The Effect of Local and General Fatigue on Knee Proprioception

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Purpose: The purpose of this study was to compare the effects of local and general fatigue loads on knee proprioception. Type of Study: Experimental controlled study. Methods: Proprioception of the knee joint was evaluated by measuring absolute angular error (AAE) at matching defined index angles before and after 2 different types of fatigue protocols (local load and general load) in 27 healthy male volunteers. Local load was provided with maximum isokinetic knee flexion-extension on the isokinetic dynamometer, and general load was 5 minutes running on a treadmill. Results: After local load, a significant decrease in peak torque of knee flexors and extensors was found, but no significant change in AAE was seen. In contrast, after general load, a significant increase of AAE was noted without significant muscle weakness. Conclusions: The different results in previous studies evaluating the effect of fatigue on knee proprioception may have been affected by the difference of fatigue protocols, whether local or general load. Although local load was intended to produce local fatigue of the knee, which may cause dysfunction of muscle mechanoreceptors, general load may have produced general fatigue and affected other mechanisms in the proprioceptional pathway. The results of the present study suggest that decreased reproduction ability after general load is not due to the loss of peripheral afferent signals, but to other factors, especially deficiency of central processing of proprioceptive signals. Clinical Relevance: To prevent knee injury caused by fatigue-induced proprioceptional decline, muscle endurance training alone is not enough, and neuromuscular training, including central motor programming, is essential. Key Words: Knee proprioception—Fatigue effects—Central motor programming.

Recently, researchers have widely assumed that joint proprioception plays an important role in maintaining the functional stability of the joint. The sensory receptors for proprioception, called mechanoreceptors, are located in the skin, muscles, tendons, and joint capsule as well as in the ligaments. Mechanoreceptors function as transducers that convert mechanical load in the joint to afferent impulses. This information is finally integrated for the motor programming required for precision movements and contributes to reflex muscle contraction, providing dynamic joint stability.

Deterioration in proprioception as a result of physical or mental fatigue may be a risk of knee ligamentous injury. Previous reports that the incidence of injury to skiers is higher in the afternoon and that to football players is higher in the third quarter suggest that fatigue in athletes may produce a decline of knee proprioception and be one of the risk factors for knee ligament injuries. Muscle fatigue has been shown to adversely alter joint proprioception and impair neuromuscular control in the lower extremities. Although many authors have studied the changes that occur in proprioception after fatigue, they have not established what components in the propriocep-
tional pathway do not function sufficiently after fatigue. Therefore, researchers do not know whether muscle receptors, joint receptors, the central nervous system, or other components are mainly responsible for decreases in proprioceptive sense.

The difference in fatigue protocol, which was local load to the knee or general load, may have affected these results. Local load by isokinetic exercise in the laboratory is intended to produce local fatigue of the knee, which may cause dysfunction of muscle mechanoreceptors. General load, which more practically simulates sports activity in athletes, may produce not only local fatigue of the knee but also general fatigue, which may affect other mechanisms in the proprioceptional pathway.

We hypothesized that the difference between local fatigue and general fatigue affects the changes in knee proprioception after exercise. Therefore, the purpose of the current study was to evaluate the effects of local and general fatigue loads on knee joint proprioception and to determine which components in the neuromuscular control pathway may change after fatigue. Furthermore, we discussed the possibility of preventing knee ligament injuries that may be caused by proprioceptive insufficiency during fatigue.

**METHODS**

**Subjects**

Twenty-seven healthy male volunteers (age range, 19 to 31; average, 22.2 years) were recruited for this study. Subjects with a history of lower limb (lower back, hip, knee, ankle, or foot) injuries or vestibular or neuromuscular disorders were excluded. All subjects provided informed consent, and the study was approved by the Ethics Committee of Hirosaki University School of Medicine.

**Evaluation of Proprioception**

Skinner et al.8 reported that reproduction of knee joint angle was more sensitive to fatigue loading than kinesthesia, which is assessed by measuring the threshold to detection of passive motion. Therefore, joint position sense was used to evaluate knee proprioception in this study. Furthermore, researchers have reported that active muscle contraction produces a more precise sensation of limb position15 and should therefore reflect the influence to muscle receptors located in the fatigued knee extensor and flexor structures. Therefore, the technique of open-kinetic chain and active knee positioning was chosen for measuring joint position sense.

Proprioception of the knee joint was evaluated by measuring absolute angular error (AAE), which was determined as the mean value of the absolute error between passively positioned knee angle and actively reproduced knee angle in 8 consecutive trials (Fig 1). Passive angle positioning initially was randomly selected from 10° to 80°. The dominant leg, which was determined by asking the subject which leg they would predominantly use to kick a ball, was designated as the test leg. Subjects were seated in a comfortable position, with the legs hanging freely, and blindfolded to remove visual input. Passive positioning by the examiner was performed by extending the knee from the starting position of 90° of flexion to a preselected flexion angle between 10° and 80°. After holding the leg in this position for 3 seconds, the examiner replaced the leg to the starting position. The subject was then instructed to actively reproduce the same knee angle that was passively positioned by the examiner. Eight trials were recorded with a digital video camera and analyzed on a computer screen as
static images. Each knee joint angle produced passively and reproduced actively was measured by computer software (Canvas 3.0; Deneba Systems, Miami, FL). The mean AAE between passively positioned knee angle and actively reproduced knee angle in 8 trials was determined.

**Fatigue Protocol**

The AAE of the knee joint was measured before and after 2 different types of fatigue loading (local and general load). The local load applied to the extremity consisted of 60 consecutive maximum concentric contractions of the knee extensors and flexors on the isokinetic dynamometer (Cybex 6000; Lumex, Ronkonkoma, NY) at a speed of 120°/second. The general load was provided by 5 minutes of running at 10 km/h on a treadmill (8700 Sprint Treadmills; Landice, Randolph, NJ) with a 10% uphill grade. The local load protocol was performed first, and then the general load protocol was performed more than 2 weeks later. We established the washout period of 2 weeks between protocols to eliminate the learning effect.8

Local fatigue of leg muscle was evaluated by measuring changes in peak torque on a standardized isokinetic exercise protocol. Isokinetic peak torque of knee flexor and extensor at a speed of 120°/second was determined before and after each fatigue protocol. Heart rate (in beats per minute) was monitored as an indicator of general fatigue during the fatigue protocol.

**Data Analysis**

Test-retest reliability of AAE was evaluated between prefatigue AAE mean values using Pearson correlation coefficient ($r$). The changes in AAE, peak torque of knee extensors and flexors, and heart rate were statistically compared between local and general loads using a one-way repeated measures analysis of variance (ANOVA). The level of significance was set at $P = .05$.

**RESULTS**

All 27 subjects successfully completed the study. We found that the AAE was reliable in measuring static knee joint angles, because the Pearson correlation coefficient and the corresponding $P$ value were $r = 0.645$ and $P = .0002$.

After local load to the knee, no significant change in AAE ($3.8° \pm 1.1°$) was detected compared with that before loading ($3.4° \pm 0.9°$) (Fig 2), but significant decrease of peak torque of knee flexors and extensors was found (Table 1). After local load, heart rate was significantly increased compared with the prefatigue state (Table 1).

In contrast, after general load, a significant increase of AAE was noted ($5.1° \pm 2.1°$) (Fig 2) without significant changes in peak torque of knee flexor and extensor (Table 1). After general load, heart rate was significantly increased compared with prefatigue and after local load (Table 1). We also noted a significant difference of AAE after loading between local and general load protocols (Fig 1). General load produced the greater percent change in AAE (57.0%), whereas local load produced a smaller change (13.3%).

**TABLE 1. Changes of Peak Torque of Knee and Heart Rate (mean ± SD)**

<table>
<thead>
<tr>
<th></th>
<th>Prefatigue</th>
<th>After Local Load</th>
<th>After General Load</th>
</tr>
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<tbody>
<tr>
<td>Peak torque of knee extensor (% body weight)</td>
<td>80.5 ± 11.5</td>
<td>49.0 ± 12.3*</td>
<td>80.8 ± 14.1</td>
</tr>
<tr>
<td>Peak torque of knee flexor (% body weight)</td>
<td>46.1 ± 9.0</td>
<td>26.2 ± 7.1*</td>
<td>43.0 ± 10.4</td>
</tr>
<tr>
<td>Heart rate (beat/min)</td>
<td>68.0 ± 5.5</td>
<td>103.1 ± 22.0*</td>
<td>159.7 ± 21.4†‡</td>
</tr>
</tbody>
</table>

*Significantly different from prefatigue ($P < .05$) and after general load ($P < .05$); one-factor ANOVA.
†Significantly different from prefatigue ($P < .01$).
‡Significantly different from after local load ($P < .05$).
DISCUSSION

The present study is the first to clarify the different effects of local fatigue and general fatigue on knee proprioception by measuring joint position sense in the same subjects. We noted that only the general fatigue load had a statistically significant effect on knee proprioception. Skinner et al.8 also found a decrease of knee proprioception, with a 15% decrease of knee flexion and extension work output after general fatigue load. General fatigue load was a series of interval running sprints. They concluded that muscle receptors have a primary role for joint position sense.

However, our results are different from those of Skinner et al. in that muscle weakness of the knee could not be seen. Proprioceptional decline without muscle weakness of knee after general load suggests a change in the proprioceptional pathway without influence from muscle mechanoreceptors.

The increase of AAE after general load may be caused by deficiency of central processing of proprioceptive signals, that is, caused by central fatigue processes. Central fatigue may diminish precision of motor control, interrupt voluntary muscle-stabilizing activity to resist imparted joint forces, and finally put the knee at risk for knee ligament injury. The inverse relationship between cognitive function and heavy exercise has been suggested.18-20 Davey et al.21 reported that very severe physical exertion using a bicycle ergometer tends to produce a deterioration in mental performance, although a moderate amount of physical exertion produces a significant improvement.

In addition, Marks et al.13 suggested that motor learning effects on knee proprioception, because they found a significant improvement in joint position sense in the control group after a 5-minute rest interval. This result suggests that proprioception can be improved by neuromuscular training.22 The result of the current study that improvement of proprioception could not be seen after 2 weeks suggest that this interval is enough to eliminate the effect of memory and learning. Further study to clarify the relationship between training effect and time interval should be performed.

Conversely, no significant change in knee proprioception was seen after local load to knee flexor and extensor muscles, although peak torques were significantly decreased. This result was consistent with the results of Marks and Quinney.13 The discrepancy between no significant change in AAE and significant weakness of knee muscle strength suggests that the local load to the knee did not induce dysfunction of the muscle mechanoreceptor. Another suggestion is that an unknown mechanism might compensate dysfunction of the muscle mechanoreceptors with the neural input from the other mechanoreceptors located in the capsule, ligament, and skin.

Muscular fatigue may affect joint position sense for several reasons. In interpreting the results of AAE, definitely distinguishing between degradation of sensory afferent input from mechanoreceptors and degradation of motor output and central motor programming is difficult, because the active repositioning test we used reflects all neuromuscular control pathways. Further research should be performed to develop the functional examination of neuromuscular control pathway to differentiate central motor programming and peripheral afferent information from mechanoreceptors.

The limitation of the present study was that no other parameter except heart rate was used to assess general fatigue level. Monitoring bloody lactic acid level or VO₂max might provide additional information on fatigue status. However, assessing the several fatigue parameters simultaneously would make measuring knee proprioception immediately after exercise difficult. Therefore, we used the convenient measures of heart rate, reflecting general fatigue (fatigue of cardiovascular system), and peak torque of knee flexor and extensor, reflecting local fatigue of knee muscle.

Researchers have documented that female athletes showed a 4-fold to 6-fold higher incidence of knee injury than did male athletes.23,24 The decrease of proprioception might be one of the risk factors of knee ligament injury.25 and gender difference in proprioception could be expected. However, because Lattanzino et al.6 reported that female knee proprioception may not be significantly reduced under all types of fatigue intervention compared with male proprioception, we selected healthy men for subjects, to eliminate the gender difference effect and to discuss the isolated effect of fatigue on knee proprioception. Future study is necessary to clearly ascertain gender differences in knee proprioception after fatigue.

The results of this study show that general load may diminish motor control by the central nervous system. We suggest that the time-interval to recover from central fatigue during exercise should be established in a future study to decrease the incidence of knee injuries for athletes. Also, the fact that general load affected knee proprioception without muscle weakness indicates that muscle endurance training alone is not enough and that neuromuscular training26,27 including central motor programming, is essential to...
prevent knees from injury caused by the decrease of knee proprioception after fatigue.

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REFERENCES