The Effects of Knee and Ankle Muscles Surrounding the Knee and Ankle Joints on One-Leg Static Standing Balance

OH-YUN Kwon1), HOUNG-SIK CHO1), CHUNG-HWI YI2), HYUK-CHEOL KWON3)

1) Department of Rehabilitation Therapy, Hanseo University, 360 Daegok-li, Haemi-Myon, Seosan city, Chungchungnam-Do, 356-820, Korea. TEL +82 455-60-1383.
2) Department of Rehabilitation Therapy, Yonsei University
3) Department of Physical Therapy, Taegu University

Abstract. The purpose of this study was to determine whether knee and ankle muscle fatigue affect one-leg static standing balance. We compared the affects of muscle fatigue between the knee and ankle joints on one-leg static standing balance. Sixty-four healthy subjects were used for this study: 44 men and 20 women, with an average age of 19.5. One leg static standing balance was measured at pre-fatigue and post-fatigue status by an instrumented balance assessment system (Kinesthetic Ability Training Balance Platform) which is commercially available for testing and balance training. Isokinetic exercises performed at 180 degree/sec on the Cybex 1200 were used to induce muscle fatigue. One-leg static standing balance ability was significantly decreased after knee and ankle muscle fatigue. There was a significantly greater decrease in one-leg static standing balance ability in ankle joint muscle fatigue as opposed to the knee joint muscles. Although these phenomena were not clearly understood, these results have important implications for rehabilitation of fatigable patients. These results suggest that excessive fatigue during rehabilitation may increase risk of reinjury and falling due to balance disturbance in patients with diseases involving fatigue. Further studies are required to determine the physiological mechanisms of muscle fatigue that play a role in decreasing one-leg static standing balance.

Key words: Muscle fatigue, Balance, Isokinetic exercise.

INTRODUCTION

Human motor performance, whether on the athletic field, in activities of daily living, or in the physical therapy clinic, is influenced by fatigue. Efforts to obtain or maintain peak performance frequently seek to abate or delay the onset of fatigue1). Acute and chronic forms of fatigue are common complaints of endurance competitors2). Muscle weakness and increased fatigability are two of the primary symptoms of patients with neuromuscular disease3).

It is difficult to define and assess fatigue objectively because it interacts with physical, mental, and psychological variables1). Several possible definitions for fatigue have been proposed4). One such definition is that fatigue is the decreased capacity of muscle to produce tension or shortening resulting from prior activity5).

Human balance is maintained through a complex process involving sensory detection of body motion, integration of sensorimotor information within the central nervous system, and the execution of appropriate musculoskeletal responses6). Factors influencing balance such as age7,8), muscle weakness9), vibration sense10), respiration11), and visual input12) have been studied. However there have
been no studies on the effect of muscular fatigue on balance yet. Physical therapists may meet patients with fatigue-related diseases such as multiple sclerosis, postpolio syndrome, progressive muscular dystrophy, chronic fatigue syndrome, myopathies, and neuromuscular junction disease. Fatigue may be the most common single complaint in these patients. Nevertheless fatigability is difficult to describe and objectively assess. It is often underemphasized in discussions of the signs and symptoms of these diseases.

Boda et al. (1995) reported that chronic fatigue syndrome patients have gait abnormalities when compared with sedentary controls. This could be due to balance problems, muscle weakness, or dysfunction of the central nervous system. Knee and ankle sport injuries occur most frequently at the end of a sporting event, when a participant is more likely to be fatigued. This phenomenon has been noted particularly in recreational skiing, in which anterior cruciate ligament ruptures frequently occur at the end of day. So we hypothesized that knee and ankle muscular fatigue could have an effect on one-leg standing balance and that ankle muscle fatigue should have a greater affect on one-leg static standing balance change than knee fatigue. The purpose of this study was to determine whether knee and ankle muscle fatigue affects one-leg static standing balance. We compared knee and ankle joint musculature for the affect of fatigue in these respective components on one-leg static standing balance.

None of the subjects had a recent or remote history of significant lower extremity injury, none had had lower extremity or spinal surgery, and none had experienced muscle weakness, joint deformity or limited range of motion of the lower extremities. Also no subject had a history of vestibular or central nervous system problems or peripheral neuropathy of the lower extremities. All subjects who participated were without appreciable disease.

One leg static standing balance was measured by an instrumented balance assessment system (KAT 2000, Breg Inc., Vista, CA, 1994), which is commercially available for testing and/or balance training. Validation and calibration of this device has been reported in a previous investigation.

The balance assessment/training system consists of an inherently unstable platform supported at its central point on a small pivot. The stability of this platform is controlled by varying the pressure in a pneumatic bladder which is positioned between the platform and the base of the device. The platform is instrumented by a two-axis tilt sensor which quantifies position of the transverse plane. A score is calculated by measuring the distance from the tilted position to the reference position and adding up the absolute numbers over the duration of the test. The lower the score, the better the balance index; zero is a perfect score.

With the subject comfortably positioned standing barefoot on one leg on the platform, we instructed the subject to fold his/her arms across his/her chest and flex the dominant side knee slightly. The screen was turned toward the subject, who was then instructed that the purpose of the test was to center the red cursor in the center of the test screen and to hold the platform as steady as possible for the duration of the test. The subject was allowed 3–5 minutes to practice while viewing the computer screen. The balancing device was adjusted and calibrated for each subject according to the subject’s weight.

One-leg static standing testing was conducted
without any visual feedback from the computer screen. For the actual test, the screen was turned away from the subject’s view. The test lasted 20 sec.

For each test we measured one-leg static standing balance five times for each subject. In most subjects, a learning effect was noticed and the first repetition was eliminated from data analysis. After each set of 4 repetitions we took the mean value as the score for that test.

After the initial one-leg static standing balance test, each subject was fatigued using the Cybex 1200 at 180 degree/sec in a sitting position, as described by Sinacore et al. (1993)\textsuperscript{17). All subjects performed isokinetic exercises with their dominant knee. Exercise was continued repeatedly until 50% of the initial peak torque was reached. When the subjects were fatigued to less than 50% of the initial peak torque in the knee flexor and extensor muscle groups, we stopped the isokinetic exercise, whereupon the subjects were immediately retested on the balance assessment system. The patient then performed the one-leg static standing balance test once more.

After 3 days, we measured one-leg static standing balance after the ankle joint muscles were fatigued on the dominant side, using the same protocol as for the knee. Isokinetic exercises were performed at 180 degree/sec to evoke fatigue at the ankle joint muscle with the subject prone and the knee flexed to 90 degrees.

One-way repeated analysis of variance was used to compare the one-leg static standing balance between pre-fatigue and post-fatigue on the ankle and knee joint muscles. Using the same one-way repeated analysis of variance, we then determined in which joint a greater decrease in one-leg static standing balance occurred after muscle fatigue. Independent t-tests were used to compare peak torque and balance index with respect to gender. The significance level was set at a value of p<0.05. Data were analyzed using the SAS computer package.

**RESULTS**

All 64 subjects completed the tests. Table 2 shows the mean values of initial peak torque of the knee and ankle joint muscle groups in males and females, respectively. There were significant differences between peak torque in males and in females in all muscle groups. The initial peak torques of all muscle groups were greater in males than in females (Table 2).

The mean values of initial peak torque of knee extensors, flexors, ankle plantar flexors, and dorsiflexors were 74.72 ft/lb, 41.20 ft/lb, 35.22 ft/lb, and 20.98 ft/lb, respectively.

Table 3 shows the comparison of mean values of balance indices in males and females at pre-fatigue and post-fatigue, respectively. There were no significant differences.

<table>
<thead>
<tr>
<th>Muscle group</th>
<th>Male (n=44)</th>
<th>Female (n=20)</th>
<th>t-Value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensor</td>
<td>85.02 (23.61)</td>
<td>51.40 (13.56)</td>
<td>7.19</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Flexor</td>
<td>46.68 (29.15)</td>
<td>29.15 (8.20)</td>
<td>7.77</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Ankle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dorsiflexor</td>
<td>27.75 (9.70)</td>
<td>17.80 (4.46)</td>
<td>3.72</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Plantar flexor</td>
<td>38.61 (6.76)</td>
<td>22.43 (4.97)</td>
<td>4.53</td>
<td>p&lt;0.05</td>
</tr>
</tbody>
</table>

The one-leg static standing, pre-fatigue balance test on the dominant side of the knee joint muscles revealed a mean score of 212.64 (range, 101 to 742). The post-fatigue mean score was 311.03 (range, 126 to 962). The mean score of pre-fatigue of ankle joint muscles was 216.53 (range 101 to 742). The mean score of post-fatigue of ankle joint muscles was 421.00 (range 137 to 898). The mean score was greater post-fatigue than pre-fatigue. The balance index score is inversely proportional to balance ability, with a higher score reflecting poorer balance.

There was a significant difference between pre-fatigue and post-fatigue at both joint muscles (F=120.74, p<0.01), (Table 5). The increased balance index mean scores at post-fatigue of the knee and ankle muscles were 98.36 (range 37 to 347),
and 204.47 (range 10 to 603), respectively.

There was a significant difference between increments in balance index scores after knee muscle fatigue and those after ankle muscle fatigue ($F=5.05$, $p<0.05$). The increment in balance index scores after ankle muscle fatigue was greater than that after knee muscle fatigue (Table 5).

**DISCUSSION**

In this study, we used isokinetic exercise to evoke muscle fatigue. Although muscle fatigue has been the subject of considerable investigation, there is still relatively little known regarding its causes\(^{18}\). Local muscle fatigue is the diminished response of a muscle to a repeated stimulus. This is a normal physiologic response of muscle and is characterized by a reduction in the force-producing capacity of the neuromuscular system\(^{19}\). The diminished response of muscle is due to a combination of the following factors.

1) Disturbances in the contractile mechanism of the muscle itself because of a decrease in the storage of energy, insufficient oxygen\(^{20}\), and a build-up of lactic acid\(^{21}\).

2) Inhibitory (protective) influences from the central nervous system\(^{1,22}\).

3) Decrease in the conduction of impulses at the myoneural junction\(^{23}\).

Electrically stimulated contractions effectively eliminate the central nervous system from participation in force generation\(^1\). However, we evoked muscle fatigue by voluntary isokinetic exercise in this study, so we could not rule out completely the influence of the central nervous system.

We chose the flexed knee protocol instead of a straight knee protocol to exercise the ankle muscle in this study. Tightness in the calf muscles can limit ankle range of motion in the straight knee protocol. In addition, the soleus is a key muscle in controlling postural sway\(^{24}\). We measured the effects of muscle fatigue of the knee and ankle on one-leg static stand-
ing balance. The one-leg static standing balance ability was significantly decreased after fatigue. There are some possible reasons why muscular fatigue may affect one leg static standing balance. The response of the IA primary afferents is greater to phasic stretch than to tonic stretch, whereas the secondary afferents respond more to tonic than to phasic changes. Mense studied the effect of temperature on the spindles and found that, in a prestretched muscle, warming increased the firing rate of the group IA afferents and Golgi tendon organs, whereas the majority of the secondary endings showed a depression and cessation of firing when heated. Exercise increases temperature in the muscles, which may affect the sensory endings in the muscle spindles. Tonic muscles play a greater role in maintaining static posture than do phasic muscles. Exercise increases muscle temperature temporarily, which then results in the depression of firing of secondary endings in the muscle spindles. Decreased firing of the secondary endings decreases the tonic response which is related to static posture. Muscle fatigue around a joint may thus inhibit the joint’s proprioceptive muscular feedback system, unfavorably influencing one-leg static standing balance.

When compared with nonfallers, fallers have shown significantly decreased peak torque and power output of the knee extensors and flexors, and ankle dorsiflexors and planter flexors at constant velocities of 60 degree/sec (slow) and 120 degree/sec (moderate). Muscle power may thus affect the ability to maintain body balance. Fatigued muscles cannot produce optimal muscle power to hold one-leg static standing balance due to build-up of lactic acid, slowing of motoneuron firing frequencies, and enzymatic deficiencies. We feel that the study on fallers supports the finding of our present study that muscle power plays an important role on one-leg static standing balance. We compared knee muscle fatigue and ankle muscle fatigue and found that ankle muscle fatigue was significantly more affected on one-leg static standing balance change. The weakness of the ankle joint muscles affects stability. Specifically, when compared with nonfallers, fallers demonstrated marked relative weakness of the ankle compared with knee musculature.

Also the ankle movement strategy described earlier appears to be used most commonly in situations in which the perturbation to equilibrium is small and the support surface is firm. From this point of view, ankle joint muscle fatigue has a greater effect on standing balance than does knee muscle fatigue. This may be a possible reason why ankle muscle fatigue had a greater effect on one-leg static standing balance change than did the knee.

The results of this study clearly support our hypothesis that knee and ankle muscular fatigue can significantly decrease one-leg static standing balance ability. Also, ankle muscle fatigue had a greater affect on one-leg static standing balance. Although these phenomena were not clearly identified, these results have important implications for rehabilitation in fatigable patients. Excessive fatigue produced during rehabilitation of fatigable patients may increase risk of reinjury and falling due to balance disturbance after muscular fatigue. Further studies are required to determine the physiological mechanisms of muscle fatigue that take part in decreasing one-leg static standing balance.

REFERENCES

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