

Quadriceps Muscle Fatigue and Knee Joint Position Sense in Healthy Men



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ABSTRACT

Purpose: Proprioception is a part of the somatosensory system responsible for sending information to the central nervous system to monitor the status of various body parts relative to each another. One of the main causes of impaired proprioception is fatigue. In the following study, the effects of fatigue on quadriceps muscle and hence on knee proprioception in healthy subjects was studied.

Methods: This is a pretest-posttest study. By available sampling, 34 healthy young subjects with a mean (SD) age of 22.15 (1.97) years, a normal knee motion range and muscle strength, with no skeletal muscle nerve damage, volunteered for this study. The subjects tested the target angle reconstruction (45° flexion) of their knee joints while contracting the quadriceps muscles. We used a digital inclinometer to assess proprioception before and after fatigue. Then, by using the paired t-test, the rate of constant error and absolute error were compared. For the statistical analyses, SPSS (version 16) was used.

Results: quadriceps muscle fatigue causes a significant increase in the error rate of the knee joint reconstruction angle at 45° (absolute error and constant error) ($P < 0.05$).

Conclusion: Quadriceps muscle fatigue decreases accuracy and increases absolute error and constant reconstruction angle of the knee joint in healthy individual.

Keywords:

Knee, Proprioception, Fatigue, Quadriceps muscle

1. Introduction

Proprioception is a part of the somatosensory system, responsible for collecting information and sending it to the central nervous system to monitor the status of various body parts relative to each another [1, 2].

Proprioception is also responsible for controlling neuro-muscular signals and processing information from stimuli to the central nervous system (CNS), as well as receiving signals from afferent neurons [2]. joint position sense is an important factor in joint coordination, muscle stiffness and integrated movement and Disruption of it could lead to injury [3]. Several factors can disrupt proprioception, followed by the motor control dysfunction and abnormal load on the joints.

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One of these factors is fatigue [4, 5]. The ability to work or performing sports activities during muscle fatigue is of great importance. The majority of injuries inflicted on athletes occur at the end of the exercise, and especially in their lower extremities [6]. Muscle fatigue is the loss of the capacity of muscle power generation during voluntary contraction [7]. Exercising to fatigue may change subjects' reproduction ability of knee joint angles. This may represent a decline in proprioceptive function after heavy exercise bouts [8].

Analysing the joint position sense is one of the most common test to assess proprioception. The accuracy of the reconstruction of the joint angle is measured by active and passive joint angles or by evaluating and carefully considering the subjects joint angle movement abilities [9]. So far several studies have examined the effect of muscle fatigue on proprioception of the joints. Some studies reported that fatigue impairs proprioception [1, 8, 10, 11], and some reported no effect [12-14]. Therefore, conflicting results have been found in this field. Different kinds of fatigue, their mechanisms and different effects on proprioception in previous studies indicate the need for further research.

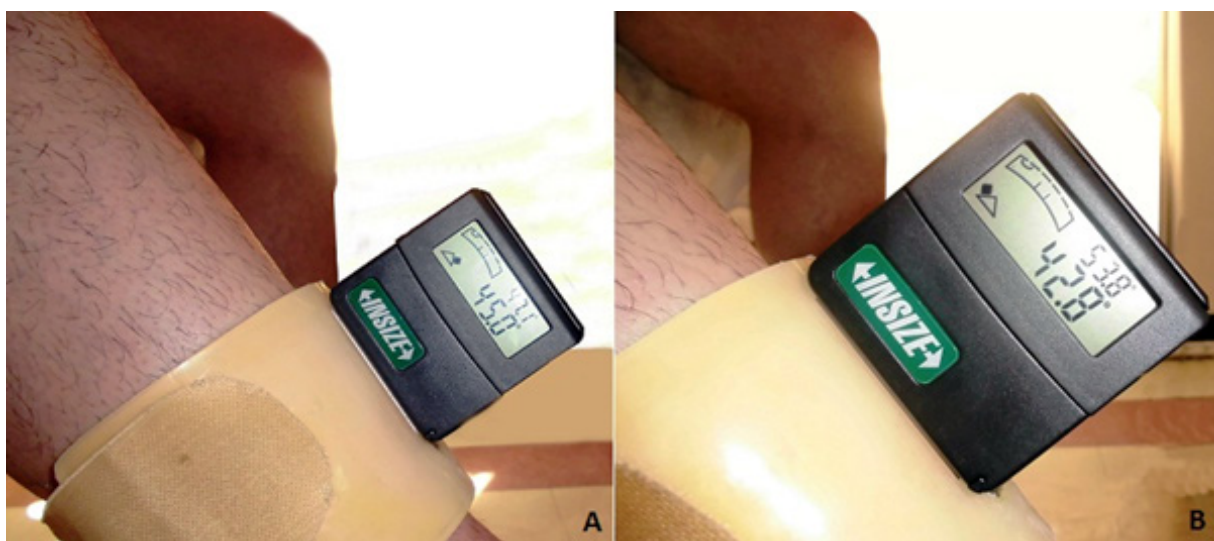
The knee is the one of the most complex and largest joints in the body. Many people have reported injuries during sports and work activities [15]. The quadriceps muscles of the lower extremities are among the most important muscles in keeping the knee joint dynamic and stable [16]. Therefore, this study aimed to evaluate the effect of quadriceps muscle fatigue on regeneration of the knee joint angles.

2. Materials and Methods

This study has pretest-posttest design and is interventional. A total of 34 healthy male volunteers using available sampling method were selected to participate in the study. Exclusion criteria included a history of lower extremity injury in the last 6 months and especially fractures in the lower extremity, surgery in the past year, as well as neuromusculoskeletal disorders (diagnosed by especial tests), vestibular disorders, and cardiovascular problems. This study was done in Tehran City in the academic year 2015-2016.

Firstly, the maximum isometric quadriceps strength of each participant was measured using a dynamometer (pull-push dynamometer-zemic 250 kg). The subject would sit on a bed that was designed to be used with the dynamometer. The subject's dominant knee was positioned and flexed at 90° angle. The dynamometer was placed 2 fingers above the lateral malleolus on the anterior part of the tibia. The subject was asked to apply maximum voluntary isometric contraction of quadriceps femoris muscle to the dynamometer for 3 seconds, and the force was recorded. This procedure was repeated 3 times and their average results was recorded for later comparison.

During the next phase, the errors of the joint angles reconstruction were measured. We used digital (INSIZE INC. (USA) 0°-180°, accuracy of 0.1°) to measure the extent of reconstruction error of the knee angle [17]. Also a device was designed to place the inclinometer on the mid-calf of the subject. The subject's thigh was fixed on the bed. The examiner placed the subject's knee at the target angle (45°) and asked



PHYSICAL TREATMENTS

Figure 1. A. Examiner passively move the knee into target angle (45°) and ask subject to keep it for 7 seconds. B. The subject reconstruct the angle with closed eyes.

the subject to contract his quadriceps muscle and hold it in place for 7 seconds. The examiner then returned the subject's knee to its original position and asked him to close his eyes and reconstruct the target angle by moving the knee from the original 90° angle towards the target 45° angle.

Subsequently, the fatigue protocol was put in place. The subject sat on a chair; a weight which was 70% of the maximum quadriceps isometric force was tied around the subject's leg. The subject was asked, to the extent of his ability, repeatedly perform the knee extension range of motion until he was no longer able to execute the move. Then, a weight which was 50% of maximum isometric force of the quadriceps was tied and the subject was asked to repeat the fatigue protocol to the best of his ability. The movements were done in such a way that each contraction cycle lasted 8 seconds (4 seconds of concentric contraction and 4 seconds of eccentric contraction of the quadriceps muscle). Next, the maximum isometric force of the quadriceps was measured again and if it was 50% or less, compared to the initial obtained value, the proprioception assessment would be carried out. Otherwise, the fatigue protocol was repeated [18, 19]. The extent of error of the knee angle reconstruction, before and after fatigue, was measured by the inclinometer (Figure 1).

To accurately evaluate proprioception, 2 variables were considered: 1) Absolute error, which measures the difference between the measured angle and the target angle without taking into consideration the direction of error, and 2) Constant error, which measures the difference between the measured angle and the target angle, taking into consideration the direction of error. False positive errors, or over-

estimates, are going over the target angle, and false negative errors, or underestimates, are not reaching the target angle [20]. The fewer errors, the more accurate and stable the reconstruction would be. Using the Kolmogorov-Smirnov statistical analysis, the normality of the data were revealed. This information was used for statistical calculation of the parametric tests. In order to compare the variable of proprioception, before and after fatigue, paired sample t test was used. The significance level for all calculations in the statistical analysis was considered at P=0.05. For the statistical calculations, SPSS (version 16) was used.

Ethical considerations

After visiting the test setting (Control Laboratory of Faculty of Rehabilitation, Iran University of Medical Sciences), the participants signed informed consent forms that have been approved by the Ethics Committee of Iran University of Medical Sciences.

3. Results

The demographic data included age, height, weight, and body mass index (Table 1). The absolute and constant error of the measured angle were compared before and after fatigue, which showed a statistically significant difference (absolute error, P<0.001; constant error, P=0.006) (Figure 2 and Table 2).

4. Discussion

The results of this study showed that the quadriceps muscle fatigue decreases the accuracy of the reconstruc-

Table 1. Demographic characteristics of the study participants.

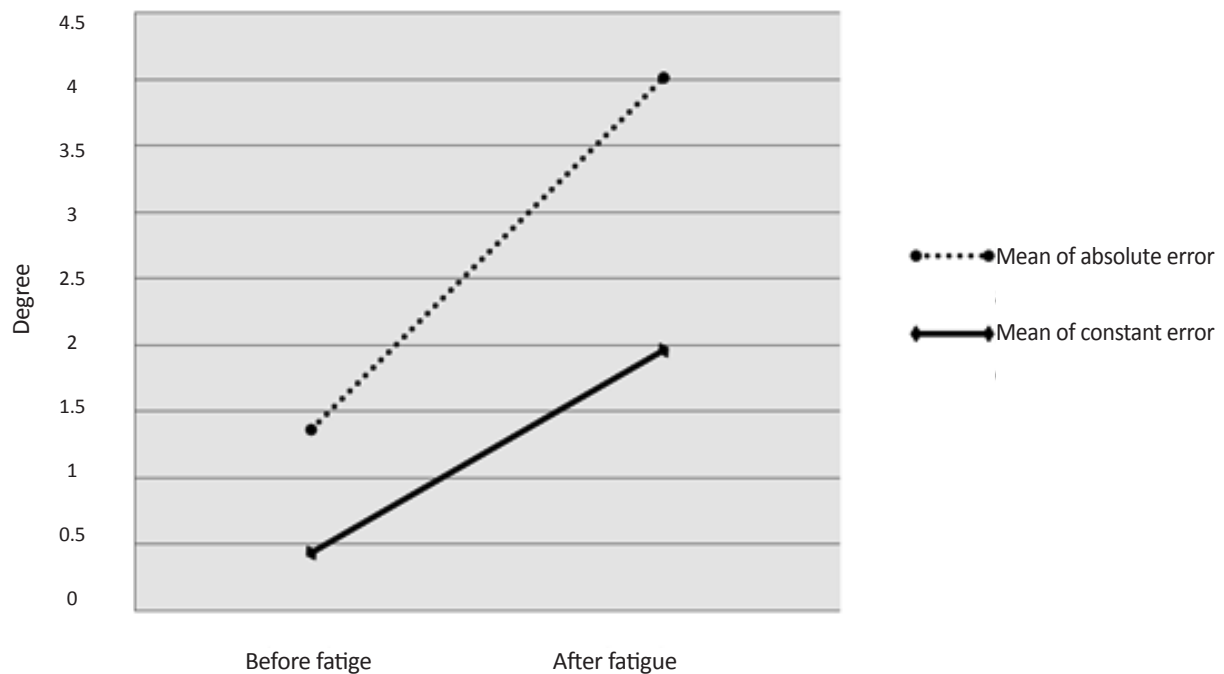
	Mean	SD	Minimum	Maximum
Age (y)	22.15	1.97	19	25
Height (m)	1.77	0.05	1.65	1.88
Weight (kg)	72.85	6.49	60	85
Body mass index (kg/m ²)	23.15	1.87	20.68	28.08

PHYSICAL TREATMENTS

Table 2. Comparing the absolute and constant errors of knee joint repositioning angle (45°), before and after quadriceps muscle fatigue.

Variables	Before fatigue		After fatigue		t	Significant level
	Mean	SD	Mean	SD		
Absolute error (degree)	1.37	0.39	4.01	0.89	19.105	0.000
Constant error (degree)	0.44	1.05	1.96	2.99	2.961	0.006

PHYSICAL TREATMENTS



PHYSICAL TREATMENTS

Figure 2. Comparing the absolute and constant errors of knee joint repositioning angle (45°), before and after quadriceps muscle fatigue.

tion of the joint angles in young men. Considering the role of proprioception in reconstruction of joint angles, muscle fatigue can have direct effects in this regard, which increases the risk of potential damage.

There are various reasons for this finding. Following muscle fatigue, pain receptors are activated through the production of metabolites caused by muscle contraction [21]. These metabolites directly affect the pattern of muscle spindle discharge, resulting in the reduction of muscle's afferent signals [7]. The reduction in the sensitivity of proprioceptive afferent nerves, which are responsible for relaying information to CNS, can reduce the accuracy of the reconstructed joint angle. Yaggie et al. found that the impairments in the position sense that occurred after fatigue could be due to the reduction of motor neuron output and sensitivity of the muscle afferents groups III and IV [22].

In another study conducted by Ribeiro et al. on knee proprioception of elderly individuals, the extent of absolute error of the reconstructed knee angle increased after fatigue of the quadriceps muscles. Based on these findings, they suggested that muscle fatigue, following an increase in the threshold of muscle spindle discharge can impair proprioception [23]. It can also impair the control of muscle nerves and disable muscles to maintain joint dynamic stability [24].

The study results of the Miura et al. who examined local fatigue on knee proprioception are contrary to our results [14]. In their study, local fatigue did not have any effect on knee proprioception. This difference can be due to the procedures carried out in the 2 fatigue studies. In the study conducted by Miura et al., there was no objective criterion for determining the exhaustion threshold and all study participants were equally tired. Thus, their participants might not measure up to the fatigue criteria of our study (50% or less than the maximum muscle strength). Furthermore, the measured target angle in Miura et al. study was randomly chosen to be between 10° and 80° . During this range of motion in some angles, ligaments play an important and crucial role in proprioception of the knee angle, and therefore, muscle fatigue can be compensated by this factor. The measured target angle in our study (45°) is an angle that the muscle has its most share in maintaining the dynamic stability of the joint.

According to the obtained mean constant error, most people surpassed the target angle and had more positive errors (overestimate). It could be due to increase in the threshold of muscle spindle discharge. According to the results of Sajjadi et al. who studied the effect of fatigue on proprioception of the neck between men and women, men showed a higher amount of positive errors compared to woman who had more negative errors [25]. This result can indicate that men do not follow the Internal Forward

Model hypothesis (which was introduced by Givoni et al.). They stated that in the Internal Forward Model, the brain compares and integrates the predicted feedback to the actual feedback it receives from the quadriceps muscles. This comparison leads to the assumption that the quadriceps muscle is longer than its actual state and accordingly the proprioceptive error occurs [26].

The following study indicates that quadriceps muscle fatigue to the amount of 50% maximum muscle strength, will result in decrease in the accuracy and increase in reconstruction error at 45° angle of the knee joint. This increase in error occurs more in the form of overestimate (surpassing the target angle) and creating more positive errors.

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Conflict of Interests

The authors declared no conflict of interests.

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