Effect of Trunk-Muscle Fatigue and Lactic Acid Accumulation on Balance in Healthy Subjects

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Objective: This study sought to determine the effects of trunk-muscle fatigue and blood lactic acid elevation on static and dynamic balance. Intervention: Fatigue was induced by an isokinetic protocol, and static and dynamic balance were assessed during bilateral stance using a Kinesthetic Ability Trainer. Subjects participated in a fatigue protocol in which continuous concentric movements at 60°/s were performed until the torque output for both trunk flexion and extension dropped below 25% of the calculated peak torque for 3 consecutive movements. Measures: Before and immediately after the fatigue protocol, blood lactic acid measurements and static- and dynamic-balance measurements were recorded. Results: An increase in lactic acid levels was detected in all subjects. According to a dependent-samples t test, significant differences in balance and lactic acid values were found after the fatigue protocol. There was no correlation between lactic acid accumulation (change between pre-fatigue and postfatigue levels) and balance-score differences. Conclusion: Trunk-muscle fatigue has an adverse effect on static and dynamic balance. Keywords: postural control, exertion, stability

The skeletal elements of the spine form an unstable system, behaving similarly to a series of inverted pendulums. Spinal stability has been proposed as being dependent on active (muscle), passive (bony geometry and ligaments), and neural subsystems. Of these, the musculature has been heralded as the critical link with maintaining spinal stability, postural control, and balance. Balance, the ability to maintain the body’s center of gravity over its base of support, depends on a well-functioning postural-control system. This complex feedback system is based on the central processing of visual, vestibular, and somatosensory inputs on the afferent side and corresponding purposeful neuromuscular action on the efferent side. Impairments in the sensory system have been associated with various pathologic conditions including recurrent injuries.

One such impairment, which also might affect the somatosensory system and, thus, movement and postural control, is muscle fatigue. Muscle fatigue is a complex and multifaceted condition involving physiological, biomechanical, and...
psychological elements. Lactate accumulation and acidosis are widely believed to be the cause of muscle fatigue. Increased lactic acid accumulation is related to increased hydrogen-ion fatigue, which result in decreased action potentials, changes in sarcoplasmic release of calcium, and decreased activities of muscle enzymes. Hence, direct inhibition of, and a decrease in, force generation occurs in that muscle. A close negative correlation between force generation and increased hydrogen-ion concentration has been observed. Increased lactic acid accumulation resulting from trunk-muscle fatigue might lead to decreased force generation and, therefore, impaired balance.

Postural-muscle fatigue has been reported to alter anticipatory postural adjustments and muscle activity in trunk muscles and in lower limb muscles. Muscle fatigue induces changes in the internal body state affecting both peripheral and central components, and it can impair coordination and increase the risk of musculoskeletal injuries. In addition, muscle fatigue diminishes spinal stability through the loss of muscular coordination.

Although negative effects of trunk-muscle fatigue on balance have been studied extensively, to our knowledge no study has investigated the effect of increased lactate concentration on balance. The purpose of the current study therefore was to determine the effects of trunk-muscle fatigue and blood lactate concentration on static and dynamic balance. We hypothesized that static and dynamic balance would be impaired after a trunk-muscle-fatigue protocol.

Methods

Participants

Sixteen healthy male university students (mean age 22.75 ± 2.21 years, height 177.62 ± 6.67 cm, body weight 76.06 ± 12.57 kg) with no previous lower extremity or back injury, neurologic deficit, or vestibular impairment participated in this study. The study protocol was approved by our local ethics committee, and informed consent was obtained from all participants.

Testing Procedure

Testing was completed in 2 sessions. In the preliminary session, subjects were familiarized with the balance-assessment system, the Kinesthetic Ability Trainer (KAT) 3000 (Breg, Vista, CA). The KAT 3000 consists of a movable platform supported on a central point by a small pivot. A tilt sensor on the platform is connected to a computer, which registers the deviation of the platform from a reference position 18.2 times each second. The distance from the central point to the reference position is measured at every registration, and from the summation of these distances a score (the balance index) can be calculated. A low balance index implies a good ability to perform the balance test. Use of the KAT 3000 and reliability of the balance data have been described previously.

After the preliminary session, subjects participated in a testing session, which consisted of measuring blood lactic acid levels and static and dynamic balance immediately before (prefatigue) and after (postfatigue) the fatigue protocol. For lactic acid measurements, blood samples were taken from the earlobe and
analyzed with a YSI Sport 1500 L-lactate analyzer with a cell-lysing agent (Yellow Springs Instruments, Yellow Springs, OH). Before each test the analyzer was calibrated with 5 mmol/L standard and checked for linearity using 15 mmol/L and 30 mmol/L standards as stated in the user manual.

For balance testing, subjects were asked to maintain bilateral stance on the platform\textsuperscript{17,18} before and immediately after trunk-muscle fatigue. Subjects performed static- and dynamic-balance tests consecutively in random order. During balance tests, subjects kept their eyes open\textsuperscript{6,12,19,20} so they could view a monitor screen. They stood barefoot\textsuperscript{16} on a force platform with their arms placed across their chest. On the force platform the pressure pillow was set on bar 6, which is the proposed pressure value in the KAT 3000 user manual. Subjects were told to keep the red X in the center of the monitor screen. The time and distance that the red X cursor spent away from the monitor center were used to calculate a static KAT score. Balance scores range from 0 to 6000. During the dynamic-balance test, subjects traced a point moving in a clockwise circular pattern in the middle of the monitor screen using a red X. The point was set to move at a medium speed setting of 3. The time and distance that the red X cursor spent away from the point were used to calculate a dynamic KAT score. As in the case of the static test, lower scores suggest better balance.

**Fatigue Protocol**

The fatigue protocol was performed on an isokinetic dynamometer (Cybex 770 Norm Lumex Inc, Ronkonkoma, NY) with movement patterns consisting of trunk flexion and extension. The lower limbs were stabilized by tibial and thigh pads. A belt was used to secure the pelvis and to limit the use of the hip-flexor muscles. A shoulder harness and backrest provided anchorage to the moving upper section of the apparatus. These methods were based on a previously published protocol for studying fatigue\textsuperscript{21} (Figure 1). In this protocol, fatigue was assumed when 3 consecutive repetitions fell below 25% of the initial trunk-flexor and -extensor peak torque. This protocol was chosen because, compared with 50% peak torque, muscle fatigue below 25% of peak torque takes longer to reach, and hence indicators of muscle fatigue (ie, lactate) become more clear. Because flexors are weaker than extensors, during the fatigue protocol the flexors fatigued more rapidly than the extensors. All subjects continued the fatigue protocol, however, until the extensor movement dropped below 25% of peak torque. Subjects were secured in the isokinetic device in the appropriate body position based on measurements taken during the preliminary session. Peak torque was calculated during 5 trials of maximal effort during concentric flexion and extension movements of the trunk at 60°/s. After 2 minutes’ rest, subjects began continuous concentric movements at 60°/s until the torque output for both directions dropped below 25% of the calculated peak torque for 3 consecutive movements. Subjects were given verbal encouragement during the isokinetic performance to continue the movement pattern until fatigue was achieved. Once 3 consecutive repetitions had dropped below 25% of peak torque, fatigue was assumed. To prevent effects from recovery, a blood sample was taken within 3 to 5 seconds, and subjects then progressed to the static- and dynamic-balance measurements randomly.
Statistical Analyses

Differences in prefatigue and postfatigue KAT 3000 scores and lactic acid levels were analyzed using a paired-samples $t$ test. Pearson product–moment correlations were calculated to determine the relationships between static and dynamic balance and lactic acid levels. The level of significance was set a priori for all analyses at .05.

Results

Static- and dynamic-balance scores and lactic acid concentrations before and after the fatigue protocol are given in Table 1. Both static and dynamic KAT scores increased after the fatigue protocol, which indicated impaired balance. Results of...
a paired-samples t test revealed a significant difference in both static (P < .001) and dynamic (P < .001) balance after trunk-muscle fatigue. In addition, a significant difference was observed in lactic acid concentration (P < .001). No significant correlations were found, however, between static-balance KAT scores and lactic acid concentrations (r = .191, P = .478) and dynamic-balance KAT scores and lactic acid concentrations (r = .409, P = .116).

Discussion

Our findings demonstrate impairment in static and dynamic balance as a result of trunk-muscle fatigue. Similarly, previous studies have shown decreases in postural stability, postural control,13 postural-correction activities,15 and trunk coordination14,22 after fatigue. For instance, Miller and Bird23 found that fatigue of proximal musculature negatively affected postural control more than fatigue of distal musculature. There are several possible reasons for which trunk-muscle fatigue might affect motor-control ability. While one is maintaining posture, corrective contractions in response to small joint perturbations are constantly occurring. Because fatigue slows neural transmission,6 perhaps the ability to efficiently create compensatory contractions about a joint is reduced, resulting in a lack of neuromuscular control and greater changes in joint position. This larger variability in joint motion in the absence of corrective muscle actions might result in diminished postural control, as indicated by greater excursion of KAT 3000 scores.6

In the current study, one of the mechanisms that might be responsible for such a decline in muscle power and postural control—the effect of lactic acid accumulation on balance—was investigated. Taylor et al24 found that lactic acid, potassium, bradykinin, and arachidoic acid accumulated in the muscle during activity to fatigue, and thus Vuillerme et al25 indicated a possibility that these elements might affect postural control. These results support our findings. Lactic acid accumulation in peripheral tissues results in a decrease in the ability of the muscle to perform work. This might be explained by the fact that lactic acid dissociates into lactate and H+. Given the greater concentration of lactic acid in the blood after fatigue, there is a higher concentration of hydrogen ions. The greater concentration of hydrogen ions results in decreased pH. A decrease in pH is the classic cause of muscle fatigue.26 Along with increased lactic acid levels and H+ concentrations, decreases occur in the ability of troponin to bind Ca++, in sarcoplasmic release and uptake of Ca++, and the activities of several enzymes. These lead to a decreased response of the efferent muscle fibers, as well as poorer muscle contractions to maintain balance.26 Lactic acid accumulation also causes a decline in the force production of the contracted muscle, which results in a decrease in the muscle force needed to maintain postural control.18 In our study, as balance scores increased lactic acid concentrations also increased, although these relationships were not significant. Perhaps the small sample size of our study is a reason for not finding a significant correlation. Future studies with larger sample sizes could obtain more definitive results.

The current study had some limitations. Balance and lactic acid measurements were performed immediately before and after the fatigue protocol. Repeating balance and lactic acid measurements after the fatigue protocol until
the values returned to baseline levels would provide a clearer picture about how quickly balance and lactic acid levels recover. In addition, blood samples taken directly from the working muscles would give us more valid results about lactic acid accumulation. Another limitation of the current study is that the trunk-muscle-fatigue protocol we used is likely not representative of the manner in which trunk muscle generally fatigues during daily activities or sports environment. Therefore results of the current study can only be generalized to the laboratory environment. In the current study, the fatigue protocol was applied by using concentric contractions and single-contraction speed. For future studies, it is recommended to use fatigue protocols with different contraction types and speeds to reach more generalizable results.

**Conclusions**

The findings of the current study indicate impairment in both static and dynamic balance and increased lactic acid levels after trunk-muscle fatigue. Changes in balance scores and lactic acid accumulation were not correlated, however.

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**References**


