Effect of induced fatigue on dynamic postural balance in healthy young adults

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Background

Fatigue may impair the proprioceptive and kinesthetic properties of joints and has been shown to have a negative effect on neuromuscular control, thus increasing the risk for injury.

Purpose

This study aimed to determine the effect of induced whole-body fatigue on dynamic balance control in healthy young adults.

Participants and methods

Thirty healthy young participants of both sexes were included in this study; their ages ranged between 18 and 22 years. All of the participants were tested on the Biodex Stability System (BSS) at a stability level 4, subjected to induced fatigue on a treadmill, and then retested directly on the BSS again to evaluate dynamic postural balance.

Results

There was a significant decrease in the overall stability index, anteroposterior stability index, and mediolateral stability index of dynamic balance at stability level 4 of BSS in healthy young adults as *P*-values were 0.0001, 0.0001, and 0.0001, respectively.

Conclusion and implication

It was concluded that induced whole-body fatigue decreased the dynamic postural balance (overall stability index, anteroposterior stability index, and mediolateral stability index) in healthy young adults. This implies that muscles of a fatigued individual are at increased risk for musculoskeletal injury, and steps should be taken during conditioning and rehabilitation programs to prevent muscle fatigue through balance training and endurance exercises to avoid disturbed balance related to fatigue among young healthy adults.

Keywords:
balance, fatigue, measurements, postural stability

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Introduction

The maintenance of balance is important in the prevention of injuries and this ability depends on proprioceptive input from musculotendinous and capsuloligamentous mechanoreceptors in conjunction with visual and vestibular input to the central nervous system (CNS) [1–3]. This input is used in both feedback and feed-forward loops to provide the appropriate neuromuscular response [3,4]. Alterations in any of these inputs would disturb balance and increase the risk of injury [5].

Fatigue may alter the proprioceptive and kinesthetic properties of joints by increasing joint laxity and by causing sensorimotor and biomechanical deficits, such as reduced muscle strength and activity, therefore decreasing neuromuscular control, thus increasing the risk for injury [6,7].

Therefore, physical therapy evaluation should consider balance as an important element. The clinician must predict the ability of an individual to safely and independently function in a variety of environments such as the home, school, and community [8]. Quantification of postural control is often necessary to assess the level of injury or ability to function to initiate an appropriate plan of care [9].

Many studies have discussed the effect of induced fatigue on measures of dynamic balance tests in elderly and athletes using different methods and different populations, but to the best of our knowledge, no research has been carried out on healthy young adults. Therefore, this study aimed to determine the effect of induced whole-body fatigue on dynamic balance control in a group of healthy young adults [10–16].

Participants and methods

This an experimental design study that was carried out in the Balance Laboratory at Faculty of Physical Therapy, Cairo University, in the period from September 2013 to December 2013 to investigate the effect of induced fatigue on dynamic postural balance in healthy young adults.

This study included only 30 participants out of the 70 volunteers who expressed a desire to undergo the test and fulfilled the selection criteria. Every participant was subjected to a primary examination to obtain a complete picture of their health status, to identify any contraindications, and to determine whether the patient could participate in the study.

Measurements were performed under the following standardized conditions: (i) measurements were carried out by the same investigator and (ii) the same balance measures were assessed before and after induced fatigue for each patient using the Biodex Stability System (BSS).

The patients were excluded if they had repeated lower extremity injuries, fractures or deformities, history of surgery to the lower extremity, history of cerebral concussions, visual or vestibular disorders, and any neurological deficit affecting balance.

Furthermore, a compulsory 2-week washout period was performed for all patients who had previously had any muscle relaxants or analgesics. The use of all nonessential pain relievers were prohibited 24 h before the testing sessions to exclude the effect of any cause of relaxation that could delay fatigue. Only five participants were excluded as they were under analgesics. This study was approved by the Faculty of Physical Therapy Ethical Committee and all patients signed a confirmed consent form before participation in the study.

All of the participants were tested on the BSS, subjected to induced fatigue on a treadmill, and then retested directly on the BSS again to evaluate dynamic postural balance.

Biodex Stability System

The device used in this study (Biodex Medical Systems Inc., Shirley, New York, USA) was a foot platform (circular in shape with a diameter of 21.5´ and a height of 8´ above the floor, which permits up to 20° tilting from horizontal in all directions), support rails that were adjustable from 25´ to 36.5´ above the platform, and could be swung away if desired, a display module whose height was adjustable from 51´ to 68´ above the platform and angle was adjustable from vertical back to 45°, with a display viewing area of 122 mm × 92 mm and a display resolution of 320 pixels ×240 pixels, and a printer. This testing machine with a multiaxial standing platform, allowing up to 20° of surface tilt, creates a dynamic situation similar to actual functional activities that result in instability.

BSS has eight stability levels with level 8 being the most stable one where the instrument's platform was tilted with difficulty and the participants can easily maintain their balance on it. Whereas level 1 was the least stable level as it becomes very difficult for the participants to maintain stability on the instrument's platform [17].

Stability indexes

The stability index represents the variance of platform displacement in degrees from level. A high number is indicative of considerable motion, which indicates a problem with balance [18]. The participant's ability to control the platform's angle of tilt was measured by the system and noted as a stability index. The data on the balance of the tested participants were supplied to the system. These data included anteroposterior stability index (APSI), mediolateral stability index (MLSI), and overall stability index (OSI). The smaller the amount of sway, the lower the numerical value of these indexes [18].

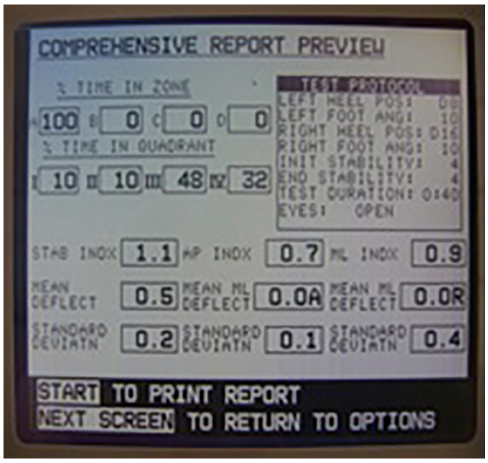
(1) OSI: represented the variance of foot platform displacement in degrees, from level, in all motions during the test. A high number was indicative of considerable movement during this test.
(2) APSI: represented the variance of foot platform displacement, in degrees, from level, for motion in the sagittal plane.
(3) MLSI: represented the variance of foot platform displacement, in degrees from level, for motion in the frontal plane [18].

Each participant received a verbal explanation about the test steps. When the system was on, the first displayed screen was the main menu. It allowed us to choose entering testing, training, or system utilities. Choosing to enter testing showed the next screen, which allowed determination of the test parameters such as test duration and the stability level chosen. The weight and height of the participant were recorded and the next screen was used for the centering process (Fig. 1). The next screen was the stability test screen, where the start key was pressed to unlock the platform and begin the test. A cursor appeared during the test tracing the movement of the platform while the clock counted till the time of the test ends. The next screen showed a menu. The examiner chooses the numeric report option on this screen to allow the participant's numeric screen appear. Pressing start while on this screen initiates printing of the report, which includes the numeric values of the APSI, MLSI, and OSI (operation and service manual) [19].

Figure 1

Patient standing on the Biodex Stability System.

Figure 2



The participant's report review on the Biodex Stability System.

Step 1: balance assessment

The participants were tested without footwear and asked to perform two test trials before a specific test condition for the purpose of instrument familiarity before data collection. Then, the participant was first asked to assume the test position (standing on both feet) with arms held at the sides and to attempt to control his/her balance as much as possible [18]. Each participant was asked to center him/herself on the foot platform before starting the test (Fig. 1).

The following test parameters were introduced into the device:

(1) Participant's weight, height, and age.
(2) Platform firmness (stability level): all participants were tested on stability level 4 for 20 s [20].

Then, the start key was pressed in the control panel to unlock the platform (which took 5 s) with an auditory alarm just before the beginning of the test. The participant was instructed that the platform was unstable just after the alarm. Each participant was instructed to maintain a level platform for the period of the test. For each test trial, the participant attempted to keep the platform level for 20 s with double-leg support [18].

Instructions were provided for the participants to focus on a visual feedback screen directly in front of them and attempt to maintain the cursor, which represents the center of the platform, at the center of the bullseye on the screen equated to a level platform. At the end of each test, a printout report was obtained. This report included information on OSI, APSI, and MLSI (Fig. 2).

Step 2: fatigue induction

Fatigue induction was performed through running on a treadmill using the standard Bruce protocol as Lepers *et al*. [21] found that muscular fatigue affected balance greater following the treadmill exercise compared with the cycle test [22]. The participants started walking on a treadmill at a speed of 2.7 km/h and a grade of slope (10%) for 3 min. Thus, 3 min into the test, the speed was adjusted to 4.02 km/h and the slope was adjusted to 12%, after 6 min into the test, the speed was adjusted to 5.47 km/h and the slope to 14%, and so on; the test continued until the participant was exhausted that is he/she was not able to continue further.

Step 3: balance reassessment

The participant was asked to repeat the same balance testing procedures directly after fatigue on the treadmill to measure post OSI, MLSI, and APSI.

Statistical analysis

The SPSS (version 17; SPSS Inc., Chicago, Illinois, USA) statistical software package was used for statistical analyses. All data are expressed as mean and SD. The level of significance was set at P value less than 0.05. Data were first analyzed using the Kolmogorov-Smirnov test to identify a normal distribution. A paired Student's t-test was used to assess dynamic postural balance before and after induced fatigue. A preliminary statistical power analysis determined that a sample size of 30 for this study was adequate to achieve more than 80% power depending on the OSI.

Results

This study was carried out on 30 volunteers of both sexes (10 men and 20 women) recruited from among the students of the Faculty of Physical Therapy, Cairo University. Their age ranged from 18 to 22 years, height ranged from 150 to 180 cm, weight ranged from 52 to 79 kg, and BMI ranged from 18.38 to 29.02. The demographic data of the participants are shown in Table 1. Dynamic postural balance in the form of OSI, APSI, and MLSI was measured before and after induced fatigue as shown in Table 2.

Table 1 Participants' demographic data

Items	Mean ± SD/*n* (%)
Age (years)	18.46 ± 0.57
Weight (kg)	64.12 ± 7.71
Height (cm)	165.73 ± 7.59
BMI (kg/m^2)	23.36 ± 2.54
Sex	
Male	10 (33.3)
Female	20 (66.7)

Overall stability index

The OSI decreased significantly after induced whole-body fatigue with a percentage of 93.61% (before: 1.88 ± 0.44; after: 3.64 ± 1.12; $P < 0.0001$).

Anteroposterior stability index

The APSI decreased significantly after induced whole-body fatigue with a percentage of 96.59% (before: 1.47 ± 0.34; after: 2.89 ± 0.89; $P < 0.0001$).

Mediolateral stability index

The MLSI decreased significantly after induced whole-body fatigue with a percentage of 90.71% (before: 1.40 ± 0.37; after: 2.67 ± 0.87; $P < 0.0001$).

Table 2 Overall stability index, anteroposterior stability index, and mediolateral stability index before and after induced fatigue

Dynamic postural balance	Before induced fatigue	After induced fatigue	*P*-value
Overall stability index	1.88 ± 0.44	3.64 ± 1.12	<0.0001*
Anteroposterior stability index	1.47 ± 0.34	2.89 ± 0.89	<0.0001*
Mediolateral stability index	1.4 ± 0.37	2.67 ± 0.87	<0.0001*

*Significant.

Discussion

Our clinical study was carried out to determine the effect of induced whole-body fatigue on dynamic balance control in a group of healthy young adults. It showed that there was a significant decrease in OSI, APSI, and MLSI of dynamic balance at stability level 4 of BSS immediately after fatigue induction in healthy young adults.

There are primary reasons that have been proposed to explain why fatigue decreased the dynamic postural balance. The first explanation was that balance is controlled by the CNS through the integration of sensory information from the vestibular, somatosensory, and visual systems and when the muscles that control balance are fatigued, these systems would be affected, thus inhibiting proper balance control [23]. Second, the muscular fatigue increases the muscle spindle discharge, which disrupts the afferent feedback input to CNS that causes alterations in proprioceptive and kinesthetic properties of joints, which has a negative effect on postural control [11–24]. Finally, the application of a fatigue protocol on a part of the body and the muscles acting on a joint causes the sensory receptors to send messages to the CNS that result in the reduction of the speed of neural transmission in afferent and efferent neurons ending in a muscle group. Therefore, dynamic balance control is decreased after fatigue induction, whereas in the present study, whole-body fatigue induction was performed; thus, this explanation partially clarifies why dynamic balance decreased after induced fatigue [25].

To our knowledge, most studies in the literature of our scope investigated the effect of fatigue on dynamic postural balance on specific body parts and not the whole body, which makes our results partially and not entirely in agreement with their results.

Steib *et al.* [10] found that in an unfatigued state, there was no difference in static and dynamic measures of postural control, but after fatigue induction by treadmill running for ~14 min to exhaustion (between 12 and 20 km/h), all postural control measures were negatively affected.

Also, Simoneau *et al*. [24] examined how moderate fatigue by fast walking affected the control of balance on ten healthy young adults as they reported an initial negative impact on the control of balance.

In addition, Miura *et al*. [26] and Lee *et al*. [27] found that the muscular fatigue induces an adverse change in the proprioception as well as postural control [11–14].

Also, the results of the study were supported by Gribble *et al*. [7,11,28], who found a significant decrease in all reach directions of the Star Excursion Balance Test after lower extremity muscle fatigue in healthy participants, which indicated that the balance was affected by fatigue.

In terms of the risks accompanying improper balance control, Ingram *et al*. [29] found that alterations in neuromuscular and biomechanical properties in the lower limbs resulting from fatigue were the primary contributor to the female anterior cruciate ligament injury mechanism because of improper balance control.

Yaggie and Armstrong [15] also examined the impact of lower extremity fatigue on balance indexes using the Sport-KAT-2000 system before and immediately after the fatigue protocol. They reported that lower extremity fatigue adversely affected balance index scores, which is in agreement with the results of our current study.

In addition, Wilkins *et al.* [30] studied the performance on the Balance Error Scoring System and investigated how it is impaired after fatigue. They used a seven-station fatigue protocol to simulate the activity during an exercise. The increase in Balance Error Scoring System scores immediately after fatigue indicated that the balance was affected by fatigue.

Furthermore, Harkins *et al.* [31] explored the effect of two types of fatigue on the duration of postural stability defect, and reported that as the amount of fatigue is increased, the defect in postural control system is increased. Also, Marco *et al.* [32] induced fatigue in 20 individuals on a treadmill, where the speed increased every minute to reach exhaustion, and proved that there was a significant reduction in balance after the application of the fatigue protocol.

Our results were in partial agreement with the results of Letafatkar *et al.* [16], who carried out a research on the effect of inducing exhaustive exercises on 30 professional male athletes on functional stability. A Biodex device and Running-based Anaerobic Sprint Test were used to measure balance and induce fatigue, respectively. The researchers concluded that muscle fatigue reduced functional and lateral stability; however, it is not likely to affect posterior and anterior stability. This can be explained by the fact that when an individual suffers from fatigue, CNS compensates for the disturbances created in the functional stability of the body to some extent [16].

Dehnavi *et al.* [33] also observed how fatigue affected basketball players with functional ankle instability compared with 12 healthy individuals. The result proved that dynamic postural control decreased significantly after the induction of fatigue in both groups and it affected the participants of both groups equally. This means that the participants in the experimental group coordinated postural control mechanisms with fatigue. On the basis of the results of this study, it can be concluded that fatigue, in both healthy players and those with functional ankle instability, makes them susceptible to ankle sprain because of defects in postural control [33].

In addition, Nardone *et al.* [34] used a treadmill aerobic fatigue protocol and reported increases in the sway path of the center of pressure and median frequency of the center of pressure velocity after the fatigue protocol.

There are additional physiological mechanisms that could explain these findings. Reports have shown impaired muscle spindle sensitivity following prolonged exercise in animals, possibly because of the influence of metabolites or/and inflammatory substances or through the modulation of reflex pathways originating from small-diameter muscles afferents [35–37]. Sense of position and movement in humans was altered under muscle fatigue [37,38].

Also, Simoneau *et al.* [39] tested the balance stability of recreational and highly skilled biathletes in their upright shooting position before and after a metabolic activation similar to that observed in competition. They reported that skilled athletes were less affected by fatigue, suggesting that skills could attenuate the specific effect of fatigue on balance control [39].

However, Johnston *et al.* [40] reported results that were not in agreement with those of the present study as they reported that fatigue of the lower extremity muscles caused a significant decrease in static balance, but not in dynamic balance.

Also, Rozzi *et al.* [18] reported results that were not in agreement with the result of our current study; they found that fatigue did not increase body volatility that is caused by reduction of balance. One of the reasons for this contradiction in results might be the variation in fatigue-inducing protocols and the test methods used to measure balance [18].

Only one of the studies found that the muscular fatigue did not cause an adverse postural change [13]. As the postural control is retained through some afferents that arise from the visual, vestibular, and somatosensory systems that stimulate the continuous muscular contractions [11,13,14] and as the muscular fatigue changes the effectiveness of muscular contraction and proprioceptive information, these results are not surprising [13,27,41].

Other studies showed different effects (significant increase, decrease, or no change) of fatigue on dynamic balance abilities using jump-stabilization measures or balance time on unstable surfaces [42–44].

The diversity between these findings emphasizes the need for a gold standard assessment for the detection of sensorimotor control changes under unstable postural conditions [45].

Specific comparisons of the reports of previous studies in the literature could not be made easily because of variations in the fatigue protocols and the balance measurements. One possible limitation in the current study is the inability to quantify muscular fatigue objectively and that we just depended on subjective exhaustion for each individual; thus, we cannot ascertain that all participants were completely exhausted. Another possible limitation is that each participant was asked to perform two test trials before the specific test condition for the purpose of instrument familiarity before data collection. Some participants had difficulty in familiarizing themselves with the BSS and needed more than two test trials to adapt with the BSS before stability indexes could be measured. Finally, lack of a control group and lack of long-term assessment were also other limitations in this study. Thus, further studies are required to assess dynamic balance with different levels of stability rather than level 4 and measure dynamic balance in patients with different disorders.

Conclusion

According to the findings of this study, it was concluded that induced whole-body fatigue decreased the dynamic postural balance in healthy young adults. This implies that muscles of a fatigued individual are at increased risk for musculoskeletal injury, and steps should be taken during conditioning and rehabilitation programs to prevent muscle fatigue through balance training and endurance exercises to avoid disturbed balance related to fatigue among young healthy adults.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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