test.

As can be observed, paired t-test showed that fatigue in both groups of thigh adductor and abductor muscles lead to a significant reduction in the total score of the SEBT.

**Table 2.** Results of paired t-test regarding the comparison of changes in the total score of the star excursion balance test after fatigue in adductor and abductor muscles of the thigh (n = 15)

| Interpretation | P | T | Mean difference | Muscle group |
|---|---|---|---|---|
| Significant | < 0.001 | 5.39 | 65.59 | Thigh adductors |
| Significant | < 0.001 | 5.84 | 52.79 | Thigh abductors |

*C) Determination of the effect of fatigue in plantar flexors of the ankle on total score of dynamic balance:* Results of paired t-test regarding the comparison of the total score of the SEBT after fatigue in ankle plantar flexor muscles showed a significant reduction in the total score of the test with a mean difference of 76.80 (P< 0.001; T = 10).

**Comparison of the effect of fatigue in five muscle groups on total score of dynamic balance in the star excursion balance test**

As table 3 presents, the results of assessing analysis of variance of total score of mean of balance (repeated measures ANOVA), the comparison of the mean total score of balance in the SEBT before and after fatigue showed a significant reduction in balance after fatigue in all 5 groups of thigh extensor muscles, thigh flexor, thigh abductor, thigh adductor, and ankle plantar flexors. However, no significant difference was observed in the effect of fatigue in lower limb muscles and the total score of dynamic balance between the groups.

**Table 3.** Results of repeated measures analysis of variance of fatigue in the five groups of muscles and total score of dynamic balance in the star excursion balance test

| Interpretation | P | T | Mean square | Groups |
|---|---|---|---|---|
| Significant | <0.001 | 213.15 | 168950.60 | With groups |
| Significant | 0.370 | 1.07 | 854.90 | Between groups |

**Star excursion balance test**

This section aimed to investigate the changes in balance score in each of the 8 directions of the SEBT in the knee extensor and flexor, thigh adductor and abductor, and ankle plantar flexor muscle groups using paired t-test.

*A) Effect of fatigue in muscles on anterior direction of the star excursion balance test:* Paired t-test showed a difference in the scores of the anterior direction of the SEBT after fatigue in flexor and extensor muscles of the knee, hip abductor and adductor, and ankle plantar flexors compared to the pretest scores. In other words, in the anterior direction, the achievement distance of these muscles was lower in the posttest compared to the pretest, and these differences were statistically significant (P ≤ 0.05) (Table 4).

*B) Effect of muscle fatigue on the anterior-interior direction the of the star excursion balance test:* Paired t-test showed a difference in the scores of the anterior-interior direction of the SEBT after fatigue in the knee flexor and extensor muscles, hip abductor and adductor, and ankle plantar flexors compared to the pretest. In other words, toward the anterior-interior direction, the achievement distance of these muscles was significantly lower at posttest than pretest (P ≤ 0.05) (Table 4).

*C) Effect of muscle fatigue on the interior direction of the star excursion balance test:* Paired t-test showed a statistically significant difference in the scores of the interior direction of the SEBT after fatigue in the flexor muscles of the knee, hip adductor, and ankle plantar flexors compared to the pretest. In other words, in the interior direction, the posttest achievement distance of these muscles was significantly lower than the pretest achievement distance (P ≤ 0.05) (Table 4).

*D) Effect of fatigue in muscles on the posterior-interior direction of the star excursion balance test:* Paired t-test showed a difference in the scores of the interior-posterior direction of the SEBT after fatigue in the flexor and extensor muscles of the knee, hip abductor and adductor, and ankle plantar flexors compared to the pretest.

**Table 4.** Investigation of changes in balance score in each of the directions of the star excursion balance test in the muscle groups

| Anterior direction | | | | |
|---|---|---|---|---|
| **Interpretation** | **P** | **T** | **Mean square** | **Muscle group** |
| Significant | < 0.001 | 5.24 | 15.24 | Knee extensor |
| Significant | < 0.001 | 6.21 | 15.25 | Knee flexor |
| Significant | < 0.001 | 6.60 | 13.90 | Thigh adductor |
| Significant | < 0.001 | 5.15 | 9.19 | Thigh abductor |
| Significant | < 0.001 | 6.42 | 16.96 | Ankle plantar flexor |
| **Toward anterior-interior direction** | | | | |
| **Interpretation** | **P** | **T** | **Mean square** | |
| < 0.001 | 14.01 | 3.45 | 12.48 | Knee extensor |
| < 0.001 | 7.52 | 5.86 | 11.39 | Knee flexor |
| < 0.001 | 8.45 | 5.22 | 11.41 | Thigh adductor |
| < 0.001 | 6.72 | 4.95 | 8.61 | Thigh abductor |
| < 0.001 | 10.92 | 4.42 | 12.48 | Ankle plantar flexor |
| **Toward interior direction** | | | | |
| **P** | **T** | **Standard deviation** | **Mean square** | |
| < 0.001 | 4.74 | 7.95 | 9.74 | Knee extensor |
| < 0.001 | 5.13 | 6.29 | 8.34 | Knee flexor |
| 0.03 | 3.51 | 8.85 | 8.02 | Thigh adductor |
| < 0.001 | 6.32 | 5.19 | 8.47 | Thigh abductor |
| < 0.001 | 9.75 | 4.85 | 12.23 | Ankle plantar flexor |
| **Toward posterior-interior direction** | | | | |
| **P** | **T** | **Standard deviation** | **Mean square** | |
| < 0.001 | 3.97 | 7.32 | 7.52 | Knee extensor |
| 0.04 | 2.16 | 7.32 | 2.04 | Knee flexor |
| 0.04 | 2.15 | 9.18 | 5.12 | Thigh adductor |
| 0.01 | 2.67 | 7.21 | 4.98 | Thigh abductor |
| < 0.001 | 5.58 | 2.28 | 6.46 | Ankle plantar flexor |
| **Posterior direction** | | | | |
| **P** | **T** | **Standard deviation** | **Mean square** | |
| < 0.001 | 3.97 | 7.32 | 7.52 | Knee extensor |
| 0.04 | 2.16 | 7.32 | 2.04 | Knee flexor |
| 0.04 | 2.15 | 9.18 | 5.12 | Thigh adductor |
| 0.01 | 2.67 | 7.21 | 4.98 | Thigh abductor |
| < 0.001 | 5.58 | 2.28 | 6.46 | Ankle plantar flexor |
| **Lateral direction** | | | | |
| **P** | **T** | **Standard deviation** | **Mean square** | |
| < 0.001 | 5.93 | 9.26 | 14.18 | Knee extensor |
| < 0.001 | 4.44 | 6.84 | 7.86 | Knee flexor |
| < 0.001 | 5.67 | 7.66 | 11.22 | Thigh adductor |
| 0.03 | 2.24 | 9.43 | 5.71 | Thigh abductor |
| < 0.001 | 2.17 | 8.77 | 7.19 | Ankle plantar flexor |
| **Lateral-anterior direction** | | | | |
| **P** | **T** | **Standard deviation** | **Mean square** | |
| < 0.001 | 4.06 | 15,93 | 16.71 | Knee extensor |
| < 0.001 | 4.19 | 9.86 | 10.66 | Knee flexor |
| < 0.001 | 4.02 | 11.11 | 11.56 | Thigh adductor |
| 0.15 | 1.50 | 9.30 | 3.61 | Thigh abductor |
| < 0.001 | 5.23 | 11.57 | 15.64 | Ankle plantar flexor |

In other words, toward the posterior-interior directions, the difference between the posttest and pretest achievement distance of these muscles was statistically significant; it was significantly lower in the posttest ($P \leq 0.05$) (Table 4).

*E) Effect of muscle fatigue on the posterior direction of the star excursion balance test:* Paired t-test showed a difference in the scores of the posterior direction of the SEBT after fatigue in the knee extensor and flexor, thigh abductor and adductor, and ankle plantar flexor muscles compared to the pretest.

In other words, in posterior direction, the posttest achievement distance of these muscles was significantly lower compared to the pretest achievement distance ($P \leq 0.05$) (Table 4).

*F) Effect of fatigue on the posterior-lateral direction of the star excursion balance test:* Paired t-test showed a difference in the scores of the posterior-lateral direction of the SEBT after fatigue in the knee flexor and extensor, hip abductor and adductor, and ankle flexor plantar muscles compared to pretest. In other words, in the posterior-lateral direction, the achievement distance of the knee extensor, and hip adductor and abductor, and ankle plantar flexor muscles was significantly lower in the posttest compared to the pretest ($P \leq 0.05$). However, this difference was not significant for the knee flexor muscles.

*G) Effect of fatigue on the lateral direction of the star excursion balance test:* Paired t-test showed a difference in the score of the lateral direction of the SEBT after fatigue in the knee flexor and extensor, hip abductor and adductor, and ankle plantar flexor muscles compared to pretest. In the lateral direction, the achievement distance of these muscles was significantly lower in the posttest compared to pretest ($P \leq 0.05$) (Table 4).

*H) Effect of fatigue on the lateral-anterior direction of the star excursion balance test:* Paired t-test showed a difference in the score of the lateral-anterior direction of the SEBT after fatigue in the knee flexor and extensor, hip abductor and adductor, and ankle plantar flexors compared to pretest. Thus, in the lateral-anterior direction, the achievement distance was significantly lower in the posttest compared to the pretest ($P \leq 0.05$) for the knee extensor and flexor, and hip plantar flexor muscles; however, this difference was not significant in the thigh abductor muscles (Table 4).

**Comparison of the effect of muscle fatigue on balance score in the anterior direction**

The comparison of the effect of muscle fatigue in the knee flexor and extensor, thigh abductor and adductor, and ankle plantar flexor muscles on the balance score toward the anterior direction of the SEBT indicated a significant difference among these muscle groups in terms of balance score. In order to identify which 2 muscle groups differ significantly, Scheffe's post hoc test with equality of variances was used. The results showed that the achievement rate of military forces toward the anterior direction after muscle fatigue in the ankle plantar flexor was not significantly different from the achievement rate after fatigue in the hip abductor muscles ($P = 0.01$) (Table 5).

**Comparison of the effect of fatigue on balance score of the direction of toward anterior-posterior**

Comparison of the effect of fatigue in the knee flexor and extensor, hip abductor and adductor, and ankle flexor plantar muscles on the balance score in the interior-anterior direction of the SEBT indicated a significant difference in achievement rate of military forces after muscle fatigue toward the anterior direction ($P = 0.18$).

**Comparison of the effect of fatigue on balance score of the interior direction**

Comparison of the effect of fatigue in the knee flexor and extensor, hip abductor and adductor, and ankle plantar flexor muscles on the balance score of the interior direction of the SEBT did not indicate a significant difference in the achievement rate of the military forces after muscle fatigue toward the interior direction ($P = 0.43$).

**Table 5.** Results of repeated measures analysis of variance of muscles of the lower limb after fatigue toward the anterior direction

| Post hoc Statistics | | | | | | |
|---|---|---|---|---|---|---|
| Interpretation | P | 4.5 | F | Mean square | Sum of squares | Anterior Direction |
| Significant | 0.01 | * | 3.63 | 65.47 | 261,90 | |

**Table 6.** Results of repeated measures analysis of variance of muscles of the lower limb after fatigue toward the anterior-lateral direction

| Interpretation | P | 4.5 | P | 1.4 | P | F | Mean square | Sum of squares | Anterior Direction |
|---|---|---|---|---|---|---|---|---|---|
| Significant | < 0.001 | * | < 0.001 | * | 0.02 | 2.88 | 200.80 | 803,21 | Anterior-lateral |

**Comparison of the effect of fatigue on balance score of the posterior-interior direction**

Comparison of the effect of fatigue in the knee flexor and extensor, hip abductor and adductor, and ankle flexor plantar muscles on the balance score of the direction of toward posterior-interior of the SEBT did not indicate a significant difference in the achievement rate of the military forces after muscle fatigue toward the interior direction (P = 0.06).

**Comparison of the effect of fatigue on balance score of the direction of toward posterior**

Comparison of the effect of fatigue in the knee flexor and extensor, hip abductor and adductor, and ankle flexor plantar muscles on the balance score of the direction of toward posterior of the SEBT did not indicate a significant difference in the achievement rate of the military forces after muscle fatigue toward the interior direction (P = 0.06).

**Comparison of the effect of fatigue on balance score of the direction of toward posterior-lateral**

Comparison of the effect of fatigue in the knee flexor and extensor, hip abductor and adductor, and ankle flexor plantar muscles on the balance score of the direction of toward posterior-lateral of the SEBT did not indicate a significant difference in the achievement rate of the military forces after muscle fatigue toward the posterior direction (P = 0.84).

**Comparison of the effect of fatigue on balance score of the lateral direction**

Comparison of the effect of fatigue in the knee flexor and extensor, hip abductor and adductor, and ankle plantar flexor muscles on the balance score of the lateral direction of toward of the SEBT did not indicate a significant difference in the achievement rate of the military forces after muscle fatigue toward the posterior direction (P = 0.53).

**Comparison of the effect of fatigue on balance score of the anterior-lateral direction**

Comparison of the effect of fatigue in the knee flexor and extensor, hip abductor and adductor, and ankle plantar flexor muscles on the balance score of the anterior-lateral direction of the SEBT indicated a significant difference in the achievement rate of the military forces after muscle fatigue toward the posterior direction. In order to identify the 2 muscle groups that differed significantly, Scheffe's post hoc test with the equality of variance was used. The results indicated that the achievement rate of the military forces after fatigue in the knee extensor muscles was significantly different from that after fatigue in the thigh abductor muscles and achievement rate after muscle fatigue in the ankle plantar flexor and thigh abductor muscles toward lateral-anterior direction (P < 0.001) (Table 6)

## Discussion

Since most exercise activities are performed in a dynamic environment, dynamic balance is of utmost importance in performing military activities and exercises, and is an important factor in the performance of the military. Therefore, the aim of the current study was to investigate the effect of fatigue in each muscle group of the lower limbs on the dynamic balance of military forces and compare the effect size of each of them.

The results of this study showed that there is an inverse relationship between lower muscles fatigue and individual balance, and increase of fatigue in muscles causes a decrease in balance. Fatigue in the extensor and ankle plantar flexor muscles has a higher effect on disruption of the dynamic balance of military forces compared to fatigue in other muscles (knee flexor, and thigh abductor and adductor). The comparison of the effect of fatigue in these 5 groups of muscles on the total score of dynamic balance showed that the minimum rate of disruption of balance was related to fatigue in hip abductors. However, this difference was not significant compared to the other muscle groups. The highest percentage of reduction in achievement distance was related to the knee extensors toward the lateral-anterior and anterior-interior directions. The reason for this might be the different roles of each of the lower limb muscles in performing SEBT.

The individual is trying to reach maximum achievement distance toward the anterior direction, and thus, must lean backwards and his body must be in extension to preserve his balance. In this posture, gravity on the upper section of the body leads to higher rotation of the knee, which has to be controlled by eccentric torque in the quadriceps femoris muscle.

Additionally, the observed decline can be attributed to inappropriate function of the muscles and sensory effects of fatigue. The initiation of fatigue in an area of the body and in muscles acting on one joint leads to the signaling of sensory receptors to the central nervous system, and this system responds to prevent muscle damage through sending signals to reduce the contractile activity of the muscle.[18] Inhibitory mechanisms of the neuro-muscular system such as the Golgi tendon organs are of utmost importance in the prevention of the generation of muscular power beyond the strength of bones and connective tissues. This control of muscular distress is a spontaneous inhibition. When the distress on muscular tendons and inner connective tissue constructs is beyond the strength of the Golgi tendon organ, motor neurons of the muscle are inhibited; this reaction is spontaneous inhibition.[19,20]

Therefore, the initiation of fatigue in a muscle group leads to a decline in the speed of neural signaling in afferent and efferent pathways into the muscles; this factor might also play a role in the decline of dynamic balance and distance achievement of participants after fatigue. The SEBT requires neuro-muscular control for the appropriate positioning of the joint and the strength of its surrounding muscular structure during the test. In order to better performance in star excursion balance test for the relied foot during performing of test require ankle dorsi flexion, knee flexion, and thigh flexion; therefore, the lower limbs require appropriate motor range, power, activity of deep receptors, and muscular neural control. Toward the posterior direction, a greater decrease in achievement distance was observed after fatigue in the knee flexor compared to after fatigue in the knee extensor muscles. This could be explained by the effect of gravity on the body, which leads to thigh flexion rotation. In order to perform this test toward the posterior direction, flexion is required in the body to be able to open the leg toward the back, and in this posture, eccentric contraction of the hamstring muscles is needed to resist thigh flexion rotation. Each military activity and exercise requires various levels of sensory-motor processors to perform skills and neuro-muscular protection to prevent injury. Military exercises have various motor patterns, most of which are performed dynamically. Hence, management of dynamic balance is important in the better performance of skills and it is considered necessary to prevent the occurrence of musculo-skeletal damages.

The findings of the current study showed that the maximum effect of fatigue on reducing achievement distance in SEBT is related to fatigue in the ankle plantar flexor and knee extensor muscles. Thus, fatigue in these 2 muscle groups should be taken into consideration in military exercises, because fatigue in the ankle plantar flexor muscles can cause ankle damages in these individuals, and fatigue in the knee extensor muscles affect movement pattern and knee control during military performance and cause a reduction in the activity of muscle spindles and neuro-muscular control. During these exercises, due to fatigue in this muscle group and decline in neuro-muscular control, knee joint stability is reduced and the risk of damage will increase. As a result of fatigue in the knee extensor muscles, rotator forces applied to the knee change within the exercises, and can lead to ligament and meniscus damage in the knee joint. In case of imbalance and fatigue in the muscles surrounding the knee, the individual is susceptible to knee damage such as damage to the anterior cruciate ligament (ACL), which is very common. In general, findings obtained regarding decline in balance control due to fatigue are in line with findings of the previous research by Yaggie and McGregor,[21] Vuillerme et al.,[22] and Rozzi et al.,[23] in which decline in balance control was reported after fatigue. However, our findings are inconsistent with the findings of Rozzi et al.,[23] who did not find a significant decline in the balance of individuals after fatigue. This inconsistency might be due to interventional factors such as the amount of rest on the day prior to the test, the nature of the tasks, the individuals were encountered during the day, activity level, and readiness, the participants, or use of different fatigue application protocols in athletes.

One of the limitations of this study was working with the military and preparing participants by performing the tasks 5 times until muscle fatigue with time intervals.

## Conclusion

The results of this study showed that there was an inverse relationship between lower limb muscle fatigue and individual balance, and an increase in muscle fatigue causes a decrease in balance. Fatigue in the extensor muscles and the ankle plantar flexor has a greater effect on the disruption in dynamic balance of the military forces compared to fatigue in other muscles. The minimum rate of disruption of balance was related to fatigue in the hip abductors; however, this difference was not significant compared to the other muscles. In conclusion, it can be stated that there is an inverse relationship between lower limb fatigue and the individual's balance, and increase in fatigue level in muscles decreases balance.

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## Conflict of Interest

Authors have no conflict of interest.

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