Journal of Rehabilitation Sciences and Research

Journal Home Page: jrsr.sums.ac.ir

Original Article

Effects of Acute Fatigue of the Tibialis Anterior Due to a Weight-Bearing Muscle Activity on the Ankle Joint Position Sense in Healthy Subjects

Ali Ghanbari, Farahnaz Ghafarinejad*, Farshid Mohammadi

Department of Physiotherapy, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Shiraz, Iran

ARTICLE INFO

Article History:
Received: 18/3/2014
Revised: 14/7/2014
Accepted: 5/8/2014

Keywords:
Joint position sense
Fatigue
Weight bearing activity
Ankle joint

ABSTRACT

Background: Joint position sense (JPS) is comprised of sensory input from several sources, including skin, joint capsule/ligaments, and muscular receptors. If the muscle receptors play a leading role in detecting joint position awareness, then muscle fatigue might yield a declination in JPS. The aim of this study was to evaluate if a sustained fatiguing contraction of the tibialis anterior (ankle dorsiflexor) could alter the ankle JPS.
Methods: This was a cross-sectional study in which 40 healthy subjects (age, 23.9±2.3 years; height, 172.6±5.7 cm; weight, 67.8±4.7 kg) were recruited. Subjects were asked to recognize 2 pre-recognized positions (10° in dorsiflexion (DF) and 21° in plantarflexion (PF)) for 2 experimental conditions: normal and fatigued. Muscular fatigue was induced in the tibialis anterior of the dominant leg by using an isometric test. The average of the absolute angular error (AAE) deviations from the target positions of three trials were recorded as scores for both fatigue and non-fatigue conditions.
Results: There was significant decrease in subjects' abilities to recognize active and passive repositioning of their ankle after a fatigue protocol (P=0.0001).
Conclusion: The acuity of the ankle JPS is reduced subsequent to a fatigue protocol.

Introduction

The increased participation of people in sports and recreational activities has raised the incidence of sports-related injuries [1-2]. Studies have shown that sport injuries occur mostly during the later stages of a game, when the athletes are fatigued [3].

It is well-known that exercise-induced fatigue compromises the neuromuscular control of lower limbs, which could predispose the knee or ankle joints to injury [1-2, 4-7].

*Corresponding author: Farahnaz Ghafarinejad, Department of Physiotherapy, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Chamran Avenue, Abiverdi Street, Shiraz, Iran, **Tel:** +98-71-36271551, **Fax:** +98-71-36272495,
E-mail: ghafarif@sums.ac.ir

One physiological mechanism by which muscular fatigue attenuates the neuromuscular control is alteration of joint position sense (JPS) [1]. JPS is defined as the ability to assess the position of a body segment without the assistance of vision [8]. Joint mechanoreceptors, skin and muscle receptors (Golgi tendon organs and muscle spindle afferents) are the main sources of JPS [9]. However, it is generally believed that the most important contribution is from muscle receptors [10, 11].

The metabolic acidosis and the decrease in muscle pH associated with exercise can reduce Golgi tendon organ (GTO) responses [6]. Research has confirmed that a fatiguing protocol alters JPS in different joints such as the shoulder, elbow, lumbar spine, and knee [6, 12-21]. Several studies have focused on the effects of muscular fatigue on JPS of the ankle joint. They have investigated different muscle groups including plantar flexors, dorsiflexors, and evertors [6, 9, 18, 22, 23].

The fatigue protocol in these studies generally included exercise activity in an open kinematic chain. To the best of authors' knowledge, no study has investigated the alteration of ankle JPS after muscular fatigue during a closed-chain exercise. It is unknown whether the detrimental effects of muscular fatigue during a weight-bearing activity are different with those of a non weight-bearing exercise. Jan et al [24] found greater improvement in knee joint sense of position when the patients with knee osteoarthritis participated in an 8-week weight-bearing exercise program compared to those who performed non-weight-bearing exercise. This evidence indicates that weight-bearing exercise is apparently more challenging for the neuromuscular control system. Thus, it could be hypothesized that if a weight-bearing exercise program would be able to enhance JSP, then fatiguing a muscle through a weight-bearing activity may have more detrimental effects on JSP than a non-weight-bearing exercise. The present study was designed to investigate if the effect of tibialis anterior fatigue on ankle JPS is different after open- or closed-chain exercises.

Methods

Based on the information obtained from a pilot study of 10 people and using a convenient sampling method, a group of 40 healthy male subjects (age, 23.9±2.3 years; height, 172.6±5.7 cm; weight, 67.8±4.7 kg) volunteered to participate in this study. The exclusion criteria were any previous history of ankle joint trauma or diseases, neurological deficits, or restricted joint mobility. The participants were non-athletes and were not involved in any regular exercise program.

The subjects were instructed not to participate in any heavy exercise or physical activity 24 hours before the study. At the beginning of the measurement session, the researchers explained the aim of the study and the procedures to the subjects and obtained their informed consent. The study was approved by the Ethics Committee of Shiraz University of Medical Sciences.

The subjects were divided randomly into the two groups of open- and closed-chain exercise. In the first group, the fatigue protocol included a non-weight bearing exercise for the tibialis anterior muscle while the subjects in the second group performed the exercises in a weight-bearing condition.

Ankle JPS was assessed by the subject's ability to reproduce active and passive repositioning of the ankle. A pedal goniometer was designed based on the model presented by Chan et al [25] for the assessment of ankle plantarflexion (PF) and dorsiflexion (DF). The participant was seated on a chair while his dominant leg was in the pedal goniometer. The chair was high enough to keep the foot off the ground. The subject's eyes were closed in order to remove visual cues. The subject's ankle was moved passively from neutral position (0° PF) to the target positions of 10° in DF or 21° in PF and held there for 5 seconds. The ankle was then passively returned to the starting position (0° PF) and the subject was asked to actively reproduce the same target positions. For passive testing, the examiner moved the ankle in the specified direction and asked the subject to say "stop" whenever he felt the ankle has reached the target position. In each goniometry test, one reading of joint angle was used for assessing ankle joint position. The absolute angular error (AAE), defined as the difference between the target angle and the reproduced angle, was used for the assessment of ankle JPS. The intra-tester reliability of measurements was obtained as ICCs of 0.76 for plantarflexion and 0.73 for dorsiflexion, which seems to be in an acceptable range.

The maximal voluntary contraction (MVC) of the tibialis anterior was assessed by a dynamometer ((MIE, Ltd., Leeds, UK). The reproducibility of measurements of this device was previously established in research that reported an ICC of 0.76 to 0.85 [26]. In the open-chain group, while the subjects were in a seated position, they were asked to perform an isometric contraction of the tibialis anterior equal to 70% of their MVC and hold the contraction as long as the dynamometer showed a number above 50% of MVC [27]. Fatigue was defined as a state when the contraction force reached below 50% of MVC. The fatigue protocol in the closed-chain group was similar to that of the open-chain group except that the subjects were standing on a platform, off the ground, with their feet shoulder-width apart. They were asked to dorsiflex their ankle with the dynamometer attached to a hook on the ground.

Immediately after the fatigue protocol, ankle JPS was assessed using the method described before.

Statistical Analysis

SPSS (version 15.0) was used for statistical analysis of the study data. The mean values of AAE were compared before and after the fatigue protocol in each group using the Wilcoxon test. Mann-Whitney test was used for comparing the mean AAE between the two study groups. The level of significance was set to be less than 0.05.

Results

No statistically-significant difference was found between the two study groups in mean age, weight, height, and MVC of the subjects (data not shown). Also, there was no difference in mean AAE of the two groups prior to the interventions (Table 1).

Within each study group, statistically-significant differences were found for the mean AAE during passive and active testing of PF and DF before and after the fatigue protocols (Tables 2 and 3). Comparing the two groups revealed that, only for PF, the mean changes in AAE were significantly different in both active and passive testing. There were greater changes in AAEs in the closed-chain group compared to the open-chain group (Table 4).

Discussion

The study showed that fatiguing the tibialis anterior

Table 1: comparing of the two study groups before interventions in absolute angular error (AAE) values for ankle joint position sense of two target positions (10° DF and 21° PF)

Target Position	AAE (degree)	Non-weight- bearing group*	Weight- bearing group*	P value
Active Testing	DF	0.9±0.9	0.8±0.7	0.820
	PF	1.7±0.9	1.4±0.8	0.327
Passive Testing	DF	0.1±0.3	0.3±0.4	0.989
	PF	0.6±0.6	0.5±0.6	0.640

*Values are means±SD, DF=Dorsiflexion, PF=Plantarflexion

Table 2: Absolute angular error (AAE) values for ankle joint position sense of two target positions (10° DF and 21° PF), before and after the fatigue protocol in non-weight-bearing group

Target Position	AAE (degree)	Pre-fatigue*	Post-fatigue*	P value
Active Testing	DF	0.9±0.9	2.2±0.9	< 0.0001
	PF	1.7±0.9	3.4±0.9	<0.0001
Passive Testing	DF	0.1±0.3	1.4±0.5	<0.0001
	PF	0.6±0.6	2.1±0.5	<0.0001

*Values are means±SD, DF=Dorsiflexion, PF=Plantarflexion

Table 3: Absolute angular error (AAE) values for ankle joint position sense of two target positions (10° DF and 21° PF), before and after the fatigue protocol in weight-bearing group

Target Position	AAE (degree)	Pre-fatigue*	Post-fatigue*	P value
Active Testing	DF	0.8±0.7	2.3±0.8	<0.0001
	PF	1.4±0.8	4.5±0.8	<0.0001
Passive Testing	DF	0.3±0.4	1.7±0.6	<0.0001
	PF	0.5±0.6	2.9±0.6	<0.0001

*Values are means±SD, DF=Dorsiflexion, PF=Plantarflexion

Table 4: comparison of the mean changes in absolute angular error (AAE) values for ankle joint position sense of two target positions (10° DF and 21° PF), between weight-bearing and non-weight-bearing groups

Target Position	Changes in AAE (degree)	Non-weight bearing group*	Weight bearing group*	P value
Active Testing	DF	1.3±0.5	1.5±0.6	0.445
	PF	1.7±1.1	3.1±0.8	<0.0001
Passive Testing	DF	1.3±0.4	1.3±0.5	0.947
	PF	1.5±0.7	2.4±0.5	<0.0001

*Values are means±SD, DF=Dorsiflexion, PF=Plantarflexion

muscle could impair the ankle JSP in both PF and DF movements. This would support the view that fatigue may influence the mechanoreceptors in the muscles around the ankle joint [28, 29]. Our findings may be comparable to the previous studies [6, 9, 23, 30]. The results of the present study are in agreement with that of Forestier [30], who reported reduced ankle JSP after DF fatigue. On the other hand, Gurney [9] reported that a fatiguing protocol involving both ankle plantar flexors and dorsiflexors had no effect on ankle JPS and concluded that muscle fatigue does not play a part in ankle JPS. Shields [23] also found that DF fatigue minimally influenced the ankle JPS. South [6] observed that a fatiguing exercise program of the peroneal muscles did not affect ankle JPS.

The discrepancy between our findings and others could be partly explained by the different fatigue protocols used in the studies. While in both Forestier [30] and our studies muscular fatigue was induced by using an isometric test, others [6, 9, 23] used isokinetic isometric or concentric exercise. Apparently, the type of muscle contraction is an influential factor in this regard, and warrants further research. A recent study showed that concentric contractions induced a greater impairment of elbow position sense compared to isometric and eccentric contractions [4]. However, it is unknown whether the same pattern may be applied to other joints, including the ankle. Another possible influential factor might be the workload or intensity of the exercise used for muscular fatigue. Gurney et al [9], Shields et al [23], and South et al [6] used a workload of 50% of peak torque; whereas we and Forestier et al chose a workload of 70% of MVC. Perhaps the fatigue made by 50% of peak torque may not be enough for ankle dorsiflexors to impair JPS.

The present study found that there were greater AAEs in PF movement within the closed-chain group compared with the open-chain group. This finding supports the study hypothesis and denotes that tibialis anterior fatigue due to a weight-bearing exercise is more effective in impairing ankle JPS than a non-weight bearing exercise. Jan et al found greater improvement in knee joint sense of position after an 8-week weight-bearing knee exercise program compared to those who performed non-weight-bearing exercise. Consequently, the results of this study and the evidence provided by Jan et al suggest that weight-bearing exercise may be more challenging for the neuromuscular control system.

The exact mechanisms by which fatigue may influence JPS have not been elucidated, but several possible mechanisms have been reported. It has been suggested that increased joint laxity may play a role in JPS changes following fatigue, because it has been demonstrated that fatigue increases the laxity of joint ligaments [31], and subjects with increased laxity have poorer JPS [32].

The relative contribution of joint and muscle receptors to measured JPS deficits following fatigue protocol has remained controversial. It is generally accepted that the greatest contribution to position sense is from muscular receptors [1, 5, 10]. Because fatigue would presumably affect muscle receptors more than joint receptors, decreased JPS may be due to loss of muscle receptor input [1]. Several reports have investigated that muscle receptor activity may be decreased with fatigue [29, 33-36]. These possible changes in the afferent input of muscle receptors may cause changes in neuromuscular control of the limb and lead to a decrease in the body's ability to control the limb. The results of the present study support these suppositions.

Conclusion

There was significant decrease in subjects' abilities to recognize active and passive repositioning of their ankle after a fatigue protocol. When the two study groups were compared, we found that, only for PF, there were greater changes in AAEs in closed-chain conditions compared to open-chain conditions. In general, the study findings partially supported the hypothesis that fatiguing a muscle through a weight-bearing activity may have more detrimental effects on JSP than a non-weight-bearing exercise.

Conflict of Interest: None declared.

References

1. Hiemstra L, Lo I, Fowler PJ. Effect of fatigue on knee proprioception: implications for dynamic stabilization. The Journal of orthopaedic and sports physical therapy. 2001;31(10):598.
2. Gabbett TJ. Incidence, site, and nature of injuries in amateur rugby league over three consecutive seasons. British Journal of Sports Medicine. 2000;34(2):98-103.
3. Miyasaka K, Daniel D, Stone M, Hirshman P. The incidence of knee ligament injuries in the general population. Am J Knee Surg. 1991;4(1):3-8.
4. Fortier S, Basset FA, Billaut F, Behm D, Teasdale N. Which type of repetitive muscle contractions induces a greater acute impairment of position sense? Journal of Electromyography and Kinesiology. 2010;20(2):298-304.
5. Gandevia S. Neural control in human muscle fatigue: changes in muscle afferents, moto neurones and moto cortical drive. Acta physiologica scandinavica. 1998;162(3):275-83.
6. South M, George KP. The effect of peroneal muscle fatigue on ankle joint position sense. Physical Therapy in sport. 2007;8(2):82-7.
7. Johnston 3rd R, Howard ME, Cawley PW, Losse GM. Effect of lower extremity muscular fatigue on motor control performance. Medicine and science in sports and exercise. 1998;30(12):1703.
8. Bouët V, Gahery Y. Muscular exercise improves knee position sense in humans. Neuroscience letters. 2000;289(2):143-6.
9. Gurney B, Milani J, Pedersen ME. Role of fatigue on proprioception of the ankle. J Exerc Physiol. 2000;3(1):8-13.
10. Lattanzio P-J, Petrella RJ. Knee proprioception: a review of mechanisms, measurements, and implications of muscular fatigue. Orthopedics. 1998;21(4):463.
11. Gandevia S, Enoka R, McComas A, Stuart D, Thomas C. Neurobiology of muscle fatigue. Advances and issues. Advances in experimental medicine and biology. 1995;384:515.
12. Gear WS. Effect of different levels of localized muscle fatigue on knee position sense. Journal of sports science & medicine. 2011;10(4):725.
13. Ribeiro F, Mota J, Oliveira J. Effect of exercise-induced fatigue on position sense of the knee in the elderly. European journal of applied physiology. 2007;99(4):379-85.
14. Ribeiro F, Oliveira J. Factors Influencing Proprioception: What do They Reveal? 2011.
15. Ribeiro F, Santos F, Goncalves P, Oliveira J. Effects of volleyball match-induced fatigue on knee joint position sense. European Journal of Sport Science. 2008;8(6):397-402.
16. Allen TJ, Leung M, Proske U. The effect of fatigue from exercise on human limb position sense. The Journal of physiology. 2010;588(8):1369-77.
17. Allen T, Proske U. Effect of muscle fatigue on the sense of limb position and movement. Experimental Brain Research. 2006;170(1):30-8.
18. Mohammadi F, Roozdar A. Effects of fatigue due to contraction of evertor muscles on the ankle joint position sense in male soccer players. The American journal of sports medicine. 2010;38(4):824-8.
19. Paschalis V, Nikolaidis MG, Giakas G, Jamurtas AZ, Pappas A, Koutedakis Y. The effect of eccentric exercise on position sense and joint reaction angle of the lower limbs. Muscle & nerve. 2007;35(4):496-503.
20. Pinsault N, Vuillerme N. Degradation of cervical joint position sense following muscular fatigue in humans. Spine. 2010;35(3):294-7.
21. Ribeiro F, Venâncio J, Quintas P, Oliveira J. The effect of fatigue on knee position sense is not dependent upon the muscle group fatigued. Muscle & nerve. 2011;44(2):217-20.
22. Huston JL, Sandrey MA, Lively MW, Kotsko K. The effects of calf-muscle fatigue on sagittal-plane joint-position sense in the ankle. J Sport Rehabil. 2005;14:168-84.
23. Shields RK, Madhavan S, Cole K. Sustained muscle activity minimally influences dynamic position sense of the ankle. The Journal of orthopaedic and sports physical therapy. 2005;35(7):443.
24. Jan M-H, Lin C-H, Lin Y-F, Lin J-J, Lin D-H. Effects of weight-bearing versus nonweight-bearing exercise on function, walking speed, and position sense in participants with knee osteoarthritis: a randomized controlled trial. Archives of physical medicine and rehabilitation. 2009;90(6):897-904.
25. Chan M, Chu M, Wong S, Hamer P. Reliability of a pedal goniometer for the assessment of ankle inversion in the plantadlexed position. AustralianJournaloJPhysiothr: rapy36: 155. 1990;160.
26. van der Linden ML, Aitchison AM, Hazlewood ME, Hillman SJ, Robb JE. Test-retest repeatability of gluteus maximus strength testing using a fixed digital dynamometer in children with cerebral palsy. Archives of physical medicine and rehabilitation. 2004;85(12):2058-63.
27. Kennedy A, Hug F, Bilodeau M, Sveistrup H, Guével A. Neuromuscular fatigue induced by alternating isometric contractions of the ankle plantar and dorsiflexors. Journal of Electromyography and Kinesiology. 2011;21(3):471-7.
28. Hamberg J, Crenshaw AG. Sensory adaptation after a 2-week stretching regimen of the rectus femoris muscle. Archives of physical medicine and rehabilitation. 2001;82(9):1245-50.
29. Proske U, Morgan DL, Gregory JE. Thixotropy in skeletal muscle and in muscle spindles: a review. Progress in neurobiology. 1993;41(6):705.
30. Forestier N, Teasdale N, Nougier V. Alteration of the position sense at the ankle induced by muscular fatigue in humans. Medicine and science in sports and exercise. 2002;34(1):117-22.
31. Nawata K, Teshima R, Morio Y, Hagino H, Enokida M, Yamamoto K. Anterior-posterior knee laxity increased by exercise: quantitative evaluation of physiologic changes. Acta

Orthopaedica. 1999;70(3):261-4.
32. Rozzi SL, Lephart SM, Gear WS, Fu FH. Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players. The American journal of sports medicine. 1999;27(3):312-9.
33. Bigland-Ritchie BR, Furbush FH, Gandevia SC, Thomas CK. Voluntary discharge frequencies of human motoneurons at different muscle lengths. Muscle & nerve. 1992;15(2):130-7.
34. Garland SJ. Role of small diameter afferents in reflex inhibition during human muscle fatigue. The Journal of physiology. 1991;435(1):547-58.
35. Hagbarth K, Bongiovanni L, Nordin M. Reduced servo-control of fatigued human finger extensor and flexor muscles. The Journal of physiology. 1995;485(Pt 3):865-72.
36. Nyland J, Shapiro R, Stine R, Horn T, Ireland M. Relationship of fatigued run and rapid stop to ground reaction forces, lower extremity kinematics, and muscle activation. The Journal of orthopaedic and sports physical therapy. 1994;20(3):132.