

Research article

Effect of different levels of localized muscle fatigue on knee position sense

William S. Gear

Department of Health, Physical Education and Recreation, University of Minnesota Duluth, Duluth, MN, USA

Abstract

There is little information available regarding how proprioceptive abilities decline as the amount of exertion increases during exercise. The purpose of this study was to determine the role of different levels of fatigue on knee joint position sense. A repeated measures design was used to examine changes in active joint reposition sense (AJRS) prior to and following three levels of fatigue. Eighteen participants performed knee extension and flexion isokinetic exercise until torque output was 90%, 70%, or 50% of the peak hamstring torque for three consecutive repetitions. Active joint reposition sense at 15, 30, or 45 degrees was tested following the isokinetic exercise session. Following testing of the first independent measure, participants were given a 20 minute rest period. Testing procedures were repeated for two more exercise sessions following the other levels of fatigue. Testing of each AJRS test angle was conducted on three separate days with 48 hours between test days. Significant main effect for fatigue was indicated ($p = 0.001$). Pairwise comparisons indicated a significant difference between the pre-test and following 90% of peak hamstring torque ($p = 0.02$) and between the pre-test and following 50% of peak hamstring torque ($p = 0.02$). Fatigue has long been theorized to be a contributing factor in decreased proprioceptive acuity, and therefore a contributing factor to joint injury. The findings of the present study indicate that fatigue may have an effect on proprioception following mild and maximum fatigue.

Key words: Proprioception, fatigue, isokinetic.

Introduction

Ligament injuries of the knee, particularly the anterior cruciate ligament (ACL), represent a significant percentage of lower extremity injuries during athletic participation. According to Hootman et al. (2007) there are an average of 2000 ACL injuries per year in NCAA athletics. Several factors have been suggested as possible causes for ACL injuries, including decreased proprioceptive sensibility associated with fatigue of the knee musculature (Borotikar et al., 2008; Huston and Wojtys, 1996; Rozzi et al., 1999; Wojtys et al., 1996).

Proprioception is defined as the sense of joint position and movement of a joint (McCloskey, 1978). Proprioceptors (position sensors) are found in muscles, joints, and skin. These receptors are sensitive to changes in stretch, and relay information regarding joint movement and position to the CNS for interpretation and evaluation. Studies of ligament and muscle receptors indicate that ligament receptors are more sensitive near the end limits of a joint's motion, whereas muscle receptors may play a key role in the mid-range of motion (Brand, 1989; Clark et al., 1989; Grigg, 1986; Krauspe et al., 1992; Zimny,

1986). Using afferent information provided by proprioceptors, the CNS relays efferent signals to muscles to generate a muscle action or does not relay efferent signals resulting in muscle relaxation.

Fatigue is generally associated with failure of muscle to sustain an action. Other definitions include, an inability to maintain a given force and an inability to maintain a given exercise intensity (Fitts, 1996; Fitts and Balog, 1996; Green et al., 2003). Central factors (CNS factors), however, should not be overlooked. At the very least, painful input due to exertion from nociceptors may reduce an athlete's motivation to continue. At the extreme, reduced output from sensory receptors and delayed output from CNS integration centers, and/or the alpha and gamma motor systems may cause a reduction in the protective reflex mechanisms of muscles (Sjölander et al., 2002; Löscher et al., 1996).

Previous studies examining the effect of fatigue on proprioception have provided conflicting results. Skinner et al. (1986) found a decrease in the ability to reproduce joint angles after a series of interval running sprints to fatigue, suggesting that this decreased ability was due to a loss of efficiency of muscle spindles. Marks and Quinney (1993), however, did not find a significant decrease in absolute angular error score following 20 consecutive concentric and eccentric quadriceps muscle actions at maximal voluntary effort at an angular velocity of 180 degrees·s⁻¹ in sedentary females. In a study examining the effect of low-intensity work to fatigue, Björklund et al. (2000) found that extended periods of work at a low intensity diminished proprioceptive acuity, which could lead to impaired motor control further diminishing position sensibility. These studies, however, only examined the effects of maximum or extended periods of fatigue. During athletic competition, athletes commonly slow down or are unable to generate the same amount of force that they could during earlier phases of the activity. In this investigator's opinion, however, it is rare to see an athlete fatigued to the point of collapse (maximum fatigue) in sports such as soccer or basketball. It may therefore be more appropriate to view fatigue as a continuum ranging from minimal to maximum levels. To date no investigation has examined proprioception of the knee, as the level of muscle fatigue is incrementally increased. The purpose of this study was to examine the effect of different levels of isokinetically induced muscle fatigue on active joint reposition sense (AJRS) at the knee.

Methods

Participants

Eighteen participants [10 females (age = 19.50 ± 1.18

years, height = 1.66 ± 0.07 m, mass = 64.50 ± 7.08 kg), 8 males (age = 20.88 ± 1.25 years, height = 191.14 ± 8.00 cm, mass = 92.53 ± 12.38 kg)] recruited from NCAA Division III basketball and soccer programs, participated in this study. Individuals with a history of cardiovascular disease, diabetes, hypertension, pregnant and/or orthopedic pathology or injury of the knee were excluded from participating in this study. Written informed consent was obtained from each participant in accordance with university Institutional Review Board protocols.

Muscle fatigue protocol

Fatigue of the hamstring muscle group of the participant's non-dominant leg was induced utilizing a Biodex System 3 Isokinetic Dynamometer (Biodex Medical Inc., Shirley, NY, U.S.A.). The hamstrings were chosen for this investigation as they play a key role in preventing anterior displacement of the tibia relative to the femur, which is a common mechanism in ACL injury. Calibration of the Biodex dynamometer was performed prior to each testing session. Participants performed the isokinetic exercise protocol in a seated position with the seat back tilt angle set to 80 degrees to maximize the length-tension relationship of the thigh musculature (Biodex System 3 Owners Manual). Participants were secured to the chair by means of thigh, pelvic, and torso straps to minimize extraneous body movements. The lateral femoral epicondyle of the test leg was used to align the axis of rotation of the knee joint with the axis of rotation of the dynamometer resistance adapter. The resistance adapter was strapped into place approximately three cm above the medial malleolus. Gravity correction was obtained by measuring the torque with the knee in a relaxed state at zero degrees of flexion.

Following the setup procedures, isokinetic exercise was performed through an angular range of motion of 90 degrees. In order to induce different levels of fatigue, a fatigue protocol developed by this investigator was used. The fatigue protocol involved 2 phases. Phase 1 consisting of isokinetic concentric velocity spectrum training for knee extension and flexion at pre-set angular velocities of 90 degrees·s⁻¹ for 10 repetitions, 180 degrees·s⁻¹ for 15 repetitions, 240 degrees·s⁻¹ for 20 repetitions, and 300 degrees·s⁻¹ for 25 repetitions. A rest period of 40 seconds was provided between each of the four sets. Previous research indicates that complete recovery of peak torque values requires a rest period longer than 40 seconds (Bottaro, et al., 2010). The purpose of the isokinetic exercise protocol for this study, however, was to induce fatigue. Therefore, full recovery between sets was not desirable. Following a rest period of 40 seconds, participants then performed phase 2 of the isokinetic fatigue protocol at 180 degrees·s⁻¹ until the hamstring peak torque value was 90% (mild fatigue), 70% (moderate fatigue), or 50% (maximum fatigue) of the participant's peak isokinetic torque (PT) for three consecutive repetitions. Pilot work by this investigator found that this fatigue protocol produced mean RPE values of 10.25 ± 1.46 during the mild fatigue condition, 13.37 ± 1.26 for the moderate fatigue condition, and 17.81 ± 0.76 for the maximum fatigue conditions. A 70% isokinetic windowing cushion filter

was used per manufacturer recommendations (Biodex system 3 software manual, appendix B-5). Peak isokinetic torque values were determined by selecting the highest torque value during the first five knee flexion movements for each trial (Douris, 1993; Pincivero et al., 2001).

Active joint reposition sense protocol

Testing of AJRS was conducted using the same Biodex isokinetic dynamometer as the fatigue protocol. Position accuracy for the Biodex System 3 is reported as ± 1 degree (Biodex system 3 Owners Manual). Participants were blindfolded to eliminate visual cues related to joint position. The participant's leg was placed at a starting angle of 60° of knee flexion for each trial. The participant's leg was then passively moved to one of the test angles (45°, 30°, or 15° of knee flexion) by the examiner. Participants concentrated on the sensation of the presented angle for three seconds. The participant's leg was then returned passively to the starting position by the examiner. Following a three second rest period the participant attempted to actively reproduce the presented joint angle. Once the participant felt the test leg was in the position of the presented angle the participant depressed the hold/resume switch preventing the dynamometer from further movement. Participants were given 5 seconds to reproduce the presented angle.

The Biodex System 3 software package recorded and stored the absolute angular error (AAE) between the presented and reproduced angles. In a study conducted by Beynnon et al. (2000), AAE or Absolute Error Score (AES) was found to be the only measure that was both a repeatable and accurate measure for joint position sense testing. Each participant performed three trials at each angle and the average of the trials was recorded for statistical interpretation.

Warm-up protocol

Prior to testing, participants were allowed a 10 minute warm-up period that consisted of 5 minutes of stationary cycling at 50 W and 5 minutes of stretching. During the stretching portion of the warm-up, participants stretched both their hamstring and quadriceps muscle groups. Each muscle group was stretched using a common active stretching techniques consisting of a modified hurdler stretch for the hamstrings and a standing hip flexor stretch for the quadriceps. Participants completed three repetitions of each stretching exercise. Each stretch was held for 30 seconds at a point of mild discomfort (stretch) but not to the point of pain as subjectively reported by the participant. Between each repetition the muscles were returned to a neutral position for a 20-second rest period. Previous research has indicated that stretching in trained individuals does not have an effect on peak torque production (Egan et al., 2006).

Test procedures

Pre-testing evaluation was conducted in the Athletic Training Lab 24 hours prior to the first testing session. During the pre-testing evaluation, a medical history and demographic information (mass, height, and age) were obtained. Leg dominance was also determined at this time

Table 1. Sample testing protocol.

Test Session	Test angle	Test 1	Test 2	Test 3	Test 4
Day 1	15 degrees	Pre-test	30% PFT	50% PFT	10% PFT
Day 2	45 degrees	Pre-test	10% PFT	30% PFT	50% PFT
Day 3	30 degrees	Pre-test	50% PFT	10% PFT	30% PFT

PFT = Peak Flexor Torque

by asking the participant which foot they would kick a ball with. The leg indicated as the non-dominant (non-kicking) leg served as the test leg for all testing sessions. The decision to use the non-dominant leg for all testing procedures was made due to the fact that the non-dominant leg is involved in stabilization during activities such as kicking. Previous research indicates that there is no difference in proprioception between the dominant and non-dominant leg (Barrack et al., 1984). Participants were also introduced to the Biodex System 3 Isokinetic machine and the testing procedure to be used in the study at this time. During the initial pre-testing evaluation, each participant was also introduced to the testing procedures for AJRS. Testing of AJRS was conducted on three separate days with a minimum of 48 hours between testing days. Table 1 provides an example of a testing protocol used for one participant. Fatigue level was counterbalanced between tests and test sessions to minimize the effect of fatigue. Participants were also asked to refrain from participating in any lower extremity exercise routines for the remainder of the study.

First testing session

Upon entering the Athletic Training Laboratory, participants were provided a 10-minute warm-up period as described above. Following the warm-up, participants were pre-tested for one of the randomly assigned AJRS test angle (15°, 30° or 45°). Following the pre-test, fatigue levels were randomly assigned and participants performed the isokinetic fatigue protocol as described above until torque output was 90%, 70%, or 50% of the peak flexor torque value for three consecutive repetitions. Participants were then post-tested on the same AJRS angle as the pre-test following the isokinetic exercise session. Participants were given a 20-minute rest period following the initial testing. Following the rest period, the participant performed the isokinetic fatigue protocol until torque output fell below one of the remaining percentages of peak torque being tested for three consecutive repetitions. Following the second isokinetic exercise session, participants were post-tested on the AJRS test angle from the pre-test. This procedure was repeated for a third exercise session at the remaining percentage of peak torque.

Second testing session

Participants returned to the Athletic Training Laboratory 48 hours after the first testing session. Upon entering the laboratory, participants were provided the same 10-minute warm-up period as the first testing session. Following the warm-up, participants were pre-tested for one of the randomly assigned AJRS test angles that was not tested the first day. Following the pre-test, fatigue levels were randomly assigned and participants performed the isokinetic fatigue protocol as described above until torque output was 90%, 70%, or 50% of the peak flexor torque

value for three consecutive repetitions. Participants were then post-tested on the same AJRS angle as the pre-test following the isokinetic exercise session. Participants were given a 20-minute rest period following the initial testing. Following the rest period, the participant performed the isokinetic fatigue protocol until torque output fell below one of the remaining percentages of peak torque being tested for three consecutive repetitions. Following the second isokinetic exercise session, participants were post-tested on the AJRS test angle from the pre-test. This procedure was repeated for a third exercise session at the remaining percentage of peak torque.

Third testing session

Participants returned to the Athletic Training Laboratory 48 hours after the second testing session. Upon entering the laboratory, participants were provided the same 10-minute warm-up period as the first and second testing session. Following the warm-up, participants were pre-tested on the final AJRS test angle. Following the pre-test, fatigue levels were randomly assigned and participants performed the isokinetic fatigue protocol as described above until torque output was 90%, 70%, or 50% of the peak flexor torque value for three consecutive repetitions. Participants were then post-tested on the same AJRS angle as the pre-test following the isokinetic exercise session. Participants were given a 20-minute rest period following the initial testing. Following the rest period, the participant performed the isokinetic fatigue protocol until torque output fell below one of the remaining percentages of peak torque being tested for three consecutive repetitions. Following the second isokinetic exercise session, participants were post-tested on the AJRS test angle from the pre-test. This procedure was repeated for a third exercise session at the remaining percentage of peak torque.

Data analysis

Mean AAE values for AJRS were used for data analyses. A 3-way mixed factorial analysis of variance [fatigue level (no fatigue, 90% PT, 70% PT, 50% PT)] x knee angle (15°, 30°, 45°) x gender (male, female)] for repeated measures was utilized to determine statistical significance. All tests of significance were carried out at an alpha level of $p < 0.05$. Pairwise comparisons using the Bonferroni adjustment were used to determine which findings were significant at the 0.05 level. Statistical procedures were performed using the PASW Statistics package (v 18.0).

Results

Means and standard deviations for AAE for AJRS 15°, 30°, and 45° are presented in Table 2. The repeated measures analysis did not indicate significant interaction effects for AJRS x fatigue x gender ($F_{6,96} = 0.97$, $p = 0.45$),

Table 2. Means (\pm SD) for Absolute Angular Error in degrees by knee flexion angle.

% PHT	AJRS 15°			AJRS 30°			AJRS 45°		
	Males	Females	Total	Males	Females	Total	Males	Females	Total
Pre-test	1.90 (.94)	3.13 (1.46)	2.58 (1.38)	1.59 (.39)	2.04 (.74)	1.84 (.64)	2.41 (1.07)	1.96 (1.21)	2.16 (1.14)
90% PHT	3.61 (2.13)	2.77 (1.28)	3.14 (1.71)	2.59 (1.82)	3.93 (2.05)	3.33 (2.02)	3.41 (3.31)	3.79 (2.86)	3.62 (2.98)
70% PHT	3.04 (2.59)	3.07 (2.37)	3.06 (2.39)	2.30 (1.35)	3.38 (2.10)	2.90 (1.84)	2.93 (2.23)	3.64 (2.31)	3.32 (2.24)
50% PHT	3.14 (1.64)	2.70 (1.21)	2.90 (1.39)	4.38 (4.21)	3.89 (2.77)	4.11 (3.38)	3.25 (3.79)	3.80 (2.67)	3.56 (3.12)

AJRS = Active Joint Reproduction Sense; PHT = Peak Hamstring Torque

AJRS \times fatigue ($F_{6,96} = 0.96$, $p = 0.46$), fatigue \times gender ($F_{3,48} = 0.41$, $p = 0.74$), nor AJRS \times gender ($F_{2,32} = 0.30$, $p = 0.74$). A main effect for fatigue was indicated ($F_{2,32} = 6.27$, $p = 0.001$) but not for AJRS ($F_{2,32} = 0.18$, $p = 0.84$), nor gender ($F_{1,16} = 0.26$, $p = 0.62$). Mean and standard deviation data for AAE by fatigue are presented in Table 3. Pairwise comparisons for fatigue indicated a significant difference between the pre-test and following the 90% of peak hamstring torque measures ($p = 0.02$) and between the pre-test and following 50% of peak hamstring torque ($p = 0.02$).

Table 3. Means (\pm standard error) for absolute angular error in degrees by level of fatigue.

Level of Fatigue	AAE score
Pre-test (No Fatigue)	2.17 (.12)
90% Peak Ham T	3.35 (.39) *
70% Peak Ham T	3.06 (.38)
50% Peak Ham T	3.53 (.45) *

* Indicates a significant difference at the $p < 0.05$ level from the pre-test score. % Peak Ham T = Percentage of peak hamstring torque.

Discussion

Fatigue has long been theorized to be a contributing factor in decreased proprioceptive abilities, and therefore a contributing factor to joint injury. The present study is the first to exam the influence of different levels of fatigue on AJRS at three different knee joint angles. The main outcomes of this study were that mild and maximum fatigue levels appear to have a main effect on active joint reposition sense, but that an interaction effect between AJRS at 15°, 30°, and 45° does not exist.

The fatigue protocol used for this study was unique in the sense that it incorporated two phases, an isokinetic velocity spectrum protocol followed by work at 180°·s⁻¹ until one of three different levels of fatigue (90, 70, and 50% of peak hamstring torque) was reached. As previously stated, pilot work showed that this fatigue protocol produced mean RPE values of 10.25 \pm 1.46 during the mild fatigue condition, 13.37 \pm 1.26 for the moderate fatigue condition, and 17.81 \pm 0.76 for the maximum fatigue conditions. Given the novel nature of the fatigue protocol used in this study, direct comparison to previous research is difficult. Skinner et al. (1986) used a fatigue protocol that incorporated interval running on a track followed by 2 minutes of treadmill running at 7 mph at a 15% uphill grade, followed by a second treadmill session at a lower speed specifically aimed at fatiguing the hamstrings. Results from their study showed that reproduction sense was diminished following a maximum fatigue protocol. Although a different fatigue protocols was used, the current study did demonstrate a significant difference

between no fatigue and maximum fatigue. A recent study examining the effects of local and general fatigue on knee joint position sense found that localized fatigue to the thigh musculature via an isokinetic protocol did not effect angular error during joint reposition sense testing (Miura et al., 2004). The same study, however did demonstrate diminished joint position sense following a general fatigue protocol consisting of 5 minutes of running at 10 km/h at a 10% uphill grade.

The musculature of the thigh is typically composed of a higher percentage of fast twitch muscle fibers, which fatigue at a faster rate than slow twitch muscle fibers. Previous investigations have also found that fast-twitch muscle fibers have a greater type Ia afferent innervation as compared to slow-twitch fibers (Hortobagyi et al., 1996; Macefield et al., 1991; Mannion and Dolan, 1996; Tho et al.1997), suggesting that as muscle fatigue increases there will be a decrease in proprioceptive awareness, which could lead to a decrease in efferent responses.

One limitation of this study was the decision to assess fatigue only by measuring the decline of peak torque production in the hamstrings. The fatigue protocol used for this study involved concentric isokinetic actions of both the quadriceps and hamstrings. It is most likely that in addition to fatiguing the hamstrings, the quadriceps were also fatigued. The reason for choosing decreased peak hamstring torque as the measure of fatigue was based on the idea that fatigue of the hamstrings would lead to decreased sensory output of the muscle spindles associated with the hamstrings. Since muscle spindles are stretch receptors, decreased afferent output of the sensory organs in the posterior compartment of the thigh should lead to a decrease in proprioception, in particular joint position sense, with movements into extension.

In a study utilizing one of the same testing velocities as the current study, Marks and Quinney (1993) did not find a significant decrease in absolute angular error score following 20 consecutive concentric and eccentric quadriceps muscle actions at maximal voluntary effort at an angular velocity of 180 degrees·s⁻¹ in sedentary females. The current study found a significant difference between mild and maximum fatigue when compared to no fatigue. The different findings between the two studies may indicate that the hamstrings play a more important role in joint position sense during knee extension than the quadriceps. Further evidence of the importance of the hamstrings in knee position sense in extension may be indicated by the work of Skinner et al. (1986) as a portion of their fatigue protocol was designed to specifically target the hamstring muscles.

An additional limitation of the present study may have been that fatigue was counterbalanced for joint position sense testing. In a secondary review of the results, it

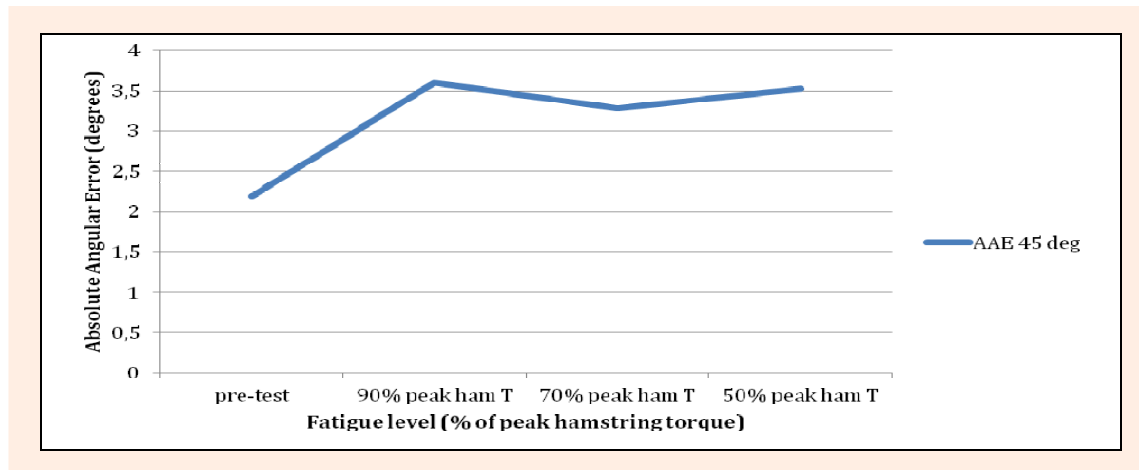


Figure 1. Potential plateau effect of absolute angular error by level of fatigue at 45 degrees of knee flexion. AAE = Absolute angular error.

appears that a plateau effect may have occurred for fatigue at a knee flexion angle of 45° (Figure 1). A true analysis of this phenomenon cannot be done at this time due to the counterbalancing of fatigue. Counterbalancing was intended to decrease the effect fatigue may have had on the statistical analysis of the data. Measuring AJRS in the order of pretest, then following 90%, 70%, and 50% of peak hamstring torque in that order may determine if a plateau effect occurred or if reproduction sense continues to decline as fatigue increases. This could provide a better understanding of how proprioception changes as fatigue increases during physical activity.

Skinner et al. (1986) speculated that decreased efficiency of muscle receptors could lead to decreased proprioceptive protection in joints. Increased fatigue of the hamstring muscle group may lead to a decrease in afferent output of the sensory organs on the posterior compartment of the leg. Decreased afferent output could diminish the effectiveness of the hamstrings from preventing anterior displacement of the tibia. This may have implications for noncontact injuries to the ACL, especially during running maneuvers that involve cutting.

Conclusion

In conclusion, the role of fatigue on proprioceptive abilities is unclear at this time. There is little information available regarding how proprioceptive abilities decline as a function of different levels of fatigue. The current investigation did find a main effect for fatigue at levels of mild and maximum fatigue. Future investigations should focus on examining if a plateau effect for joint position sense occurs as fatigue increases. An investigation examining the effect of increasing levels of exertion using methods that approximate sport activities may produce general fatigue of the musculature of the leg, which may provide a better understanding of how proprioception changes as muscle fatigue incrementally increases.

Acknowledgements

The present study did not receive support from internal or external funding agencies. The author does not have any conflicts of interest associated with this study.

References

- Barrack, R.L., Skinner, H.B., Brunet, M.E. and Cook, S.D. (1984) Joint kinesthesia in the highly trained knee. *Journal of Sports Medicine* **24**, 18-20.
- Beynon, B.D., Renström, P.A., Konradsen, L., Elmqvist, L.G., Gottlieb, D. and Dirks, M. (2000) Validation of techniques to measure knee proprioception. In: *Proprioception and Neuromuscular control in joint stability*. Eds: Lephart, S.M. and Fu, F.H. Human Kinetics. 127-138.
- Biodex System 3 Owners Manual (version 3.2). Biodex Medical Systems, Inc., USA
- Björklund, M., Crenshaw, A.G., Djupsjöbacka, M. and Johansson, H. (2000) Position sense acuity is diminished following repetitive low-intensity work to fatigue in a simulated occupational setting. *European Journal of Applied Physiology* **81**, 361-367.
- Borotikar, B.S., Newcomer, R., Koppes, R. and McLean, S.G. (2008) Combined effects of fatigue and decision making on female lower limb landing postures: central and peripheral contributions to ACL injury risk. *Clinical Biomechanics* **23**, 81-92.
- Bottaro, M., Ernesto, C., Celes, R., Farinatti, P.T.V., Brown, L.E. and Oliveria, R.J. (2010) Effects of age and rest interval on strength recovery. *International Journal of Sports Medicine* **31**, 22-25.
- Brand, R.A. (1989) A neurosensory hypothesis of ligament function. *Medical Hypotheses* **29**, 245-250.
- Clark, F.J., Grigg, P. and Chapin, J.W. (1989) The contribution of articular receptors to Proprioception with the fingers in humans. *Journal of Neurophysiology* **6**, 186-192.
- Douris, P.C. (1993) The effect of isokinetic exercise on the relationship between blood lactate and muscle fatigue. *Journal of Orthopedic Sports Physical Therapy* **17**, 31-35.
- Egan, A.D., Cramer, J.T., Massey L.L. and Marek, S.M. (2006) Acute effects of static stretching on peak torque and mean power output in national collegiate athletic association division I women's basketball players. *Journal of Strength and Conditioning Research* **20**, 778-782.
- Fitts, R.H. (1996) Muscle fatigue: the cellular aspects. *American Journal of Sports Medicine* **24**, S9-S13.
- Fitts, R.H. and Balog, E.M. (1996) Effect of intracellular and extracellular ion changes on E-C coupling and skeletal muscle fatigue. *Acta Physiologica Scandinavica* **156**, 169-181.
- Green, J.M., Crews, T.R., Bosak, A.M. and Peveler, W.W. (2003) Overall and differentiated ratings of perceived exertion at the respiratory compensation threshold: effects of gender and mode. *European Journal of Applied Physiology* **89**, 445-450.
- Grigg, P. (1986) Biophysical studies of mechanoreceptors. *Journal of Applied Physiology* **60**, 1107-1115.
- Hootman, J.M., Dick, R. and Agel, J. (2007) Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *Journal of Athletic Training* **42**, 311-319.
- Hortobágyi, T., Hamilton, J.T. and Lambert J. (1996) Fatigue effects on muscle excitability. *International Journal of Sports Medicine* **17**, 409-414.

- Huston, L.J. and Wojtys, E.M. (1996) Neuromuscular performance characteristics in elite female athletes. *American Journal of Sports Medicine* **24**, 427-436.
- Krauspe, R., Schmidt, M. and Schaible, H.G. (1992) Sensory innervation of the anterior cruciate ligament: an electrophysiological study of the response properties of single identified mechanoreceptors in the cat. *Journal of Bone and Joint Surgery* **74-A**, 390-397.
- Löscher, W.N., Cresswell, A.G. and Thorstensson, A. (1996) Central fatigue during a long-lasting submaximal contraction of the triceps surae. *Experimental Brain Research* **108**, 305-314.
- McCloskey, D.I. (1978) Kinesthetic sensibility. *Physiological Reviews* **58**, 763-820.
- Macefield, G., Hagbarth, K.E., Gorman, R., Gandevia, S.C. and Burke, D. (1991) Decline in spindle support to alpha-motoneurons during sustained voluntary contractions. *Journal of Physiology* **440**, 497-515.
- Mannion, A.F. and Dolan, P. (1996) Relationship between myoelectric and mechanical manifestations of fatigue in the quadriceps femoris muscle group. *European Journal of Applied Physiology* **74**, 411-419.
- Marks, R. and Quinney, H.A. (1993) Effect of fatiguing maximal isokinetic quadriceps contractions on ability to estimate knee-position. *Perceptual Motor Skills* **77**, 1195-1202.
- Miura, K., Ishibashi, Y., Tsuda, E., Okamura, Y., Otuska, H., and Toh, S. (2004) The effect of local and general fatigue on knee proprioception. *The Journal of Arthroscopic and Related Surgery* **20**, 414-418.
- Pincivero, D.M., Gear, W.S. and Sterner, R.L. (2001) Assessment of the reliability of high-intensity quadriceps femoris muscle fatigue. *Medicine & Science in Sports & Exercise* **33**, 334-338.
- Rozzi, S.L., Lephart, S.M. and Fu, F.H. (1999) Effects of muscular fatigue on knee joint laxity and neuromuscular characteristics of male and female athletes. *Journal of Athletic Training* **34**, 106-114.
- Sjölander, P., Johansson, H., and Djupsjöbacka M. (2002) Spinal and supraspinal effects of activity in ligament afferents. *Journal of Electromyography and Kinesiology* **12**, 167-176.
- Skinner, H.B., Wyatt, M.P., Hodgdon, J.A., Conrad, D.W. and Barrack, R.L. (1986) Effect of fatigue on joint position sense of the knee. *Journal of Orthopaedic Research* **4**, 112-118.
- Tho, K.S., Németh, G., Lamontagne, M. and Eriksson, E. (1997) Electromyographic analysis of muscle fatigue in anterior cruciate ligament deficient knees. *Clinical Orthopaedics and Related Research* **340**, 142-151.
- Wojtys, E.M., Wylie, B.B. and Huston, L.J. (1996) The effects of muscle fatigue on neuromuscular function and anterior tibial translation in healthy knees. *American Journal of Sports Medicine* **24**, 615-621.
- Zimny, M.L., Schutte, M. and Dabezies E. (1986) Mechanoreceptors in the Human Anterior Cruciate Ligament. *The Anatomical Record* **214**, 204-209.

Key points

- A repeated measures design was used to examine the effect of different levels of fatigue on active joint reposition sense (AJRS) of the knee at joint angles of 15°, 30° and 45° of flexion.
- A statistically significant main effect for fatigue was found, specifically between no fatigue and mild fatigue and no fatigue and maximum fatigue.
- A statistically significant interaction effect between AJRS and fatigue was not found.
- Secondary analysis of the results indicated a potential plateau effect of AJRS as fatigue continues to increase.
- Further investigation of the effect of increasing levels of fatigue on proprioception is warranted.

AUTHOR BIOGRAPHY

William S. GEAR

Employment

Assistant Professor, Health, Physical Education and Recreation Department. Program Director, Athletic Training Education

University of Minnesota Duluth

Degree

PhD

Research interests

Athletic training and sports medicine

E-mail: wgear@d.umn.edu

✉ William S. Gear, PhD, ATC

Department of Health, Physical Education and Recreation, University of Minnesota Duluth, 1216 Ordean Court, 105 SpHC, Duluth, MN 55812, USA