International Journal of EXERCISE SCIENCE

Original Research

The Effect of Foam Rolling of the Hamstrings on Proprioception at the Knee and Hip Joints

ERIN DAVID†, TAL AMASAY‡, KATHRYN LUDWIG‡, and SUE SHAPIRO‡

College of Nursing and Health Sciences, Barry University, Miami Shores, FL, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 12(1): 343-354, 2019. The purpose of this study was to determine the acute effect of hamstring foam rolling on proprioception at the knee and hip joints. Twenty-five participants completed two proprioceptive tests on separate days, in a random order. The joint position matching test used no visual feedback. Participants were verbally guided to a target lunge position, which was maintained for six seconds while right hip and knee angles were recorded. After rest, participants reproduced this position without guidance for six seconds. Three trials were completed at baseline, and zero, 10, and 20 minutes post-intervention. In the force matching test, participants completed three trials with feedback about force output from a graph, and three trials without. They gradually applied knee flexion force against the dynamometer until reaching target force output. This test was also completed at baseline, and zero, 10, and 20 minutes post-intervention. A significant main effect was found for absolute knee position matching error ($F(1.97, 47.36)$, $p = 0.004$). No significant differences were found between post-intervention values at zero and 10 minutes, zero and 20 minutes, or 10 and 20 minutes for absolute hip position matching error or absolute knee force matching error at zero, 10, or 20 minutes ($p > 0.05$). Foam rolling improved knee joint position sense for at least 20 minutes post-intervention, and did not decrease hip joint position sense or knee joint force sense. This indicates that foam rolling may be used immediately prior to exercise without the risk of injury due to proprioceptive deficits.

KEY WORDS: Joint position matching, force sense, self-myofascial release, knee torque

INTRODUCTION

Due to the physically demanding nature of exercise, the risk for sustaining an injury is always present. Although awareness of external factors plays an important role in detecting potential threats to safety, awareness of the body itself is just as crucial in the prevention of injury. Proprioception is the source of sensory information responsible for this bodily awareness. Components of proprioception include joint position and movement sense, the sensation of tension or force within muscles, the sense of effort, and the sense of balance (28, 31).

There are five main types of receptors that provide proprioceptive information to the central nervous system: vestibular apparatus, joint receptors, muscle spindles, Golgi tendon organs, and cutaneous receptors (31). The vestibular apparatus is located in the inner ear. It detects acceleration and the orientation of the head in space (31). The vestibular apparatus is especially important in the balance component of proprioception (31). Muscle spindles are another type of proprioceptor, located in parallel with the fibers of skeletal muscle (31). Hall and McCloskey (9) suggested that changes in fascicle length can be detected by the muscle spindles and reported to the central nervous system, thus giving muscle spindles an important role in detection of movement and joint position as muscles change length throughout the range of motion (ROM). Joint receptors also play a role in detecting joint position, mostly at the end ranges of motion (31). The golgi tendon organs are located within the tendons of the body, and are most involved in monitoring muscle tension and force (31). Cutaneous receptors, located within the skin, are important in sensing touch, pressure, and deformation of the skin (31).

During exercise, the body is often subjected to unanticipated perturbations, such as a push or shove, which require quick adjustments to the movement pattern to avoid injury. If unable to see the source of a perturbation, individuals must rely on proprioceptive information about the body to make these needed changes (29). For this reason, proprioception can play a large role in the prevention of injuries. It has been demonstrated that a proprioceptive training program can decrease the incidence of several types of injuries due to improved motor control and joint stability, including hamstring strains (15), ankle sprains (7, 23, 30, 38) and anterior cruciate ligament tears (3, 21).

In addition to proprioceptive training programs, manual therapeutic interventions have been shown to improve proprioception. One such intervention is massage, which has previously proven effective in improving joint position sense (12, 32). Henriksen et al. (12) attributed their proprioceptive improvements to the fact that massage acts on muscle spindles and cutaneous receptors, which are considered the main proprioceptors responsible for joint position sense.

Static stretching (sustained stretching in a stationary position) is another intervention that has previously improved proprioception, both in terms of joint position sense (8) and balance (5). Dynamic stretching (movement-based stretching) has also previously improved balance-related measures of proprioception and was even shown to be significantly better for improving proprioception than static stretching or combined static-dynamic stretching (1).

Less is known about the effect of interventions such as foam rolling on proprioception. A foam roller is a cylindrical tool that is often used to break down scar tissue and relieve muscle tightness. During treatment, body weight is used to apply pressure on the muscle being treated as the body glides back and forth over the roller (20). The foam roller can have several different textures or foam densities that allow for individuals to control the intensity of the intervention. Investigations have been made into the effects of foam rolling on various outcomes, such as: ROM (14, 20, 22, 24, 33, 39) muscular strength (19, 20, 11, 25, 26, 27, 35) and muscular power (27, 19, 26, 11, 13).

Improvements in ROM following foam rolling seem to be relatively consistent throughout the literature. At the ankle joint, Kelly and Beardsley (14) found that ROM improved following foam rolling of the calf musculature, despite previous findings that foam rolling alone did not produce significant improvements (33). Significant increases in knee joint ROM were identified following foam rolling of the quadriceps (20, 39) and hamstrings (22). ROM also increased at the hip joint following foam rolling of the quadriceps (39) and hamstrings (24).

Most studies investigating the effects of foam rolling on strength indicate that foam rolling does not diminish strength (2, 11, 19, 20, 25, 35), while several other studies have found evidence to support strength improvements following a foam rolling intervention (19, 26, 27, 35). Unfortunately, limited explanation of these findings was provided. Similar trends were noted for measures of power following a foam rolling protocol. Several studies demonstrated that foam rolling either improves power (19, 26, 27) or has no effect on power (11, 13). It was suggested that foam rolling dramatically increases neural stimulation, which can increase firing rate and patterning of muscle fiber recruitment (19, 26).

The effect of foam rolling on proprioception is far more unclear than its effect on other variables, due to the limited body of literature on the topic. Cho and Kim (4) is the only study to date that has examined the effect of foam rolling on proprioception. In addition to improvements in sit-and-reach test performance, they found that foam rolling of the hamstring muscles once a day led to significant improvements in joint position sense of the hip after one week of treatment (pre-intervention absolute error was 3.57° ± 2.49°, post-intervention absolute error was 1.41° ± 1.30°, which was assessed using a joint position matching task (4).

Although Cho and Kim (4) chose to examine effects on proprioception after one week of treatment, information is also needed about the immediate effects of foam rolling. Interventions that are utilized for similar purposes, including massage and stretching protocols, have demonstrated the ability to significantly improve proprioception (1, 5, 8, 12, 32). It would follow that foam rolling should have a similar effect, but this still needs to be tested. Previous research makes a decrease in proprioception seem unlikely (1, 5, 8, 12, 14, 20, 22, 32, 39). Foam rolling is frequently used as part of a warm-up before exercise, and for many, foam rollers are used on the sidelines periodically during the exercise routine. If foam rolling were to acutely decrease proprioception, which may lead to a deficit in motor control and joint stability, it may impair one's ability to detect and respond to changes in their immediate environment, increasing the risk for injury by exercising immediately after the intervention.

If there is a change in proprioception following the foam rolling intervention, it is also important to understand how long these effects last. In contrast, if there is an improvement in proprioception, individuals should know when the effect wears off. Previous studies examining the acute effects of foam rolling on ROM have found that the effects can last for at least 10-20 minutes (14, 20), but there are currently no studies that measure how long the acute effects on proprioception will last.

It seems that most of the literature on the proprioceptive effects of foam rolling and similar interventions focuses on joint position sense (4, 8, 12, 32). Joint position sense is just one of several components of proprioception (28, 31). For this reason, it may be of interest to examine whether foam rolling causes similar changes to occur for other components of proprioception, such as force sense.

Another way to expand the literature in this topic area would be to identify whether proprioceptive changes after foam rolling follow similar trends from one joint to another. For instance, Cho & Kim (4) focused their study solely on the hip joint after hamstring foam rolling. Since the hamstring is bi-articulate muscle, attaching at both the hip and knee, it is important to see if the changes at the hip joint occur at the knee joint as well since the hip joint is structured differently, has several more degrees of freedom (planes of movement), and a greater number of muscles surrounding the joint to influence proprioception.

The purpose of the current study is to determine the immediate effect of two 1-minute bouts of hamstring foam rolling on proprioception at the knee and hip joints. It was hypothesized that the foam rolling intervention would decrease absolute knee position matching error, absolute hip position matching error, and absolute knee torque matching error compared to baseline after zero, 10, and 20 minutes.

METHODS

Participants
Twenty-five healthy students served as participants in this study (Table 1). Participant selection criteria and experimental methods were approved by the Barry University Institutional Review Board. Participants were eligible to participate if they were physically active at least three days per week for the past six months. Exclusion criteria included previous hip or knee pathologies requiring surgery or performance-limiting lower-extremity injuries within the past year. Participants were asked to refrain from performing any lower body exercises 24 hours prior to data collection sessions.

Table 1. Physical characteristics of participants.

	# of Participants	Age ± SD (years)	Height ± SD (cm)	Weight ± SD (kg)
Males	9	23.44 ± 2.24	174.44 ± 7.59	90.23± 15.39
Females	16	22.56 ± 2.25	166.53 ± 8.32	70.65 ± 20.18
All	25	22.88 ± 2.24	169.38 ± 8.80	77.70± 20.63

Protocol
Upon arrival for the first session, participants were asked to sign a consent form. They also filled out a questionnaire regarding their injury history and demographic information. Height was then measured with a wall-mounted Seca stadiometer, while weight was assessed using a Seca 780 digital scale (Seca GMBH & Co. Kg., Hamburg, Germany). Each participant performed two proprioception tests, the joint position matching test (JPMT) and the force matching test (FMT). The JPMT and FMT were performed in separate sessions (at least five days apart), in a randomly determined order. For the JPMT, an 8-camera Vicon motion capture system (Vicon Motion Systems, Oxford, UK), with a sampling frequency of 240 Hz, was used to collect 3D kinematic data, which were processed using Vicon Nexus 2.5 software. Anatomical coordinates and segments were defined according to the Vicon Plug-in-Gait model using 16 pearl reflective markers (14 mm). As required by the Plug-in-Gait model, participant's leg length, knee width,

and ankle width were measured bilaterally. Markers were placed bilaterally over the following landmarks: anterior superior iliac spine, posterior superior iliac spine, lateral thigh, lateral knee joint line, lateral aspect of the fibula, lateral malleolus, calcaneus, and dorsal aspect of the second metatarsal base. In the FMT, the Biodex System 3 Isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA) was used to collect joint kinetic data. Prior to each test the participants performed a warm-up, consisting of five minutes on a stationary bicycle at a resistance of one kp and an intensity of 60 RPM (20).

For each trial of the JPMT, the participant began blindfolded in a forward lunge stance, with the right leg in the front. The participant was verbally guided to the target lunge position. The right knee was flexed approximately 25˚-35˚ from the vertical plane, as assessed using Vicon Nexus. After the knee was at an appropriate angle, the hip angle was adjusted by the participant moving the trunk forward 25°-35° from the vertical plane. Hip angle was assessed with a goniometer. Once the target lunge position was achieved, the participant was instructed to hold the position for six seconds while concentrating on the knee and hip angles. Knee and hip joint positions were recorded with the Vicon motion capture system during this time. This position was chosen since it is functional (mimicking joints positions in running or changing direction) and requires each participant to be weight bearing on the lower extremities. Weight bearing joint position matching tasks have previously been shown to be more reliable than non-weight bearing tasks (34). Moreover, shallow hip and knee angles were chosen for testing to minimize fatigue.

After the target lunge position was achieved, the participant was instructed to return to the starting position. Three seconds later, the participant was asked to reproduce the target lunge position without guidance. Once the participant thought that the target lunge position was matched, the participant signaled the investigator. The investigator then recorded the reproduced position as participant maintained it for six more seconds. This protocol was repeated two more times with 15 seconds of rest between trials (total of three trials).

After three pre-intervention JPMT trials, participants completed the foam rolling intervention on the floor using a protocol similar to that used by MacDonald et al. (20). Participants began by placing a 6 in x 12 in high-density foam roller (Yes4All, Anaheim, CA, USA) under the right hamstring muscle group proximally at the ischial tuberosity. The left leg was crossed over the right leg during the foam rolling procedure. Using the arms to move the body over the foam roller, participants used short, kneading motions to gradually move the roller down the hamstring muscles. Once the foam roller reached the distal attachments of the hamstring muscles at the knee, participants moved the roller back to the ischial tuberosity in a single, fluid motion. This process was repeated three to four times during each 1-minute bout of foam rolling. Two 1-minute bouts were completed during the foam rolling intervention, with 30 seconds of rest between bouts. After foam rolling, participants completed a post-intervention JPMT at zero, 10, and 20 minutes post-intervention.

In the FMT, the participant was in a seated position on the Biodex Isokinetic dynamometer with the knee in a 30˚ of flexion and the hip in a 55˚ of flexion, with respect to the vertical plane. These specific hip and knee angles were chosen based on previous research which found that hamstring strains tend to occur during the terminal swing phase of sprinting when the hip is flexed to 55-65° and the knee is flexed at 30-45° (36).

Following the warm-up, each participant's mean peak isometric force was then determined using the Biodex. At the beginning of each trial, participants were prompted to apply maximal effort force against the Biodex's stationary dynamometer attachment in the direction of knee flexion. Participants tried to maintain this maximal force output for six seconds as the force output was recorded. Participants were given 30 seconds of rest between the maximal force trials. This procedure was repeated two more times followed by a 5-minute break. Once the test was completed, the mean peak force for the three test trials was obtained. Twenty percent of each participant's mean peak force was calculated and served as the target force for all trials of the FMT (37).

Following the 5-minute break, participants were familiarized with the FMT protocol. Each participant was given at least one practice trial with and without visual feedback from the computer. These trials were not recorded and were repeated until participant felt comfortable with the test procedure. After familiarization, participant was given an additional minute of rest before starting the baseline FMT.

Each FMT consisted of three trials with visual feedback regarding force output, and three trials without visual feedback (37). Throughout each visual feedback trial, the Biodex computer screen displayed a graph of their force output. Participants gradually applied force against the stationary dynamometer attachment, in the direction of knee flexion, until the graph indicated that the participant had reached their previously determined target force output. At this point, the participant would try to maintain their target force output for six seconds while data were collected. Participants would then rest for six seconds before beginning the next visual feedback trial (37). At the end of the third visual feedback trial, a 1-minute rest period was allowed.

Three more trials were completed without visual feedback from the graph. For these three trials, participants would signal when they thought they had reached their target force output. At that point, the 6-second trial was recorded, followed by six seconds of rest between trials (37). After all six pre-intervention FMT trials had been completed, participants carried out the same hamstring foam rolling protocol described previously (20). Additional FMT trials were completed using the pre-intervention protocol at zero, 10, and 20 minutes post-intervention.

Statistical Analysis

Performance on the JPMT was indicated by absolute knee position matching error (AKPME) and absolute hip position matching error (AHPME). For each 6-second trial, the middle two seconds were used for analysis. For each trial of the JPMT, the differences in knee and hip angles between the target and reproduced lunge positions were calculated. The mean of these differences at the knee and hip for each testing time served as the AKPME and AHPME at those times.

Performance on the FMT was represented by absolute knee force matching error (AKFME). The middle two seconds of each 6-second trial was used for analysis. The average force output for the three trials with visual graph feedback were compared to the average force output for the three trials without visual graph feedback. The difference between these two average values at each testing time served as the AKFME at those times.

Statistics were calculated using SPSS Statistics Software Version 21 (IBM, Armonk, New York, USA). Three separate one-way repeated measures ANOVA tests were performed to determine the effect of the foam rolling intervention on AKPME, AHPME, and AKFME at four different times: pre-intervention, post-intervention at Zero minutes, post-intervention at 10 minutes, and post-intervention at 20 minutes. When a significant main effect was found, a follow-up paired samples t-test was conducted. An alpha level of 0.05 was used to determine significance level.

RESULTS

There was a significant main effect for AKPME ($F(1.97, 47.36)$, $p = 0.004$) (Figure 1), indicating that knee joint position sense was more accurate following the foam rolling intervention. No significant differences were found between post-intervention values at zero and 10 minutes, zero and 20 minutes, or 10 and 20 minutes ($p > 0.05$). This demonstrates that the knee joint position sense improvements remained constant for at least 20 minutes post-intervention.

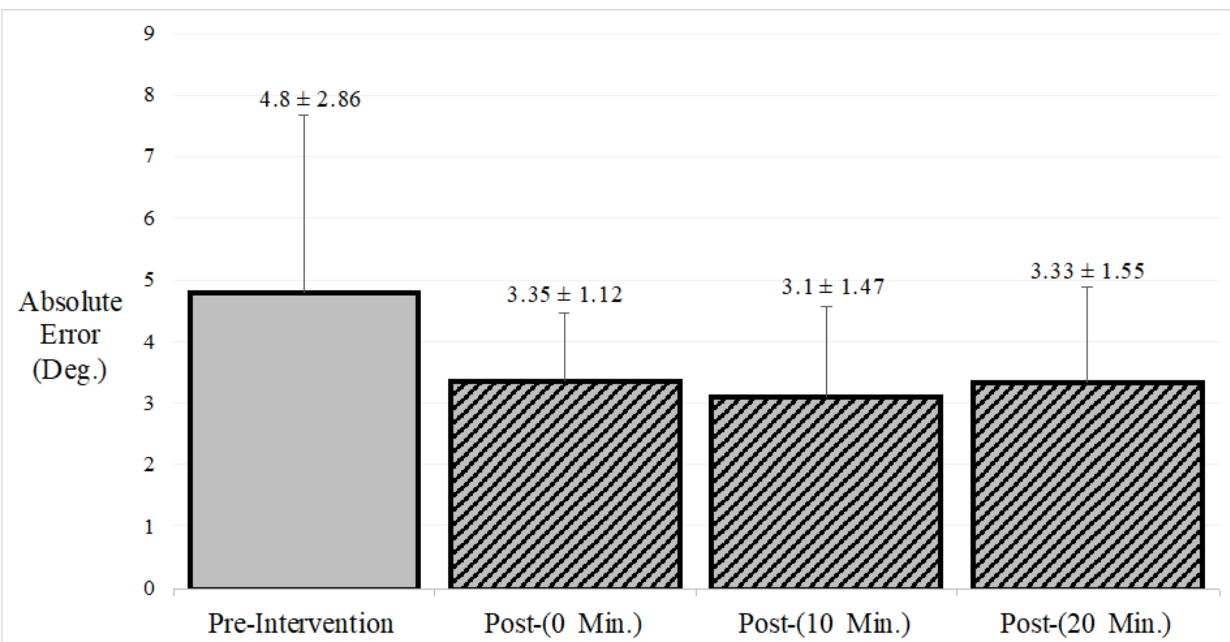

Figure 1. Absolute knee position matching error (AKPME) values before and after a foam rolling intervention. A striped pattern indicates significant difference from pre-intervention AKPME ($p < 0.05$). Post-intervention values did not significantly differ from each other.

No significant main effects were found for AHPME ($F(2.42, 58.21)$, $p = 0.24$) or AKFME ($F(3, 72) = 1.39$, $p = 0.25$). Hence, no significant differences were observed between pre-intervention and post-intervention hip joint position sense or knee joint force sense at zero, 10, or 20 minutes (Table 2).

Table 2. Mean AHPME and AKFME before and after a foam rolling intervention.

	Pre-Intervention	Post-(0 min.)	Post-(10 min.)	Post-(20 min.)
AHPME (± SD)	1.83 ± 0.98°	1.61 ± 0.81°	1.46 ± 0.67°	1.81 ± 0.71°
AKFME (± SD)	4.74 ± 3.10 N*m	3.71 ± 2.53 N*m	3.86 ± 2.81 N*m	3.69 ± 2.31 N*m

No significant differences were found between pre-intervention and post-intervention values of AHPME or AKFME at zero, 10, or 20 minutes. AHPME = Absolute hip position matching error. AKFME = Absolute knee force matching error.

DISCUSSION

The purpose of this study was to determine the acute effect of hamstring foam rolling on proprioceptive test performance. The JPMT was used to measure AKPME and AHPME. AKPME significantly decreased compared to pre-intervention values at zero, 10, and 20 minutes post-intervention, providing some support for our initial hypothesis. Massage and stretching interventions have also demonstrated the ability to immediately increase joint position sense (8, 12, 32). This increase has previously been attributed to the stimulation of muscle spindles (8, 12). Since foam rolling combines elements of both interventions, it seems logical that foam rolling would improve joint position sense by a similar mechanism.

No significant increase in AHPME was found in the current study. This is in contrast with Cho & Kim (4), who found that hip joint position sense improved significantly following a foam rolling intervention. The contrasting results may be related to the differences in methodology. In their study they tested hip joint position sense after one week of foam rolling use, whereas the current study focused on immediate effects. It is possible that the single session of foam rolling used in the current study was not enough to elicit a significant neurological response at the hip. However, similar finding in post intervention results were identified in both studies. The current study found post-intervention absolute error for the hip joint position matching test to be 1.61° ± 0.81° at zero minutes, 1.46° ± 0.67° at 10 minutes, and 1.81° ± 0.71° at 20 minutes. These values are very close to the post-intervention absolute error value of Cho & Kim (4) after one week, which was 1.41° ± 1.30°. One should also consider the fact that absolute error differs between these two studies at baseline. Cho & Kim (4) calculated pre-intervention absolute error to be 3.57° ± 2.49°, whereas the current study error was only 1.83° ± 0.98°. Since baseline values were already so low in the current study, perhaps this could explain the lack of significant differences between pre-intervention and post-intervention hip joint position sense that were seen by Cho & Kim (4).

For the force sense test, the current study found no significant differences between pre-intervention AKFME values or post-intervention AKFME values at zero, 10, or 20 minutes. Previous research by Li, Ji, Li, & Liu (18) indicated that force sense was not correlated with joint position sense. The explanation the investigators put forth was that force sense testing acts on the golgi tendon organs within the tendons, while the joint position sense test acts on golgi tendon organs and muscle spindles within the belly of the muscle (18). The intention of the foam rolling intervention was to stimulate receptors from origin to insertion of the hamstring muscle, including those within the tendons. Since the hamstring group consists of muscles with very large muscle bellies however, it is likely that a longer portion of the foam rolling intervention was spent on stimulating the muscle spindles. This could explain why significant improvements in knee joint position sense were identified in the current study, while force sense showed no such improvements.

There were a few limitations to this study. It is possible that there was a small learning curve that may have affected the results of the study. Most participants had never heard of the joint position matching test or the force sense test but were given a few attempts to familiarize themselves with the testing protocols in the few minutes prior to data collection. In a literature review by Han, Waddington, Adams, Anson and Liu (10), it was suggested that giving participants only a few opportunities to familiarize themselves with proprioception test protocols prior to data collection may lead to a learning effect and inaccurate data. They did not provide any evidence of previous studies that had found a learning effect, however. Another study by Dover and Powers (6) conducted both joint position sense and force sense tests. Although they initially worried that a learning curve would affect their data, their results indicated that this was not the case. To minimize the effect of a learning curve in our study in both test we have used the same position and had the participants practice prior to data collection. Another limitation pertains to the participants who participated in the study related to differences between gender. In one study, men had greater proprioceptive acuity than women in a weight-bearing proprioceptive test (16). There were 16 women and nine men who participated in this study. The greater number of women, who could have had poorer proprioception than the men, may have skewed the data. However, this was not the current study hypothesis.

Further research is needed to identify the implications of the findings in the current study. It is uncertain if the improvement in AKPME would be enough to prevent an injury. Previous research has shown that proprioceptive training increases proprioception enough to decrease the incidence of injuries (3, 7, 15, 21, 23, 30, 38), however, two bouts of foam rolling may not cause the same degree of proprioceptive improvement. Furthermore, the effect of foam rolling on supporting the injury rehabilitation process should be addressed. Previous studies have suggested that interventions like massage may be used prior to physical therapy sessions to improve motor performance (12). It has also been emphasized that improving proprioception is essential for re-gaining motor control following an injury (17). Perhaps the completion of foam rolling intervention prior to rehabilitation session, may increase motor performance enough to make the completion of exercises easier. This would allow individuals to challenge themselves during rehabilitation sessions, which may help them to progress more quickly through the rehabilitation process. Since the knee joint position sense improvements lasted at least 20 minutes in the current study, the increases in proprioception would likely assist performance in exercises throughout most, if not all, of a rehabilitation session. Lastly, research should aim to investigate the effects of foam rolling on proprioception between men and women.

It is still not entirely clear whether foam rolling will consistently improve proprioception between individuals, gender, joints, or muscles, although the current study did find that foam rolling of the hamstring can improve knee joint position sense. Moreover, the fact that there were no significant increases or decreases in AHPME or AKFME, is also noteworthy. This study may conclude that foam rolling does not diminish proprioception at the knee and hip, meaning that the likelihood of injury due to the proprioceptive effects of this intervention is unlikely.

REFERENCES

1. Amiri-Khorasani M. Acute effects of different stretching methods on static and dynamic balance in female football players. Int J Ther Rehabil 22(2): 68-73, 2015.

2. Behara B, Jacobson BH. Acute effects of deep tissue foam rolling and dynamic stretching on muscular strength, power, and flexibility in Division I linemen. J Strength Cond Res 31(4): 888–892, 2017.

3. Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer: A prospective controlled study of proprioceptive training. Knee Surg Sports Traumatol Arthrosc 4(1): 19-21, 1996.

4. Cho S, Kim S. Immediate effect of stretching and ultrasound on hamstring flexibility and proprioception. J Phys Ther Sci 28(6): 1806-1808, 2016.

5. Costa PB, Graves BS, Whitehurst M, Jacobs PL. The acute effects of different durations of static stretching on dynamic balance performance. J Strength Cond Res 23(1): 141-147, 2009.

6. Dover G, Powers ME. Reliability of joint position sense and force-reproduction measures during internal and external rotation of the shoulder. J Athl Train 38(4): 304-310, 2003.

7. Eils E, Schröter R, Schröder M, Gerss J, Rosenbaum D. Multistation proprioceptive exercise program prevents ankle injuries in basketball. Med Sci Sports Exerc 42(11): 2098-2105, 2010.

8. Ghaffarinejad F, Taghizadeh S, Mohammadi F. Effect of static stretching of muscles surrounding the knee on knee joint position sense. Br J Sports Med 41: 684-687, 2007.

9. Hall LA, McCloskey DI. Detections of movements imposed on finger, elbow and shoulder joints. J Physiol, 335: 519-533, 1983.

10. Han J, Waddington G, Adams R, Anson J, Liu Y. Assessing proprioception: A critical review of methods. J Sport Health Sci 5: 80-90, 2016.

11. Healey KC, Hatfield DL, Blanpied P, Dorfman LR, Riebe D. The effects of myofascial release with foam rolling on performance. J Strength Cond Res 28(1): 61-68, 2014.

12. Henriksen M, Højrup A, Lund H, Christensen L, Danneskiold-Samsøe B, Bliddal H. The effect of stimulating massage of thigh muscles on knee joint position sense. Adv Physiother 6: 29-36, 2004.

13. Jones LA, Hunter IW. Force sensation in isometric contractions: A relative force effect. Brain Res 244(1): 186-189, 1982.

14. Kelly S, Beardsley C. Specific and cross-over effects of foam rolling on ankle dorsiflexion range of motion. Int J Sports Phys Ther 11(4): 544-551, 2016.

15. Kraemer R, Knobloch K. A soccer-specific balance training program for hamstring muscle and patellar and achilles tendon injuries: An intervention study in premier league female soccer. Am J Sports Med 37(7): 1384-1393, 2009.

16. Lee SJ, Ren Y, Kang SH, Geiger F, Zhang LQ. Pivoting neuromuscular control and proprioception in females

and males. Eur J Appl Physiol 115(4): 775-784, 2015.

17. Lephart SM, Pincivero DM, Giraldo JL, Fu FH. The role of proprioception in the management and rehabilitation of athletic injuries. Am J Sports Med 25(1): 130-137, 1997.

18. Li L, Ji Z, Li Y, Liu W. Correlation study of knee joint proprioception test results using common test methods. J Phys Ther Sci 28: 478-482, 2016.

19. MacDonald GZ, Button DC, Drinkwater EJ, Behm DG. Foam rolling as a recovery tool after an intense bout of physical activity. Med Sci Sports Exerc 46(1): 131-142, 2014.

20. MacDonald GZ, Penney MDH, Mullaley ME, Cuconato AL, Drake CDJ, Behm DG, Button DC. An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. J Strength Cond Res 27(3): 812-821, 2013.

21. Mandelbaum BR, Silvers HJ, Watanabe DS, Knarr JF, Thomas SD, Griffin LY, Kirkendall DT, Garrett W. Effectiveness of a neuromuscular and proprioceptive training program in preventing the incidence of anterior cruciate ligament injuries in female athletes: 2-year follow-up. Am J Sports Med 33(7): 1003-1010, 2005.

22. Markovic G. Acute effects of instrument assisted soft tissue mobilization vs. foam rolling on knee and hip range of motion in soccer players. J Bodyw Mov Ther 19(4): 690-696, 2015.

23. McGuine TA, Keene JS. The effect of a balance training program on the risk of ankle sprains in high school athletes. Am J Sports Med 34(7): 1103-1111, 2006.

24. Mohr AR, Long BC, Goad CL. Effect of foam rolling and static stretching on passive hip-flexion range of motion. J Sport Rehabil 23: 296-299, 2014.

25. Morton RW, Olkawa SY, Phillips SM, Devries MC, Mitchell CJ. Self-myofascial release: No improvement of functional outcomes in "tight" hamstrings. Int J Sports Physiol Perform 11: 658-663, 2016.

26. Peacock CA, Krein DD, Silver TA, Sanders GJ, Von Carlowitz KA. An acute bout of self-myofascial release in the form of foam rolling improves performance testing. Int J Exerc Sci 7(3): 202-211, 2014.

27. Pearcey GEP, Bradbury-Squires DJ, Kawamoto J, Drinkwater EJ, Behm DG, Button DC. Foam rolling for delayed-onset muscle soreness and recovery of dynamic performance measures. J Athl Train 50(1): 5-13, 2015.

28. Proske U, Gandevia S. The proprioceptive senses: Their roles in signaling body shape, body position and movement, and muscle force. Physiol Rev 92: 1651–1697, 2012.

29. Riemann BL, Lephart SM. The sensorimotor system, part II: The role of proprioception in motor control and functional joint stability. J Athl Train 37(1): 80-84, 2002.

30. Riva D, Bianchi R, Rocca F, Mamo C. Proprioceptive training and injury prevention in a professional men's basketball team: A six-year prospective study. J Strength Cond Res 30(20): 461-475, 2016.

31. Schmidt RA, Lee TD. Motor learning and performance: From principles to application. 5th ed. Champaign: Human Kinetics, 2014.

32. Shin M, Sung Y. Effects of massage on muscular strength and proprioception after exercise-induced muscle damage. J Strength Cond Res 29(8): 2255-2260, 2015.

33. Škarabot J, Beardsley C, Štirn I. Comparing the effects of self-myofascial release with static stretching on ankle

range-of-motion in adolescent athletes. Int J Sports Phys Ther 10(2): 203-212, 2015.

34. Stillman BC, McMeeken JM. The role of weightbearing in the clinical assessment of knee joint position sense. Aust J Physiother 47: 247-253, 2001.

35. Su H, Chang NJ, Wu WL, Guo LY, Chu IH. Acute effects of foam rolling, static stretching, and dynamic stretching during warm-ups on muscular flexibility and strength in young adults. J Sport Rehabil 26(6): 469-477, 2017.

36. Thelen DG, Chumanov ES, Hoerth DM, Best TM, Swanson SC, Young M, Heiderscheit BC. Hamstring muscle kinematics during treadmill sprinting. Med Sci Sports Exerc 37(1): 108-114, 2005.

37. Torres R, Duarte JA, Cabri JMH. An acute bout of quadriceps muscle stretching has no influence on knee joint proprioception. J Hum Kinet 34: 33-39, 2012.

38. Verhagen E, Van der Beek A, Twisk J, Bouter L, Bahr R, Van Mechelen W. The effect of a proprioceptive balance board training program for the prevention of ankle sprains: A prospective controlled trial. Am J Sports Med 32(6): 1385-1393, 2004.

39. Vigotsky AD, Lehman GJ, Contreras B, Beardsley C, Chung B, Feser EH. Acute effects of anterior thigh foam rolling on hip angle, knee angle, and rectus femoris length in the modified Thomas test. Peer J 3: e1281, 2015.