Effects of Lower-Extremity and Trunk Muscle Fatigue on Balance

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Abstract: *Objective*: To examine the impact of lower-extremity and trunk muscle fatigue on static and dynamic balance tests.

Methods: An isokinetic dynamometer at constant angular velocities of 60°/s, 90°/s, 120°/s, and 180°/s was used to test the isokinetic strength of knee and trunk muscles in 30 healthy sedentary volunteers (14 men and 16 women). Lower-extremity fatigue was produced with the StairMaster, and trunk muscle fatigue was produced with an isokinetic dynamometer. Static and dynamic balance measurements were assessed with a balance assessment system before and after muscle fatigue in each subject.

Results: There was a significant difference between the prefatigue - postfatigue trunk and lower extremity muscles and the static balance scores. But the dynamic right, left and front balance test scores were not significantly different before and after fatigue of the trunk and lower-extremity muscles.

Conclusion: Balance is affected by a generalized fatigue of trunk muscles and lower-extremity muscles. However, it appears that static balance control is affected by the fatigue of trunk and lower-extremity muscles while dynamic balance is affected partly by trunk and lower-extremity muscular fatigue.

Keywords: Postural control, static balance, dynamic balance, muscle fatigue.

INTRODUCTION

"Balance" is defined as the ability to maintain equilibrium in a gravitational field by keeping the body mass centered over its base of support. It is also defined as the ability to react to destabilizing forces quickly and efficiently to regain stability *via* postural adjustments before, during, and after voluntary movement and in response to external perturbation. Balance, is maintained by the dynamic integration of internal and external forces and factors involving the environment. Balance is no longer considered simply a summation of static reflexes but rather a complex skill that is based on the interaction of dynamic sensorimotor processes. Balance is necessary for the selection and execution of context-specific motor responses [1-4].

Balance can be classified as either static (attempting to maintain a base of support with minimal movement) or dynamic (attempting to maintain a stable base of support while completing a prescribed movement). Postural instability, which can result from an alteration at any level of equilibrium regulation, has been studied particularly in elderly people, who exhibit decreased sensitivity in sensors, less effective information transmission in the central nervous system, and reduced muscular capacity [5-7].

Fatigue, which can impair the proprioceptive and kinesthetic properties of joints, increases the threshold of muscle spindle discharge, which in turn disrupts afferent feedback and ultimately alters joint awareness [8]. The detrimental effect of fatigue on static balance has been established [2, 9-15], but its effects on measures of dynamic balance are unknown.

To examine the ways in which fatigue affects balance, some authors have induced generalized muscle fatigue *via* strenuous aerobic exercise or selective muscle-fatiguing protocols [1,2,9,10,16,17].

It appears that there is a relationship between lower-extremity fatigue andbalance deficits; however, to our knowledge, no previous study has compared the various effects of fatigue of the lower-extremity and trunk muscles on balance. The purpose of this study was to examine the impact of fatigue of the lower-extremity and trunk muscles on the results of static and dynamic balance tests.

PARTICIPANTS AND METHODS

Thirty healthy volunteers (14 men and 16 women; age range, 22-29 years; mean age, 24 ± 2.3 years; body weight range, 48-84 kg; mean body weight, 66.4 ± 12 kg) were included in the study. They have no history of neuromuscular, orthopedic, vestibular, or ophthalmologic disease and who were not receiving any medication that might interfere with balance and postural control participated in this study. Subjects were instructed to avoid any stimulants like coffee or sports drinks until the completion of all procedures. Before the test protocols participant performed no physical activity that may be influenced muscle fatigue. After the study had been briefly described, all subjects provided written informed consent. The study was approved by the Baskent University Ethics Committee. Lower extremity and trunk fatigue testing were performed on separate days in the morning, namely, leg fatigue testing on day 2, back testing

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on day 3, so the observed results were not the combined effects.

Equipment

The Kinesthetic Ability Trainer (Fig. **1**) SportKAT 3000 (LLC, Vista, Calif) is a computerized system designed for static and dynamic balance assessment and training. These testing system generates 7 different parametric data. The sum of the scores for each quadrant in a test period is recorded as the overall balance index (BI) score. This value reflects the subject's ability to keep the platform at or near the reference position. Balance index scores range from zero to 6000, and the lower the score, the better the balance index. Zero is a perfect score, and lower values indicate better performance. In addition to the BI score, the sum of the 2 quadrant scores above the x-axis is recorded as the "front score," and the corresponding value for below the x-axis is recorded as the "back score." Similarly, the sums of the scores to the left and right of the y-axis are recorded as the "left score" and the "right score," respectively. The reliability of the balance data with the use of the SportKAT 2000 has been described previously [18].

Fig. (1). SportKAT 3000.

Cybex: A computerized isokinetic dynamometer (Cybex 770 Norm, Lumex Inc, Ronkomma, NY, USA) was used for testing and fatiguing procedures. The isokinetic strength of the knee muscles was tested at constant angular velocities of 60°/s, 90°/s, 120°/s, and 180°/s with 5 repetitions at each velocity. A 90-second rest period was allowed after each set, and a 5-minute rest was allowed after the test of each leg. Isokinetic trunk muscle strength was tested at angular velocities of 60°/s, 90°/s, 120°/s, and 180°/s for 10 repetitions with a 90-second rest between repetitions. All participant allowed five minute familiarization periods before test protocols

Fatigue Protocol

The StairMaster [19] is a device which imposes closed kinetic chain antagonistic exercise on the ankle, knee and hip similar to a stair stepper. This device was used in the study to produce lower-extremity fatigue. While the subjects were exercising at 70% of their maximum heart rate (=220-age), we calculated the number of steps per minute. Decrease in steps per minute to 50% of the initial value was considered as the onset of fatigue [10]. An isokinetic dynamometer was used to produce trunk muscle fatigue. Subjects were asked to perform their maximum effort of trunk flexion and extension at a velocity of 90°/s in the dynamometer. The fatigue criteria were determined by examining the subjects' maximum peak torque values during the test period. In the fatigue protocol, there was no limitation of the repetitions at 90°/s velocity, and the subjects were not aware of the fatigue criteria until the completion of the study. Drop in the peak torques of 3 consecutive repetitions below 50% of the pre-calculated peak torque values was considered the onset of fatigue [1,2,9].

Balance Test Protocol

In the preliminary session, the subjects were familiarized with the instrument of the balance assessment system. Each subject was allowed to practice a 3-minute adaptation and learning period before the initiation of the test series. After that introductory session, the subjects participated in the prefatigue static and dynamic balance measurements. Then, both lower-extremity fatigue and trunk muscle fatigue were produced with the StairMaster / isokinetic dynamometer respectively, as described. The balance tests were performed a few second after these fatigue protocols with the SportKAT3000, which was positioned approximately 2 meters from the dynamometer and the StairMaster. The subjects performed static and dynamic balance tests consecutively. Balance testing was performed on 3 different days. On day 1, prefatigue balance scores were recorded. On day 2 and 3, balance was tested after fatigue of lower extremity muscles and fatigue of trunk muscles consecutively. During balance testing, the subjects were asked to maintain a bilateral stance on the platform. During the static balance test, the subjects kept their eyes open to view on the monitor screen and tried to keep the red "X" in the center of the screen. During the dynamic balance test, the subjects were asked to visually follow a cursor moving in a clockwise circular pattern in the middle of the screen using the red X. The moving cursor was set to move at the medium speed setting of 3. Each subject stood barefoot on the force platform in a natural position with arms placed across the chest. The pressure pillow of the force platform was set on 6 bars. To ensure that the balance measurements were accurate, the SportKAT 3000 device was calibrated as recommended in its manual before each test.

Statistical Analysis

All statistical analyses were performed with SPSS software (Statistical Package for the Social Sciences, version 11.0, SSPS Inc, Chicago, Ill, USA). Descriptive statistics were used to present the subjects' characteristics. Means and standard deviations were calculated for each variable investigated. As the data did not have a uniform distribution, nonparametric tests were used in all statistical analysis. Pearson product moment correlation coefficients were used to analyze the strength of the linear relationships between age, body weight, and isokinetic and balance measurements. Prepost fatique balance scores were compared with Wilcoxon tests with a Bonferroni correction was used for subsequent posthoc pair.

Results: There was no correlation between age and dynamic-static balance scores (P = .260) or between weight and dynamic-static balance scores (P = .148). The isokinetic strengths of the subjects' trunk muscles and knee muscles are shown in Table **1**. Balance scores of the subjects before and after fatigue are shown in Figs. (**2**,**3**).

There was a negative correlation between trunk flexor muscle strength and front scores of static balance (r = -0.368, P = .045). There was a negative correlation between right knee flexor strength at angular velocities of 60°/s and 120°/s and the right score of dynamic balance (r = -0.368, P = .009; and r = -0.368, P = .029 for 60°/s and 120°/s, respectively). There was a negative correlation between left knee flexor strength at angular velocities of 60°/s, 90°/s, 120°/s, and 180°/s and the right score of dynamic balance (r = -0.381, P = .038; r = -0.440, P = .015; r = -0.422, P = .002; and r = -0.370, P = .016 for 60°/s, 90°/s, 120°/s, and 180°/s, respectively). There was no correlation between quadriceps muscle strength and dynamic-static balance scores.

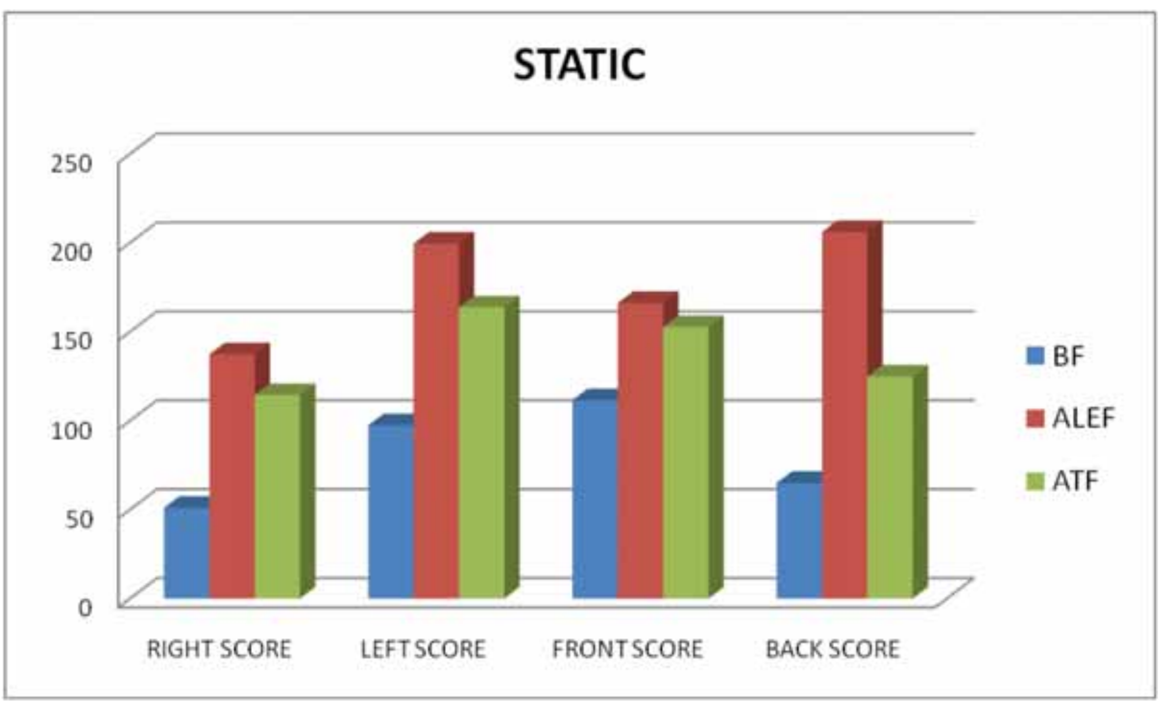
Before and after fatigue of the trunk muscles there were significant difference between the prefatigue and postfatigue balance scores of static right, left, front, and back. (P = .000, P = .001, P = .006, P = .000 respectively). Only dynamic back balance scores were significantly different before and after fatigue of the trunk muscles. (P = .028). But the right, left and front dynamic balance (P = .165, P = .299, P = .339 respectively). Figs. (**4-6**) show the same subjects' dynamic balance scores diagrams before and after fatigue of the the lower-extremity muscles and trunk muscles. The results were worse after fatigue.

The static balance scores of the right, left and back scores were significantly different before and after fatigue of the lower extremities (P = .001, P = .000, and P =.000, respectively) and the back scores of the dynamic balance test were significantly different before and after fatigue of the lower-

Table 1. Mean Isokinetic Trunk and Knee Muscle Strength Values at 4 Different Velocities*

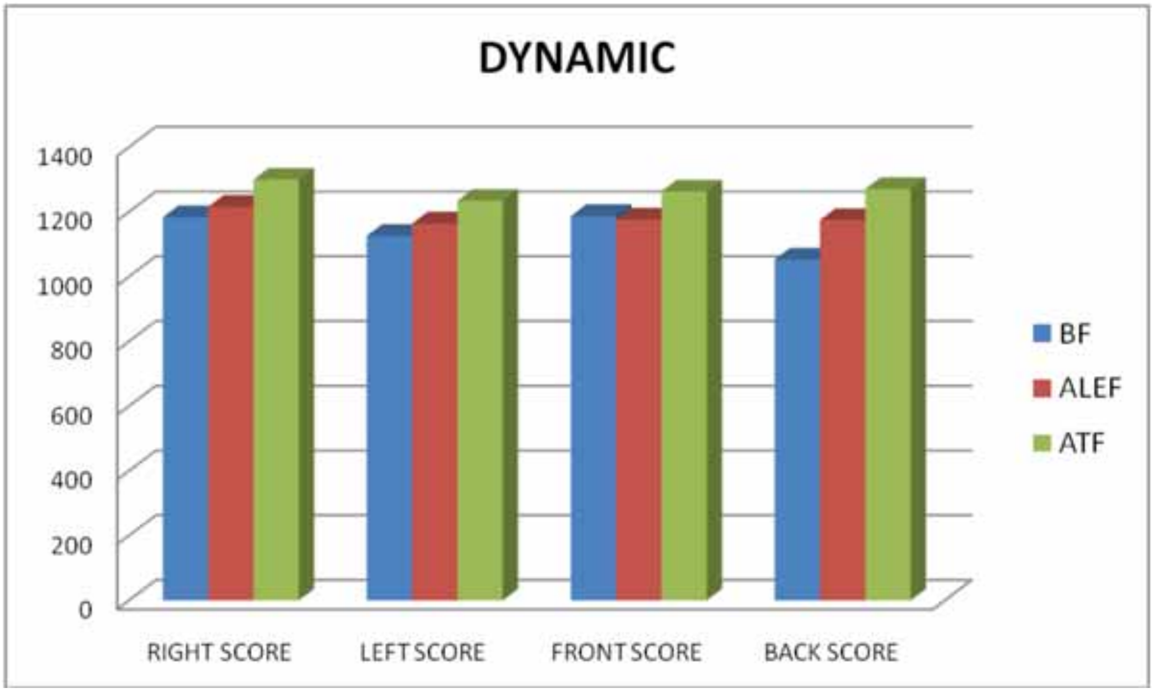
Muscles Tested	60°/s	90°/s	120°/s	180°/s
Right knee extensor	142.9 ± 73.3	115.6 ± 65.6	97.2 ± 56.2	72.7 ± 47.1
Right knee flexor	68.5 ± 38.9	51.5 ± 34.9	46.1 ± 33.0	35.8 ± 28.7
Left knee extensor	137.8 ± 81.4	112.1 ± 69.3	93.0 ± 61.2	67.9 ± 47.9
Left knee flexor	74.1 ± 50.3	66.4 ± 43.9	56.4 ± 41.9	44.1 ± 37.7
Trunk extensor	108.10± 65.2	79.8 ± 62.9	58.5 ± 58.1	26.0 ± 34.6
Trunk flexor	138.0± 56.8	113.8 ± 56.4	89.7 ± 60.1	49.0 ± 47.7

*In Newton meters.



*BF: before Fatigue, ALEF: After Lower Extremity Fatigue, ATF: After Trunk Fatigue

Fig. (2). Static balance scores of the subjects before and after fatigue.



BF: before Fatigue, ALEF: After Lower Extremity Fatigue, ATF: After Trunk Fatigue

Fig. (3). Dynamic balance scores of the subjects before and after fatigue.

extremity muscles (P = .050). The static balance scores of the front scores (P = .092) and the right, left, front scores of the dynamic balance tests were not significantly different before and after fatigue of the lower extremity muscles (P = .294, P = .596, P = .770, respectively).

DISCUSSION

Traditionally, muscular fatigue has been defined as either the inability to generate force or the loss of force production capability in addition to localized muscle discomfort and pain [20]. Muscle fatigue is an exercise-induced reduction in

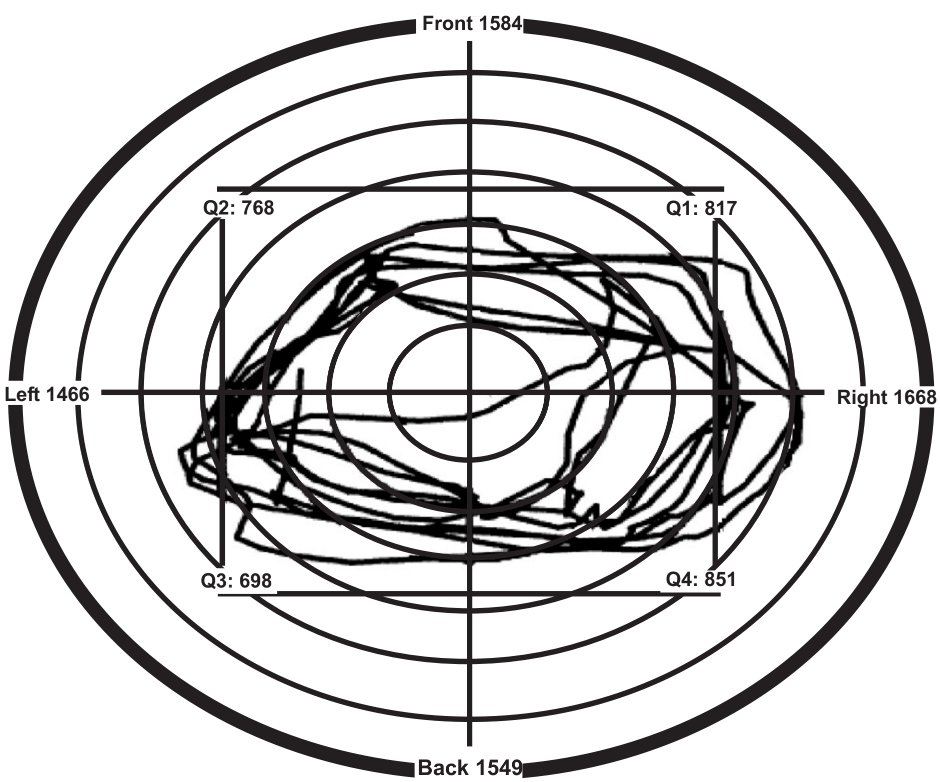


Fig. (4). Dynamic balance diagram before fatigue of the lower extremities and trunk muscles.

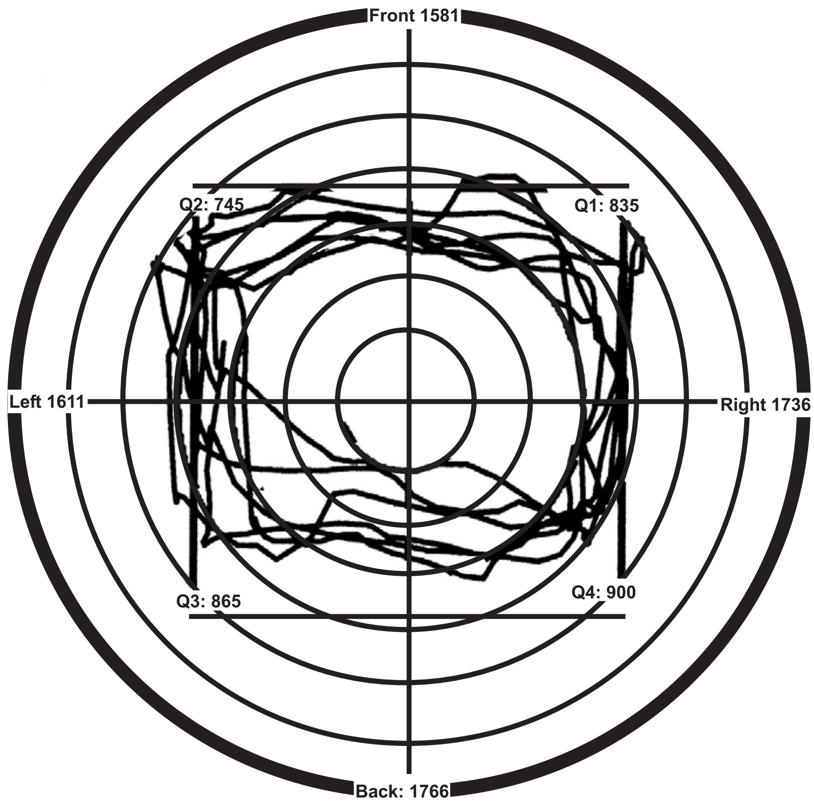


Fig. (5). Dynamic balance diagram after fatigue of lower extremities.

maximal voluntary muscle force. Muscle fatigue is related to decline in tension or force output after repeated muscle contractions. It may arise not only because of peripheral changes at the level of the muscle, but also because the central nervous system fails to drive the motor neurons adequately [21,22].

The ways in which localized muscle fatigue affects the balance are not clear. Theoretically, localized muscle fatigue may disrupt the afferent feedback system and alter conscious joint awareness. Muscular fatigue may both directly and indirectly affect neuromuscular control. Direct effect is worsening or impairment of expected learning in joint position sense. Indirectly, muscular fatigue leads to increased joint laxity that causes alterations in joint kinesthesia and position sense [23,24].

We used a commercial balance testing device to measure the effects of lower-extremity and trunk muscle fatigue on balance. Before fatigue, a negative correlation existed between static-dynamic balance scores and trunk-knee muscle isokinetic strengths.

A number of studies which evaluated the correlation between lower extremity muscle strength and balance can be found in the literature but the methods used in those studies were different from ours, so the results are not comparable.

Carter et all determined the associations among knee extension strength, medication history, medical history, physical activity and both static and dynamic balance in women diagnosed with osteoporosis.: They tested Static balance by computerized dynamic posturography, dynamic balance by timed figure-eight run, and knee extension strength by dynamometry. They found knee extension strength is a significant determinant of performance on static and dynamic balance tests in 65- to 75-year-old women with osteoporosis [25]. But we found no correlation between quadriceps muscle strength and dynamic-static balance scores

We found only one study showing a relation between trunk muscle strength and balance. That was one of our previous studies [26] where we evaluated trunk muscle strength in unihemispheric stroke patients and to assess how it relates to body balance and functional disability in this patient group. We compare the results with age match healthy individuals. The Berg balance scale was used to assess balance and isometric/ isokinetic reciprocal trunk flexion and extension strength at 60, 90, and 120 degrees/sec angular velocities were used to test trunk muscle strength. In both groups, there was a significant positive correlation between trunk muscle strength and Berg balance scale score. In this present study we also found cerelation between balance and trunk muscle strength.

In this study we found that the trunk muscle fatigue affected all static balance scores and dynamic back balance scores. But we did not find any effect on the dynamic right, left and front balance scores. After lower extremity fatigue, there was a significant difference between prefatigue and postfatigue static right, left and back balance scores, and there was significant difference between prefatigue and postfatigue dynamic back balance scores. Our results suggest that balance is affected by the generalized fatigue of trunk and lower-extremity muscles. Static balance control was affected by the fatigue of both trunk and lower-extremity muscles. The dynamic balance, however, was not signifi-

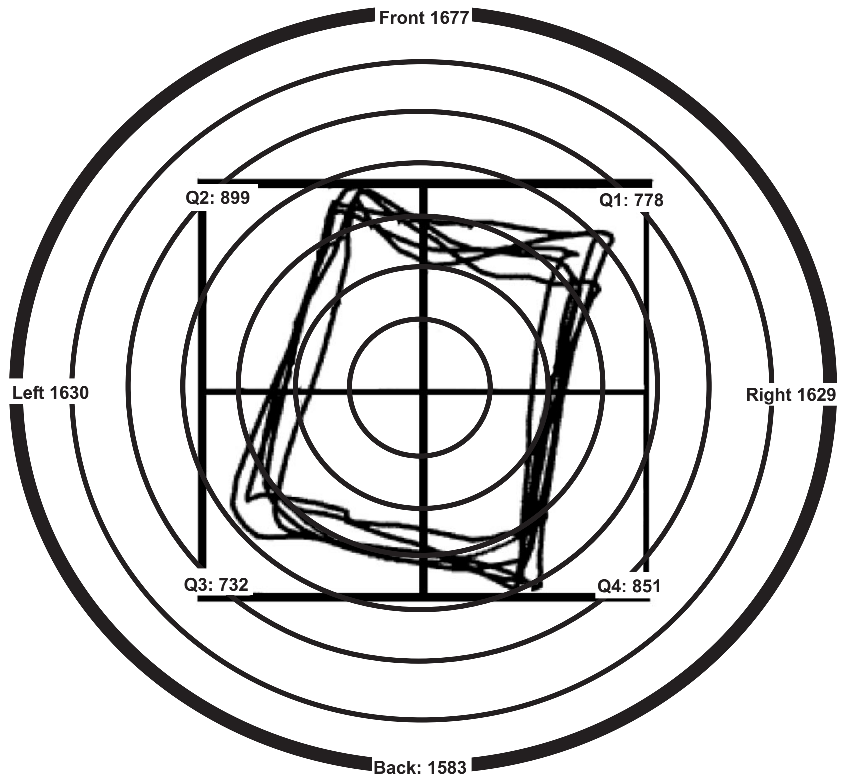


Fig. (6). Dynamic balance diagram after fatigue of trunk muscles.

cantly affected in all scores by trunk muscle fatigue and fatigue of the lower-extremity musculature. Only dynamic back score changes were significant, although Figs. (**2-4**) show decreased balance scores after trunk and lower extremity muscle fatigue. An explanation for this might be that the initial dynamic test scores had already been high. It is harder for the subjects to perform the dynamic test, so we think that a longer prefatigue familiarization period for the dynamic tests might have helped the subjects to get better initial dynamic balance scores. Our findings are somewhat similiar to the results of a previous study of elite football players by Hrysomallis and colleagues. Those authors concluded that performance in the static balance test did not reflect the performance in the dynamic balance test, and they suggested that basing evaluations of dynamic balance ability on static balance ability should be avoided [27].

Our comparison of results between before-fatigue and after-fatigue conditions suggests that fatigue increases the demands on the balance system, which includes peripheral, as well as central components.

Miller and Bird also examined the impact of fatigue of the ankle, knee, hip, and abdominal muscles on dynamic postural control [12]. Their results showed that fatigue of the knee and hip muscles caused significant decreases in stabilization time that were greater than those caused by the fatiguing of other muscle groups. They also reported that fatigue of the proximal musculature of the lower extremities affected balance more than did fatigue of the distal musculature. We found same effects on dynamic balance after fatigue of lower extremity muscle and trunk muscles.

Johnston and colleagues examined the effect of lower-extremity muscular fatigue on motor control performance [10]. They assessed static balance first with single-limb stance and then with double-limb stance. They also used the SportKAT system to perform a dynamic test. The subjects were fatigued *via* an isokinetic dynamometer. The authors found that fatigue significantly increased the subjects' scores in the balance tests. Fatigue produced a significant worsening of balance skills with the static tests. The final balance test (the dynamic limb test) showed decreased motor control performance after fatigue, but that decrease was not significant. Johnston and colleagues also determined that in the dynamic portion of the test, some subjects maintained their balancing skills despite fatigue. The balance and fatiguing methods used by Johnston and colleagues were the same as ours. Their results, similar to ours, demonstrated that fatigue of the lower-extremity muscles caused a significant decrease in static balance but not in dynamic balance Specific comparisons of the reports of previous studies in the literature can not easily be made because of variations in the fatigue protocols and the balance measurements. As with many biological measurements, balance has an intrinsic variability that is influenced by physical, biomechanical, metabolic, and psychosocial factors. Consequently, many factors (motivation, concentration, fatigue, emotional state, time of the test, and relationship with the tester) affect the reproducibility of balance outcomes.

Yaggie and colleagues examined the effects of lower-extremity fatigue on indices of balance by using the SportKAT-2000 system before, immediately after, and 10 minutes after a fatigue protocol [28]. They reported that lower-extremity fatigue adversely affected balance index scores and that recovery could occur within 10 minutes. Their balance assessment method was similar to that used in our study, but their fatigue protocol was different.

In summary, although our study was conducted in healthy subjects, the results highlight the potential deleterious effects of fatigue on the postural system. Fatigue can seriously increase the risk of injury in subjects in natural or sport situations. Theoretically, the trunk and lower extremities of a fatigued individual are at increased risk for musculoskeletal injury, and steps should be taken during conditioning and rehabilitation to help prevent muscle fatigue.

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