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Human Kinetics
ORIGINAL RESEARCH REPORT

Force Sense of the Knee Not Affected by Fatiguing the Knee Extensors and Flexors

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Context: Knee injuries commonly occur in later stages of competition, indicating that fatigue may influence dynamic knee stability. Force sense (FS) is a submodality of proprioception influenced by muscle mechanoreceptors, which, if negatively affected by fatigue, may result in less-effective neuromuscular control. ***Objectives:*** To determine the effects of peripheral fatigue on FS of the quadriceps and hamstrings. ***Design:*** Quasi-experimental study design. ***Participants:*** 20 healthy and physically active women and men (age 23.4 ± 2.7 y, mass 69.5 ± 10.9 kg, height 169.7 ± 9.4 cm). ***Interventions:*** Fatigue was induced during a protocol with 2 sets of 40 repetitions, and the last set was truncated at 90 repetitions or stopped if torque production dropped below 25% of peak torque. ***Main Outcome Measures:*** FS of the hamstrings and quadriceps was tested on separate days before and after 3 sets of isokinetic knee flexion and extension to fatigue by examining the ability to produce a target isometric torque (15% MVIC) with and without visual feedback (FS error). Electromyographic data of the tested musculature were collected to calculate and determine median frequency shift. *T* tests and Wilcoxon signed-rank tests were conducted to examine prefatigue and postfatigue FS error for flexion and extension. ***Results:*** Despite verification of fatigue via torque-production decrement and shift in median frequency, no significant differences were observed in FS error for either knee flexion (pre 0.54 ± 2.28 N·m, post 0.47 ± 1.62 N·m) or extension (pre –0.28 ± 2.69 N·m, post –0.21 ± 1.78 N·m) prefatigue compared with the postfatigue condition. ***Conclusions:*** Although previous research has demonstrated that peripheral fatigue negatively affects threshold to detect passive motion (TTDPM), it did not affect FS as measured in this study. The peripheral-fatigue protocol may have a greater effect on the mechanoreceptors responsible for TTDPM than those responsible for FS. Further investigation into the effects of fatigue across various modes of proprioception is warranted.

Keywords: proprioception, sensorimotor, neuromuscular, lower extremity

Epidemiological evidence indicates that fatigue increases the risk of musculoskeletal injury during the latter stages of athletic activity and competition.[1–8] There are multiple theories for why injuries occur under these conditions.[9–15] One potential mechanism is the impact of fatigue on the sensorimotor system or any of its subcomponents including the sensory, motor, and central integration necessary for the maintenance of functional joint stability.[16] Since peripheral fatigue occurs within the muscle and metabolic changes may affect the muscle spindle,[17] impaired muscle function may disrupt the proprioceptive information input from peripheral afferents in the muscle, including muscle spindles and Golgi tendon organs. Fatigue may also occur at the central nervous system level[18] and may negatively affect neuromuscular control and functional joint stability. The impact of fatigue on these mechanisms is important as it may play a role in musculoskeletal-injury risk in athletes and trained individuals.

Investigators have theorized many different mechanisms for fatigue and resultant injuries, including diminished muscle performance[17,19] and disrupted neuromuscular control.[20,21] Fatigue can influence joint kinematic and kinetic characteristics in a manner that may predispose an individual to injury by altering movement patterns and increasing joint forces, such as landing with significantly less knee flexion after fatigue.[11,20–24] Fatiguing exercise may result in alterations in electromyographic (EMG) characteristics during sport-specific tasks[22] and after joint perturbations.[25] Postural-control impairments have also been demonstrated in the frontal plane after fatigue of the knee and hip musculature and in the sagittal plane after fatigue of knee, hip, and ankle musculature.[26] The results of these studies indicate that fatigue may be related to changes in muscle-force production, increased knee-joint laxity, the accumulation of metabolic by-products, reduc-

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tion in muscle contractility, decreased muscle glycogen, muscle damage, viscoelastic changes, reflex inhibition, and changes in muscle stiffness.[12,14,15,17,22,25,27,28] The cumulative impact of these fatigue-related changes may be associated with the effects of fatigue on the underlying characteristics contributing to functional joint stability and increased risk of injury.

Another potential mechanism for the relationship between fatigue and injury is the effect that fatigue has on proprioception, which is essential for joint stability, as it provides the necessary afferent information for feedback and feedforward control.[16] Impaired proprioception can also cause a decreased ability to maintain postural stability. Lephart et al[29] previously demonstrated the relationship between proprioception and injury and its effects on joint stability during a systematic review of the role of the sensorimotor system in athletes' shoulders. A modification to this paradigm by substituting fatigue for ligament injury as the precipitating factor indicates the potential effects that fatigue has on proprioception, joint stability, joint laxity, and potential risk of injury (see Figure 1). Instead of a complete disruption of the static structures of the joint, as would be exhibited with ligament injury, fatiguing exercise has been previously demonstrated to cause deformation of the static components of the joint, as evidenced by increased joint laxity after fatigue, which negatively affects the mechanical stability of the joint.[30–32] A number of studies have demonstrated proprioceptive deficits after various modes of fatigue induction, with most focusing on joint-position sense (JPS) and threshold to detect passive motion (TTDPM).[14,22,33–37] Some studies have demonstrated decreased JPS of the knee after general fatigue,[34,37] while the effect of local fatigue on JPS of the knee has shown mixed results.[10,37] Other research has demonstrated significantly worse joint-angle reproduction but no changes in TTDPM of the knee after actively induced fatigue.[14] In contrast, significant changes in TTDPM in extension have been demonstrated after local isokinetically induced fatigue.[22] In a recent study,[28] JPS, TTDPM, and force sense were significantly affected by eccentric exercise. In addition, recent research has revealed that a concentric-eversion fatigue protocol alters force sense of the ankle in subjects with and without functional ankle instability.[38] The inconsistent results of these studies may be due, in part, to different fatigue protocols (local vs general, concentric vs eccentric contractions) and the use of active versus passive tests of proprioception. Force sense has not been studied as extensively as other proprioception modalities, but it may be the most important due to the importance of dynamic stabilization of the muscles through force production.

Force sense refers to a sense of resistance or heaviness[16] and is measured by testing the ability of subjects to replicate torque magnitudes produced by a group of muscles under varying conditions.[39] Force-sense examination attempts to assess the integrity of the muscle spindles and Golgi tendon organs at a specified effort,[39] as well as central processing, as the sense of effort is regulated centrally.[40] The 2 main sources hypothesized to affect force sense include the sense of tension generated by afferent feedback from the muscle and the sense of centrally generated effort.[41] Theoretically, if athletes have decreased force sense, they may have an increased risk of knee injury. While the Golgi tendon organs are sensitive to muscle tension, the muscle spindle is sensitive to rate and magnitude of length changes and is adjustable

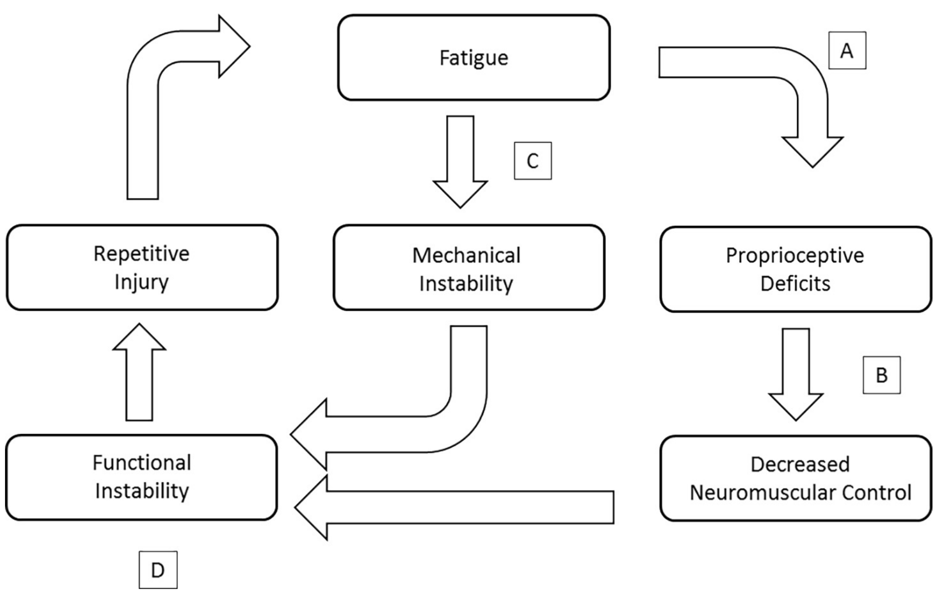

Figure 1 — Fatigue and injury paradigm. Fatigue has been demonstrated to cause (A) proprioceptive deficits, which contribute to (B) decreased neuromuscular control; fatigue may also affect (C) mechanical instability due to fatigue-related changes in joint tissues. These together contribute to (D) functional instability and ultimately may result in injury.

through γ-motor neurons.[16] In addition, increased muscle stiffness contributes to overall joint stiffness and plays an important role in functional joint stability[40] because it contributes to increased resistance to sudden joint displacements and more efficient transmission of loads to muscle spindles.[42] Therefore, force sense may play an important role during athletic movements such as landing, cutting, and jumping tasks.

Force sense likely plays an important role in the maintenance of functional joint stability under normal (nonfatigued) and fatigued conditions because the inability to produce an appropriate force may increase risk of injury. This study aimed to evaluate the effect of peripheral fatigue of the quadriceps and hamstrings on the ability to reproduce a reference force at the knee. We hypothesized that after the fatigue protocol, the ability to reproduce the target force for both movements would decrease. We also theorized that the fatigue protocol employed in the current study would successfully fatigue the knee musculature as evidenced by alterations in EMG activity and force production. Findings from this study may provide insight to the relationship between fatigue and force sense with regard to the potential for increased risk of injury due to altered and inadequate proprioception information.

Methods

Design

The study employed a quasi-experimental design with preintervention and postintervention measurements.

Participants

Healthy, physically active subjects age 18 to 30 years were recruited for participation. A subject was considered physically active if he or she participated in at least 20 to 30 minutes of activity at least 3 times per week and activity level was documented with a Tegner scale.[43] Subjects were included if they had no history of major knee injury or surgery and if they had had no recent lower-extremity injury (in the last 6 months). Subjects were excluded if they had insulin-dependent diabetes mellitus, rheumatologic disorder, cerebral vascular disorder, or any other central or peripheral disease that might interfere with sensory input; history of cardiovascular or pulmonary disease, uncontrolled metabolic disorder, compartment syndrome, or vascular condition of the lower leg; or was knowingly pregnant or had been pregnant within the past year. Subjects were also excluded if they had any pain during maximal muscle contraction, injury to the opposite knee, skin irritation or abrasion and/or history to allergy to adhesive tape, and known central and/or peripheral nervous system disorder. Recruitment took place across the university community via the investigators of the study and/or advertisement flyers. Written informed consent was obtained by the primary investigator or a coinvestigator before the administration of any research procedures. All study procedures were approved by the university's institutional review board.

Procedures

Subjects reported to the laboratory for three 1-hour testing sessions to investigate the influence of peripheral fatigue on the ability to reproduce a target force. All procedures were conducted on the dominant leg, defined as the preferred leg to kick a ball. A familiarization session was performed on day 1, where subjects were tested for maximal voluntary isometric contraction (MVIC), force sense, and isokinetic strength at 180°/s in both the flexion and extension directions. A detailed explanation of these procedures follows. On days 2 and 3, subjects underwent MVIC and force-sense testing of the quadriceps and hamstrings, respectively, before and after a local fatigue protocol. The quadriceps and hamstrings were tested on separate days, at least 7 days apart, to eliminate the effect of fatigue of one muscle group on the other. EMG data were collected during the fatigue protocol on days 2 and 3 of data collection.

MVIC and Force-Sense Protocol

Force-sense data were collected using the Biodex System 3 Multi-Joint Testing and Rehabilitation System (Shirley, NY) according to a previously used protocol.[22] Subjects were securely fastened in the test chair of the Biodex machine with the knee joint of the test limb aligned with the axis of rotation of the dynamometer and the distal lower limb secured to the dynamometer's test arm. Subjects were tested in the seated position with the knee at 45° of flexion so that the knee joint was at midrange. Subjects were provided a warm-up of 3 repetitions at self-perceived 50% maximal effort and 3 repetitions at 100% maximal force production before isometric testing. Subjects were then asked to extend or flex the knee with as much isometric force as possible for 5 seconds. Three repetitions of MVIC into extension or flexion were performed in a 5-seconds-on, 10-seconds-rest interval. The maximum torque produced for these trials was averaged as the mean MVIC.

Subjects were asked to extend or flex the knee keeping the target torque (15% MVIC) while receiving visual feedback from the computer monitor for 10 seconds (eyes-open condition; EO). The target torque of 15% MVIC was chosen because it was below the 25% fatigue criterion (described in the fatigue-protocol procedures) and would be reproducible after the fatigue protocol. Subjects were instructed to concentrate and remember the sensation of the force production and were then asked to reproduce the target torque for 10 seconds without the visual feedback from the monitor (eyes closed condition; EC). Five repetitions in extension (day 2) or flexion (day 3) were performed with visual feedback (EO) followed by reproduction without visual feedback (EC) on the dominant leg (10 repetitions in total). For force-sense data, means of all force-production/reproduction repetitions in flexion and extension were recorded. Mean force-sense error was defined as the relative difference between the reproduction value (EC) and reference value (EO) across all tests. The relative difference between visual-feedback and nonvisual-feedback trials was reported as force-sense error in Newton-meters (N·m).

Isokinetic Strength Testing

During the familiarization session, subjects completed 5 maximal repetitions of knee extension and flexion at a constant angular velocity of 180°/s to determine peak extension and flexion torque. These values were used to determine fatigue threshold during the isokinetic fatigue protocol. Subjects were provided a warm-up of 3 repetitions at self-perceived 50% maximal effort and 3 repetitions at 100% maximal force production before administration of this test.

Fatigue Protocol

The fatigue protocol was conducted immediately after the force-sense protocol and was based on a protocol previously used in our laboratory.[22] The fatigue protocol consisted of 3 bouts of isokinetic knee-extension and -flexion repetitions with 40-second rest intervals between bouts. The first and second bouts consisted of 40 maximal-effort repetitions, and during the third bout, subjects performed repetitions until the torque value of 3 consecutive repetitions fell below 25% of the initial knee-extensor (day 2) or -flexor peak torque value (day 3). If subjects did not reach fatigue in this manner, the third bout was truncated at 90 repetitions.[22]

After the fatigue protocol, the same force-sense protocol in extension (day 2) or flexion (day 3) was administered as described previously. The testing session was finished with MVIC testing as done in the beginning.

EMG Measurement

EMG activity was assessed with the Noraxon Telemyo System (Noraxon USA Inc, Scottsdale, AZ). Muscle activity of the vastus medialis, vastus lateralis, semitendinosus/semimembranosus, and biceps femoris was evaluated during the fatigue protocols using silver–silver-chloride, pregelled bipolar surface electrodes (Medicotest, Inc, Rolling Meadows, IL). These muscles were selected because of their physiological cross-sectional area and contribution to dynamic stability of the knee joint. The electrodes were placed over the appropriate muscle belly in line with the direction of the fibers, with a center-to-center distance of approximately 20 mm. A single ground electrode was placed over the proximal anterior tibia just medial to the tibial tubercle. To reduce impedance, electrode sites were shaved with an electric shaver, lightly abraded, and cleaned with 70% isopropyl alcohol. EMG signals from the electrodes were passed to a portable battery-operated FM transmitter worn by the subject and then sent to a receiver and stored on a computer for further analysis. Data were sampled at a rate of 1200 Hz and recorded with the Vicon Motus software package (Vicon Motion Systems, Inc, Centennial, CO).

Data Processing

Reduction and processing of EMG data were performed using a customized Matlab (Mathworks Inc, Natick, MA) script. All EMG signals were filtered using a band-pass filter (10–500 Hz). The absolute value of the band-pass-filtered EMG signal was calculated to rectify the data to compute integrated EMG. A low-pass Butterworth filter with a frequency cutoff of 20 Hz was applied to smooth the rectified data to obtain the linear envelope. A fast-Fourier transformation of the EMG data was performed to transform EMG data from the time domain into the frequency domain to calculate median frequency and analyze the changes in median frequency due to the protocol.

Statistical Analysis

The variables of interest for this study were force-sense error (ΔN·m) before and after the fatigue protocol, median frequency (Hz) of EMG activity during the first 3 and last 3 repetitions of the fatigue protocol, and torque production during the MVIC test (N·m) before and after the fatigue protocol. Shapiro-Wilk tests were used to assess assumptions of normality. Paired *T* tests were used to determine prefatigue-to-postfatigue changes in force-sense error and prefatigue-to-postfatigue MVIC in the flexion direction and in median frequency of the EMG data from the first 3 to the last 3 repetitions of the fatigue protocol. Since prefatigue and postfatigue force-sense error and prefatigue and postfatigue MVIC in the extension direction violated assumptions of normality, mean, SD, median, and interquartile range are presented for all variables, and Wilcoxon signed-rank tests were conducted to assess the changes from prefatigue to postfatigue. Alpha was set at $P < .05$ a priori. SPSS Statistics for Windows (SPSS Inc, Chicago, IL) version 17.0 was used for all analyses.

Results

Twenty subjects (10 men, 10 women; mean ± SD age 23.35 ± 2.70 y, height 169.73 ± 9.36 cm, weight 69.47 ± 10.92 kg, Tegner score 5.70 ± 1.30) completed the study. All but 2 were right-leg dominant.

Force-Sense and MVIC Results

Target forces, force replication in the EO condition, and force replication in the EC condition for both extension and flexion during prefatigue and postfatigue conditions are presented in Figure 2. No significant force-sense-error differences were demonstrated from prefatigue to postfatigue in extension or flexion (see Table 1). MVIC strength was significantly lower after the postfatigue force-sense measurement in both extension and flexion (see Table 1).

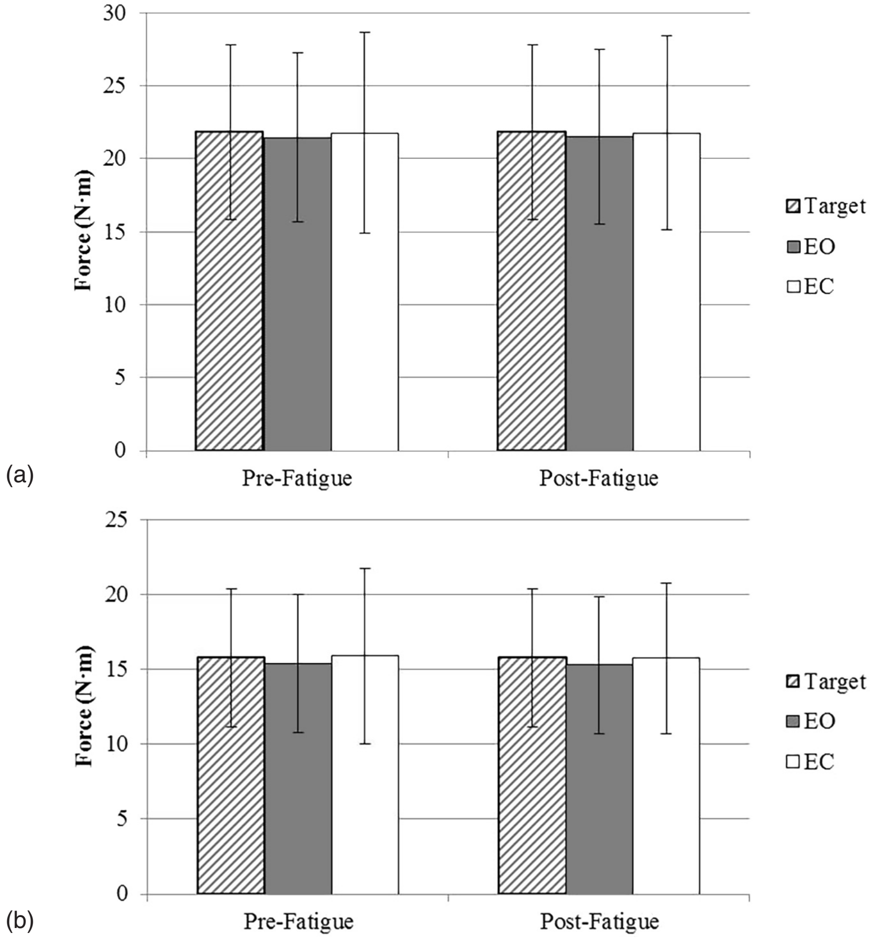

Figure 2 — No significant changes in force-sense error, calculated as difference between the visual-feedback (eyes open—EO) and no-visual-feedback (eyes closed—EC) conditions, from prefatigue to postfatigue in the (a) extension and (b) flexion directions.

Table 1 Prefatigue and Postfatigue Force-Sense Error (Δ N·m) and Mean Peak Maximal Voluntary Isometric Contraction (MVIC), N·m

	Prefatigue				Postfatigue				
	Mean	**SD**	**Median**	**IQR**	**Mean**	**SD**	**Median**	**IQR**	***P*[a]**
Force-sense error: extension	–0.28	2.69	–0.12	2.51	–0.21	1.78	–0.03	2.48	.940
Force-sense error: flexion	0.54	2.28	0.64	3.28	0.47	1.62	0.53	2.55	.907
Mean peak MVIC: extension*	145.47	40.08	133.30	38.40	131.34	32.65	116.90	41.40	.010
Mean peak MVIC: flexion**	105.06	30.57	96.65	51.50	87.69	23.40	81.50	38.60	.002

Note: Force-sense error is the relative difference between reference and reproduction forces. Mean peak is the average peak torque across 3 trials. Abbreviation: IQR, interquartile range.

[a] Changes in force-sense error and mean peak MVIC from prefatigue to postfatigue in flexion calculated with *t* tests and in extension with Wilcoxon signed-rank tests.

*Significantly different at the $P < .05$ level. **Significantly different at the $P < .01$ level.

EMG Results

Induction of fatigue was validated by assessing median frequency shift during EMG analysis during the first 3 repetitions of the fatigue protocol compared with the final 3 repetitions. Only 1 subject was truncated after 40/40/90 repetitions. The median frequency of the vastus medialis during the first 3 and last 3 repetitions of the fatigue protocol significantly decreased from 98.20 ± 12.88 to 74.73 ± 13.02 Hz ($P < .001$) and from 92.58 ± 11.07 to 57.62 ± 11.97 Hz for the vastus lateralis ($P < .001$) (see Figure 3[a]). The median frequency of the

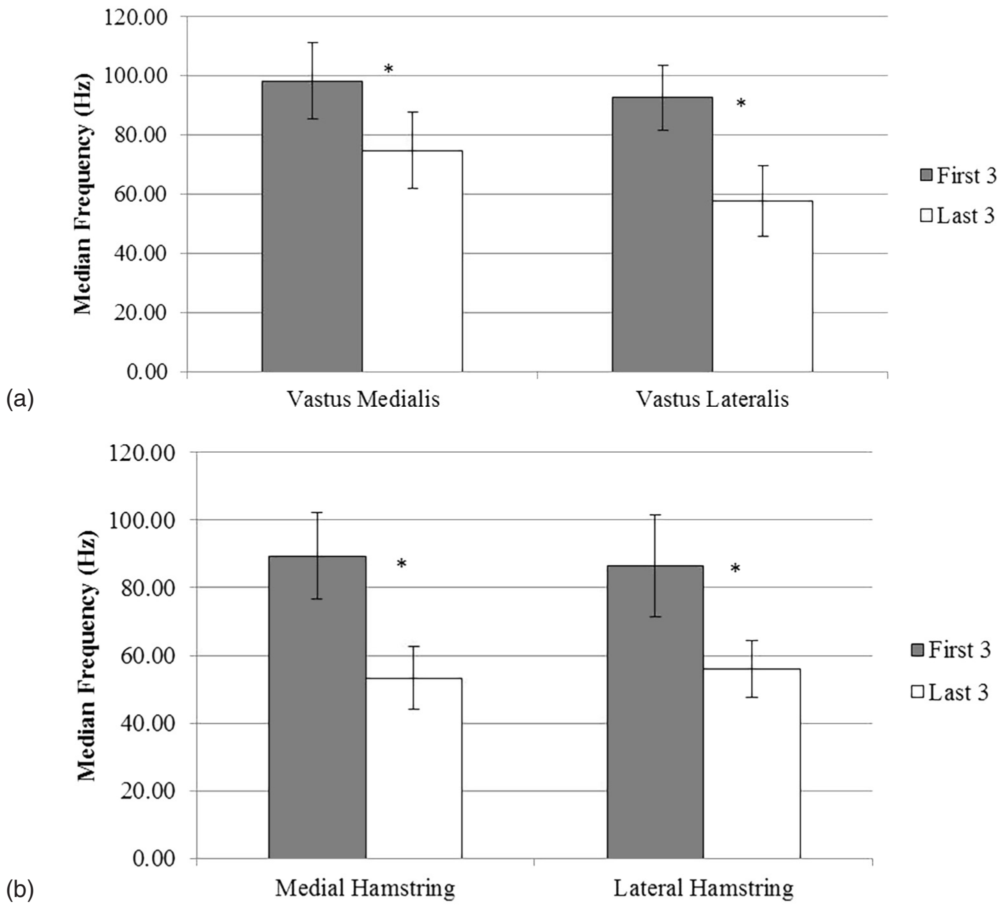

Figure 3 — Significant changes demonstrated in median frequency (Hz) of the (a) vastus medialis and vastus lateralis and (b) semitendinosus/semimembranosus (medial hamstring) and the biceps femoris (lateral hamstring) between the first 3 and last 3 repetitions of the fatigue protocol (both $P < .001$).

semitendinosus/semimembranosus during the first 3 and last 3 repetitions of the fatigue protocol significantly decreased from 89.30 ± 12.75 to 53.36 ± 9.17 Hz ($P < .001$) and from 86.56 ± 15.03 to 55.98 ± 8.40 Hz for the biceps femoris ($P < .001$) (see Figure 3[b]).

Discussion

The primary purpose of this study was to investigate the effects of quadriceps and hamstring fatigue on the ability to replicate a reference torque in the flexion and extension directions. Force sense was measured because it may play an important role during functional athletic tasks, as it is defined by a combination of sense of tension generated by afferent feedback from the muscle and the sense of centrally generated effort.[41] Since previous research has indicated that fatigue may have a negative impact on proprioception, we hypothesized that there would be decreased ability to reproduce a target force in the extension and flexion direction after fatiguing exercise. This hypothesis was based on the premise that fatigue creates both a decrease in force-generating capacity and a concurrent increase in effort, leading to reduced ability to reproduce or sense a target force, which is mediated both peripherally and centrally.

No significant differences in ability to reproduce force were noticed in the extension or flexion direction from prefatigue to postfatigue, even though a fatigue effect was evidenced by a reduced median frequency measured by EMG. These results indicate that the fatigue protocol we employed did not have an effect on force sense as measured in the current study. In this study, muscle fatigue was induced by a fatigue protocol designed to provide localized fatigue to the quadriceps and hamstrings via sets of repetitive, reciprocal concentric isokinetic contractions. The protocol was deemed adequate to produce muscle fatigue, as fatigue has been defined as a decrease in the maximum force-generating capacity of the muscle[44,45] and results demonstrated reduced median frequency during EMG analysis from the first 3 to last 3 repetitions of the fatigue protocol and significantly reduced MVIC-force production in extension and flexion after the posttest force-sense assessments.

A previous investigation by Rozzi et al[22] investigating the effects of fatigue on kinesthesia elicited fatigue using the same protocol as the current study, with fatigue established when the subject performed 3 consecutive repetitions below 25% of the initial knee-extensor peak torque value. Kinesthesia was evaluated before and after fatigue using TTDPM of the knee joint. Both men and women showed a trend toward decreased ability to sense joint motion in both flexion and extension, with women experiencing significantly worse TTDPM in the extension direction after fatigue. In addition, Rozzi et al[22] noticed an increase in onset time of contraction for the semimembranosus and lateral gastrocnemius muscle in response to a postfatigue jump landing, suggesting that the muscle activity of the dynamic stabilizers of the knee was compromised and may have contributed to the proprioceptive deficits after fatigue.

A potential reason for the lack of differences in force sense after fatigue may be the nature of the fatigue protocol used and how it may affect the sensorimotor system. The current study implemented a local fatigue protocol similar to that of Miura et al,[37] which consisted of 60 consecutive maximum concentric contractions of the knee extensors and flexors on an isokinetic dynamometer at 120°/s. While Miura et al[37] evaluated proprioception via JPS, they found no significant differences in proprioception after a locally applied fatigue protocol despite a significant decrease in peak extensor and flexor torque, but they did observe significantly worse JPS after a general fatigue protocol despite no strength loss.[37] In this case, perhaps the peripheral fatigue protocol did not produce enough motor-control deficits at the level of the central nervous system to produce JPS deficits compared with the general fatigue protocol. Likewise, we found no significant differences in force sense after a fatigue protocol with a greater number of sets to fatigue (3) with a greater number of repetitions (40/40/90) at a faster rate (180°/s), despite a significant shift in EMG median frequency and decreased MVIC-force production. Since force sense and JPS are active tests of proprioception and rely on both central and peripheral motor programming,[37] it is possible that the central programming might be more important than peripheral fatigue in controlling force sense. Furthermore, studies that have used general fatigue protocols as opposed to local fatigue protocols have demonstrated significant proprioceptive deficits, emphasizing the negative impact of centralized fatigue on the sensorimotor system.[34,37]

The type of contractions implemented during the peripheral fatigue protocol may also have influenced the results of the current study. Ju et al[33] used a local fatigue protocol of maximum concentric and eccentric contraction of the quadriceps at 120°/s for 60 repetitions and found significantly decreased JPS postfatigue. Furthermore, Torres et al[28] used sets of 30 eccentric contractions at 60% of maximal concentric peak torque at 60°/s and found diminished proprioception measured by JPS, TTDPM, and force sense to varying degrees immediately after to 48 hours postfatigue. Proske et al[41] examined force sense after eccentric muscle fatigue of the elbow flexors and found that maximal voluntary contractions remained below control values for 3 days. Notably, force errors up to 14% of the preexercise MVIC were found after fatigue. Therefore, perhaps muscle damage elicited by localized eccentric fatigue caused the decline in proprioception noted by these researchers. Perhaps concentrically induced muscle fatigue alone was not enough to induce proprioceptive changes in our study and others using similar fatigue protocols. Brockett et al[46] proposed that muscle damage produced by eccentrically induced fatigue may activate tendon organs and create a perception of a higher level of force in the muscle than was really generated, resulting in impaired force-sense estimation after eccentric fatigue. In addition, eccentric contractions are important for knee stability during functional activities, especially during deceleration.[47] Future investigations might assess the effect of different types of fatigue on force sense, including eccentric contractions, as well as functional fatigue protocols that more closely mirror training and game scenarios.

A limitation of this study is the large standard deviations exhibited for force-sense error. The large standard deviation compared with the mean error may be attributed to the fact that we assessed relative rather than absolute error. The large variance in the data set likely contributed to the absence of significance changes in force-sense error from prefatigue to postfatigue. Another limitation of this investigation is that our study sample consisted of both genders. Although force-sense outcomes did not differ between genders in the current study, research is equivocal regarding the effect of fatigue on proprioception between genders,[22,34,37] and research has implied that women may have greater resistance to skeletal-muscle fatigue than men,[45,48–50] so future studies may specifically address gender differences in force sense after fatigue.

Conclusion

This study has found that although muscle activation is decreased after local, concentrically induced fatigue of the knee flexors and extensors, proprioception measured by force sense is not affected. Future research may examine the effect of various fatigue protocols on force sense and other neuromuscular risk factors for knee injury, such as time to peak force generation, as well as kinetic and kinematic characteristics during landing and other functional tasks. These fatigue protocols may involve general fatigue, as well as mimic specific mechanisms found in sport and game activities, such as cutting, planting, and quickly changing direction. Future studies may also establish and compare the relationship between maximal force production and force sense after various methods of fatigue induction. Overall, additional research is warranted to investigate the implication of fatigue on the ability to detect force production to obtain a more thorough understanding of injury mechanism in athletes.

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