Research Article

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Effects of two different stretching techniques on proprioception and hamstring flexibility: a pilot study

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Aim: This study aimed to compare the immediate and long-term effect of proprioceptive neuromuscular facilitation (PNF) contract–relax–antagonist–contract (CRAC) exercises versus static stretching on proprioception and flexibility in males with hamstring shortness. **Patients & methods:** Knee extension angle test was used to measure flexibility and isokinetic dynamometer to evaluate proprioception. Assessments were evaluated at baseline, after first exercise and eighth week. The hamstring stretching was applied 3 days a week for 8 weeks. **Results:** Flexibility and position sense were similar in the immediate and long term ($p > 0.05$). However, the motion sense increased significantly in long term within the PNF CRAC group ($p = 0.02$). **Conclusion:** Both stretching exercises are effective for improving flexibility. Moreover, PNF CRAC improved motion sense more than static stretching in the long term.

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Keywords: exercise • flexibility • hamstring muscles • knee • proprioception

Introduction to the trial: background & rationale

The sensory information used for postural control and stability mainly arises from the vestibular system of the inner ear, vision and proprioceptive sense. Proprioceptive sensation takes place with the help of the integration of afferent signals coming from proprioceptors, as well as receptors in vestibular and visual organs [1]. Proprioceptive sense may be defined as the ability of the body to detect its position and perceive its motion without visual perception [2].

Proprioceptive sense provides stabilization in the challenging and extreme movements of the joint. It is also contributes in stabilization of joint, balance, postural control and coordination of mixed movements [3]. It enables learned and actions that require talent (e.g., cycling and driving a car) to be performed without visual and vestibular stimuli. Mechanoreceptors convert physical deformation energy into electrical energy of action potential. Mechanical stimuli received from action potentials are transmitted to the CNS by special receptors known as mechanoreceptors. Sensory information is evaluated in the spinal cord, brainstem and cortex, then returns through efferent paths and creates a motor response with movement. In this way, with the stimuli from the mechanoreceptors, the position sense enables the correct position to be found, while motion sense allows distinguishing the right or wrong position [4].

Stimulation of proprioceptors located inside organs and tissues is important for development of proprioceptive sense. Many different exercise methods are used to improve proprioceptors in rehabilitation. Effects of different exercise methods such as aerobic exercises [5], closed kinetic chain exercises [6], balance exercises [7] and stretching exercises [8] have been investigated in the literature. It has been shown that 9-week aerobic deep water walking exercises increased the position sense in the knee joint compared with the walking exercises with stroke patients [5]. It was determined that closed kinetic chain exercises performed on unstable surface for 6 weeks after anterior cruciate ligament reconstruction improved proprioception more than those applied in stable surface [6]. In another study, it was stated that 12-week balance exercises were significantly effective in the improvement of position sense in athletes with grade II lateral ankle ligament injury [7]. These studies have shown that proprioceptive sense can

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be improved by changing the sensory threshold in peripheral mechanoreceptors using different exercise programs. Like many other exercise methods, stretching exercises are one of the most frequently preferred exercise methods in the clinic for the purpose of improving proprioception [8–11].

Stretching has been used in the fields of both sports and rehabilitation for years for the purpose of improving elasticity, protection from injuries and increasing performance. The effect of stretching exercises on the muscles occurs biomechanically and neurologically. The biomechanical effect of stretching exercises begins at the sarcomere. Reducing interaction areas of myosin and actin by sarcomere allows muscle fiber lengthening [10]. Stretching exercises affect the viscoelastic properties and range of motion of the muscle–tendon unit by lengthening the muscle fibers and connective tissues. Thus, an increase in the length of the muscle–tendon unit occurs. The neurological effect of the stretching exercises of the muscles occurs when the H reflex is stimulated as a result of electrical stimulation. Postsynaptic changes occur due to autogenic inhibition in Golgi tendon organ, postsynaptic inhibition of afferents in joint and cutaneous receptors. Presynaptic inhibition causes an autogenic decrease in type IA fibers and a change in the capacity of synaptic transmission during repetitive activations [12].

There are many stretching exercises with different techniques and areas of use such as dynamic stretching, ballistic stretching, static stretching (SS) and proprioceptive neuromuscular facilitation (PNF) stretching. SS and PNF are two frequently used types of stretching. The SS is performed by stretching the target muscle groups to the point where they feel slight discomfort. PNF stretching is a combined isometric contraction in addition to passive stretching. The most commonly used techniques for stretching in PNF are contract–relax and contract–relax–antagonist–contract (CRAC) exercises. The common purpose of all is to increase flexibility and range of motion by inhibition of the target muscle group. The PNF CRAC exercises is a type of PNF stretching involving the isometric contraction of the agonist muscle, followed by relaxation, and then, concentric contraction applied on the antagonist muscle [13]. In the PNF CRAC exercises, autogenic inhibition is provided by the participation of the Golgi tendon organ, as well as reciprocal inhibition in the target muscles as a result of the concentric contraction of the antagonist muscle [14].

In recent years, studies suggesting that stretching exercises may be associated with proprioceptive sense and contribute to development of proprioceptive sense have started to be carried out [10,15]. The effects of PNF and SS on proprioceptive sense are under debate. Studies conducted in healthy individuals with PNF stretching which has several different exercises have reported that the PNF CRAC exercises contribute to development of postural control [10] whereas the PNF contract–relax exercises reduces sensitivity in the sense of motion [11]. Similarly, there is a study showing that acutely applied SS increases the sensitivity of muscle receptors by affecting the elastic components of muscle tissue and tendon [15], in addition to a study that could show no such effect of it [16].

Several studies conducted with both stretching exercises so far have proven that, with neurological inhibition of the target muscle group, its elasticity and joint movement range increase [14,17–19]. It is known that different durations of SS exercises applied both acutely [17] and long term [20,21] are effective in improving elasticity. Various techniques of PNF have also been shown to induce positive effects on elasticity in the immediate [18,22] and long term [19,23].

In application of stretching exercises, it is important to choose the application time as well as the choice of stretching technique. There are SS and PNF stretching studies applied in different volumes in the literature [24–27]. When both stretching exercises were compared, while it was reported that their long-term effects in improving elasticity are similar when the stretching time is long (100 s) for both SS and PNF (with the contract–relax exercises) [24], it was stated that SS is more successful than PNF (reciprocal inhibition exercises) when the stretching time is shorter (30 s) [25]. On the other hand, another study, where the stretching time was short (32 s) [26], determined that the immediate effects of both exercises on elasticity are similar, whereas PNF (contract–relax exercises) is more effective when the stretching time is extended (80 s) [27]. Although several studies comparing not only the immediate but also the long-term effects of both exercises on elasticity are included in the literature, it is seen that their results have not been consistent. These differences in the literature may have been caused by that the volumes of the exercises used were not similar [28–31] and that the PNF exercises compared with SS were different [24–26].

Muscle structure is an important factor affecting flexibility. Therefore, the stiffness or shortness of the muscle can affect the result of the treatment [32,33]. Shortness of the hamstring muscle, which has an important effect on lower extremity performance, is important for both sedentary and athletes. Hamstring shortness may adversely affect many functional activities related to the spine, pelvis and lower extremity, due to its anatomical structure. Hamstring shortness may negatively affect lower extremity range of motion and gait pattern, as well as cause

injuries such as plantar fasciitis [34], patellofemoral pain syndrome [35] and low back pain [36]. Spinal disorders, neural syndromes, contractures caused by injury to the CNS, sports injuries, sedentary lifestyle, and structural disorders in the musculoskeletal system and the anatomical structure of the muscle are among the causes of hamstring shortness [33]. Betterment of hamstring shortness is important in preventing injuries that may occur and improving the disorders in the musculoskeletal system [32,33].

In the literature, there are studies comparing PNF and SS exercises in individuals with hamstring shortness [33,37–40]. One of the studies comparing the effectiveness of PNF contract–relax and SS exercises on hamstring flexibility and examining the long-term effect in individuals with hamstring shortness stated that both techniques improved flexibility without showing superiority [33], while another study showed that PNF contract–relax technique improved flexibility more [37]. In studies investigating the acute effect, it has been reported that PNF contract–relax and SS exercises in a single session have similarly improved flexibility [38–40]. There is also a study reporting that PNF CRAC is more effective in improving flexibility than PNF contract–relax exercises in individuals with hamstring shortness [22]. In the studies comparing PNF with SS (individuals with and without hamstring shortness), it is seen that SS with PNF techniques improves flexibility similarly or PNF is more effective. However, PNF CRAC has been found to be superior in improving flexibility over the PNF contract–relax technique [22,41,42]. In addition to the inhibition of the target muscle in the CRAC technique, it is reported that this superiority is due to a secondary inhibition mechanism that is revealed by the contraction of the opposite muscle.

Although most studies showed that PNF and SS can improve proprioception, few studies published about this topic. In this context, it seems that the studies focused on flexibility rather than proprioception. Most studies have compared PNF contract–relax and SS. There is only one study comparing the effect of PNF CRAC and SS on flexibility (without hamstring shortness) [28]. In the literature, a study assessing and comparing the acute and long-term effects of the PNF CRAC exercises and SS on proprioceptive sense and flexibility has not been encountered in individuals with hamstring shortness. Therefore, the primary purpose of our study is to compare the acute and long-term effects of PNF CRAC and SS exercises applied for similar durations on knee joint position and motion sense in individuals with hamstring shortness. Its secondary aim is to comparatively examine the immediate and long-term effects on flexibility.

Patients & methods

This randomized comparative study was conducted in the Athlete's Health Unit of the Health Sciences Faculty of Eastern Mediterranean University. The ethical approval for this study was obtained from Eastern Mediterranean University Health Ethics Subcommittee (Protocol number: 2019/09-13, date: 19 March 2019). Individuals who were admitted to 'Athlete's Health Unit' were recruited in to the study. Each participant was informed about the study and they gave their written informed consent to participate. This study is registered at the Clinical Trials website with the clinical trial number NCT04026646.

Participants

In this study, a priori sample size calculation was performed using the G* Power software (version 3.1.9.2), taking into account the statistical tests to be used in the analyses. It was calculated that 27 participants would be needed in each group ($\alpha = 0.05$, $\beta = 0.20$ and Cohen $d = 0.8$) in order to detect statistically significant difference in a two-tailed Mann–Whitney U paired two sample test. In case of a potential dropout, the estimated number of participants was increased by 10%. As a result, the final sample size was calculated as 30 in each group. Participants were randomly assigned into two groups by minimization randomization technique (PNF or SS). A total of 36 subjects participated in this pilot study (18 individual in each group). The participants were also advised not to consume alcohol, smoke cigarette, take nutritional supplements, participate in physical activities (e.g., yoga, strength training and stretching sessions), throughout this study. Moreover, they were asked to maintain their usual nutritional and water intake over the course of this study.

Included criteria

Individuals with hamstring shortness were included in the study. In determining hamstring shortness, Youdas *et al.* as in the study, knee extension angle test was used and individuals with knee extension angle over 20° participated in the study [43]. Sedentary male individuals (who have not participated in regularly physical activity in the last 6 months) and aged 20–29 years were included in this study.

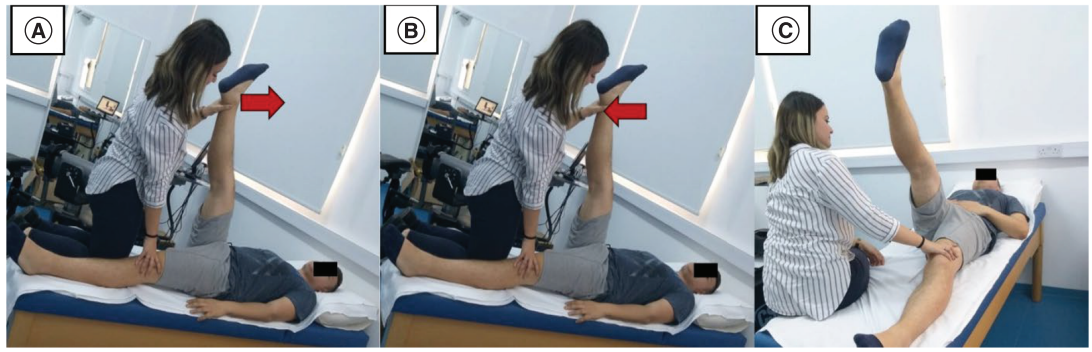

Figure 1. Proprioceptive neuromuscular facilitation contract–relax–antagonist–contract stretching exercises. (A) Hamstring stretching. **(B)** Isometrically contraction to hamstring. **(C)** Concentrically contraction the quadriceps.

Excluded criteria

Who have lower extremity injuries (strain, sprain, ligament injuries, etc.) in last 6 months, rheumatologic (rheumatoid arthritis, systemic lupus erythematosus, etc.), orthopedic or neuromuscular disease (lumbar/cervical herniation, polyneuropathy, scoliosis, fractures, etc.), trauma history (traumatic brain injury, spinal cord injuries, etc.), vestibular system disorders (vertigo, dizziness symptoms, etc.), who have visual impairments except of refractive problems and black individuals were excluded.

Outcome

Sociodemographic characteristics

General information such as age, height and weight was obtained in the sociodemographic form prepared for the preliminary evaluation of the individuals. Bodyheight was measured with a tape measure. Bodyweight was measured by a scale. BMI was calculated by using the following formula: weight (kg)/height $(m)^2$. In addition the dominant side was questioned for statistical analysis of the values.

Outcome measures

PNF CRAC stretching exercises were applied to group 1 (Figure 1) and SS exercises (Figure 2) were applied to group 2. Evaluations and exercises were applied in the 'Athlete's Health Unit' of the Health Sciences Faculty of Eastern Mediterranean University. Assessments were evaluated at pretest, before starting the first exercise. After first stretching exercise all assessments repeated to examine the immediate effect. Exercises were applied 3 days a week for 8 weeks. After 8 weeks, all assessments were repeated to examine the long-term effect (Figure 3). Exercises were performed bilaterally and 30 s rest time was provided between each stretching exercises. Additionally, all assessments were performed bilaterally and dominant lower extremity data were used in the statistical analysis. Exercises and evaluations were carried out at the same time (2:00–3:00 p.m.) to reduce the effects of the circadian variation [44]. Moreover, all evaluations and all exercises for both groups were applied by the same physiotherapist.

Knee extension angle

Knee extension angle is a method used to measure hamstring flexibility. It is accepted as the gold standard in evaluating the flexibility or length of the hamstring muscle [45]. The knee extension angle was evaluated using goniometer to measure the length of the hamstring muscle. While the patient was in the supine position, the hip and knee joints were placed 90° flexion position. Then the knee joint was extended by passively until the participant reported a mild tension. The angle missing from full knee extension was registered [43].

Proprioceptive sensory measurements

An isokinetic dynamometer (Humac Norm®, Model: 502140, Serial Number: 2710, Computer Sports Medicine, Inc., MA, USA) was used to evaluate the proprioceptive sense of participants' knee joint. Both active joint position sense and joint motion sense tests were assessed under the proprioceptive sensory measurements. The participants were placed in a 90° hip flexion in sitting position for knee joint motion test. Before the test, participants were informed about the tests and a trial was performed. Three tests were performed and a rest period of 30 s between

Figure 2. Static stretching exercises.

measurements. The difference between the target angle and the measured angle that the participant felt was registered as 'absolute error'. Average of three measurements was analyzed.

Angular velocity of 1°/s was chosen based on the results of Stillman *et al.* and Ogard *et al.* to be used in proprioceptive sensory evaluations [46,47]. For motion sense measurements, Pincivero *et al.* based on the study, 10° knee flexion position was chosen [48]. In the motion sense measurement, the position was set to 10° and the participants were instructed to press the dynamometer lock button as soon as they perceived any movement in the knee joint. In the position sense assessment, 45° knee flexion position was used based on the related studies [49,50].

While assessing the joint position sense, the knee was started in a 90° flexion position and participants were instructed to stay still for 5 s in the body position they were brought in. Afterward, the extremity was brought to starting position and participants were asked to demonstrate the target angle. Air splints were used to eliminate the tactile sense during proprioceptive sense measurements. While care was taken to preserve the silence of the environment, participants were also wearing headphones at the same time to prevent the sound coming from the isokinetic dynamometer that could affect the measurements. Also room temperature was kept at 24°C.

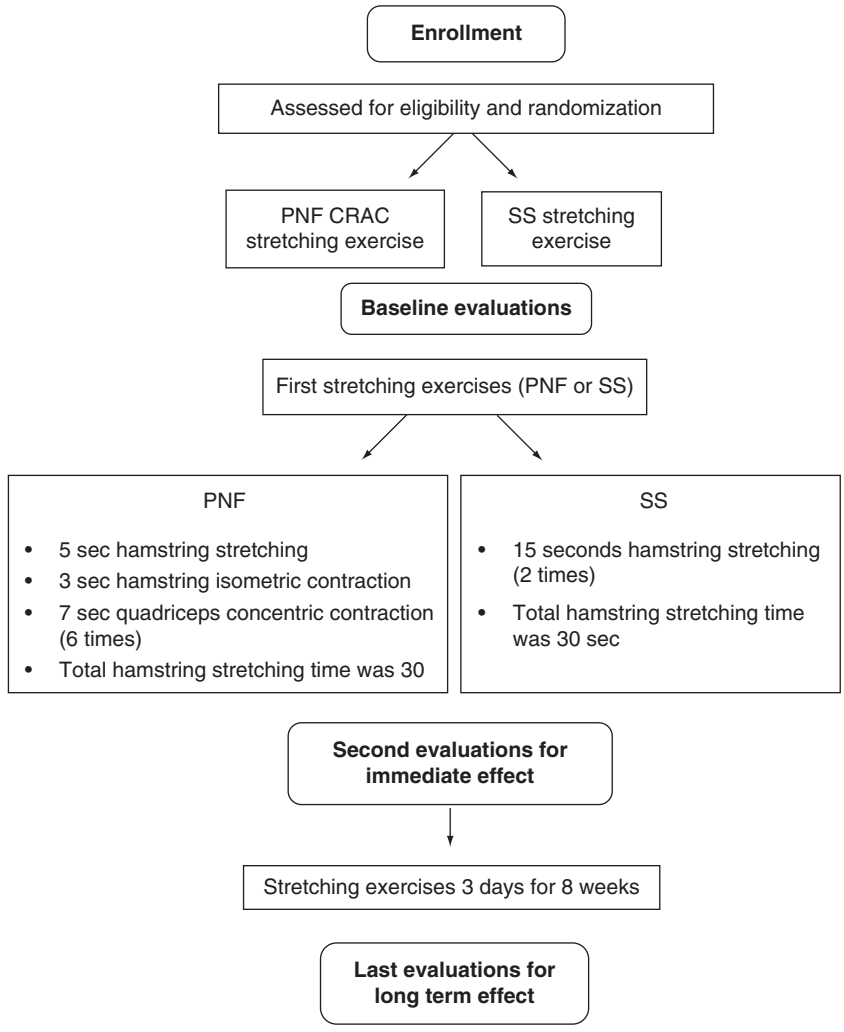

Figure 3. Study design flow diagram.
CRAC: Contract–relax–antagonist–contract; PNF: Proprioceptive neuromuscular facilitation; SS: Static stretching.

Intervention

PNF CRAC exercises

In this study, PNF CRAC exercises were used. Participant was positioned in supine position. The hamstring was stretched by passively flexing the hip with knee fully extended. The hamstring muscle was stretched until the participant first reported a mild stretch sensation; this position was held for 5 s. Next, the participant isometrically contracted the hamstring muscle for 3 s by attempting to push his leg down toward the table against the resistance of the physiotherapist. Participant was asked to concentrically contract the quadriceps muscle, by attempting to further raise the leg, for 7 s (Figure 1) [42,51]. Exercise was performed bilaterally, six times and stretching time was 30 s in total to each side.

SS exercises

The participant lay supine with the left leg fully extended. A sheet was wrapped around the foot and the participant held the ends of the sheet in each hand. The participant was instructed to keep the knee locked in full extension. The participant was instructed to bring the hip flexion by pulling on the sheet attached to the foot with both arms until the participant reported a mild stretch sensation (Figure 2). This position was held for 15 s, and then the extremity was gently lowered to the table. SS was performed bilaterally, two times and stretching time was 30 s in total to each side [25].

Table 1. Sociodemographic characteristics of the participants.

Measurements	Static group x ± SD (min–max)	PNF group x ± SD (min–max)	p-values†
Age (years)	22.11 ± 1.64 (20–26)	22.17 ± 1.86 (20–27)	0.88
Weight (kg)	77.87 ± 13.36 (57–111)	77.25 ± 13.14 (55.5–105)	0.99
Height (cm)	178.33 ± 6.49 (168–190)	178.22 ± 6.33 (167–188)	0.94
BMI, kg/m^2, x ± sd	24.08 ± 2.94 (19.15–30.0)	24.46 ± 3.80 (18.10–31.02)	0.85

†Mann–Whitney U-test.
PNF: Proprioceptive neuromuscular facilitation; SD: Standard deviation.

Table 2. Comparison of variables of between the groups.

Variables	Static group x ± SD			PNF group x ± SD			p-values†		
	Pre	Immediately	Long term	Pre	Immediately	Long term	p1	p2	p3
Knee extension angle	38.72 ± 9.77	33.44 ± 9.43	28.83 ± 8.27	39.61 ± 10.93	35.28 ± 7.64	27.44 ± 10.49	0.91	0.39	0.52
Position sense	8.52 ± 5.46	7.79 ± 4.01	8.64 ± 5.69	6.85 ± 4.05	5.94 ± 4.65	5.77 ± 3.94	0.40	0.9	0.11
Motion sense	0.53 ± 0.51	0.59 ± 0.58	0.53 ± 0.56	0.37 ± 0.57	0.42 ± 0.47	0.16 ± 0.26	0.23	0.42	**0.02**

†Mann–Whitney U-test.
p1: Pretest values of groups; p2: İmmediately test values of groups; p3: Long-term test values of groups; PNF: Proprioceptive neuromuscular facilitation; SD: Standard deviation.

Statistical analysis

The study data were analyzed using the IBM SPSS Statistics 22 software (SPSS, Inc., IL, USA). The study parameters were expressed in numbers, and mean ± standard deviation (x ± SD). Before performing the statistical tests, any potential outliers and missing data were checked. Shapiro–Wilk test was used to determine whether the data showed normal distribution. Nonparametric statistical tests were used as the data did not show normal distribution. Friedman *post hoc* Dunn test was used to detect significant differences within the group. The Mann–Whitney U-test was used to detect significant differences between the groups. Statistical significance was set at $p < 0.05$. The 'r = z ✓ n × 2' formula is used to determine the effect size of the changes over time in the SS and PNF group. Effect sizes were interpreted as small ($r \leq 0.1$), moderate ($r = 0.30$) and large ($r \geq 0.5$) [52].

Results

The PNF CRAC and SS group were similar in terms of their main age, weight, height and BMI values ($p > 0.05$; Table 1). No difference was found between the groups in the immediate and long-term results of the position sense, which is our primary outcome. Similarly, there was no statistical difference between the groups in immediate and long term in flexibility, which is our secondary outcome measure ($p > 0.05$).

However, the motion sense was statistically significantly different in long term between two groups ($p = 0.02$; Table 2). The intragroup comparisons of elasticity showed statistically significantly difference in SS group in the immediate and long term ($p = 0.00$). While statistically significant difference was found only in the long term in the PNF group ($p = 0.00$), it was not found in the immediate result. No significant differences were found in the proprioception for both groups ($p > 0.05$; Table 3).

The effect size of elasticity results was found large in long term for both groups ($r = 0.60$). The elasticity results of SS group was large in immediately effect size ($r = 0.62$); however, in PNF groups effects size was moderate ($r = 0.48$).

Discussion

This study shows that even a single session of SS and PNF CRAC exercises increased flexibility. When the exercises applied for a long time, the improvement of flexibility continues and improves further. Our study showed that while short-term SS exercise is more effective than PNF CRAC, it has similar clinical effects in the long term.

Table 3. Comparisons of the variables of within the groups.

Variables	Pre x ± SD	Immediately x ± SD	Long term x ± SD	p† x ± SD	p1 x ± SD	p2 x ± SD	r1 x ± SD	r2 x ± SD
Knee extension angle								
Static	38.72 ± 9.77	33.44 ± 9.43	28.83 ± 8.27	**0.00**	**0.00**	**0.00**	0.62	0.60
PNF	39.61 ± 10.93	35.28 ± 7.64	27.44 ± 10.49	**0.00**	0.07	**0.00**	0.48	0.60
Position sense								
Static	8.52 ± 5.46	7.79 ± 4.01	8.64 ± 5.69	0.65	–	–	0.13	0.03
PNF	6.85 ± 4.05	5.94 ± 4.65	5.77 ± 3.94	0.99	–	–	0.16	0.05
Motion sense								
Static	0.53 ± 0.51	0.59 ± 0.58	0.53 ± 0.56	0.44	–	–	0.07	0.01
PNF	0.37 ± 0.57	0.42 ± 0.47	0.16 ± 0.26	0.04	1.00	0.73	0.15	0.23

†Friedmann *post hoc* Dunn test.
p1: Values between pre-immediately test; p2: Values between pre-long term test; PNF: Proprioceptive neuromuscular facilitation; r1: Effect sizes of between pre-immediately test; r2: Effect sizes of between pre-long term test; SD: Standard deviation.

Although SS and PNF CRAC exercises have similar effects on the position sense, it can be interpreted that PNF CRAC is more effective in increasing the motion sense in long term.

PNF is an exercise used to improve strengthening and flexibility with many different methods. Although there is no study comparing the effect of SS and PNF CRAC, there are studies that have compared both the immediate and long-term effects of the PNF contract–relax [24,26,29,38] or PNF contract–relax agonist contract exercises [28,30,53] and SS on elasticity. Different stretching volumes were used in these studies. In addition, different contraction techniques have been used in PNF applications. There are studies with stretching methods similar to this study, as well as studies using different methods.

In this study, it was observed that both exercises similarly improved flexibility which is our secondary outcome, in the long term. On the other hand, while some studies examining the long-term effects of stretching exercises have shown that the PNF contract–relax agonist contract exercise and SS had similar effects on flexibility [53–55], there is also a study showing that the PNF CRAC exercise was more effective than SS [30]. Differences in the results of studies may be connected to several reasons. Several factors could explain these differences, including sample size, different PNF techniques (partner PNF vs self PNF), the length of the study and the doses of stretching [30].

Davis *et al.*, who applied stretching for a similar duration to this study and investigated the long-term effects of both exercises, reported that SS was more effective than PNF reciprocal inhibition technique in improving elasticity. The authors attributed these results to a few factors. The first was that the SS of muscles by a single repetition for 30 s may have provided inhibition by activating Golgi tendon organ, whereas the second involved the differences in the stretching mechanisms. Davis *et al.* stated that having the quadriceps muscle actively contract before the PNF stretching application facilitated the hamstring muscle, and this situation may have negatively affected the neural inhibition mechanism [25]. In this study, it was observed that both exercises improved elasticity similarly in the long run. In the study, applying SS in two sets of 15 s each and providing a 15 s resting time in-between may have prevented the inhibitor effect from emerging sufficiently. However, not having the quadriceps muscle actively contract during PNF stretching may have led to an increase in elasticity by causing neural inhibition in the hamstring muscle.

Our study examined both the short- and long-term effect. In this study, it was seen that the effects of both exercises on elasticity were similar in the immediate term. However, it was also observed that the effect size of SS was clinically greater than PNF CRAC exercises. Several studies in the literature comparing the immediate effects of SS and PNF stretching on elasticity have reported that the effects of the SS and PNF contract–relax exercises were similar [38,56,57]. There are two studies in the literature which used a similar stretching duration to that in our study and compared the immediate effects on hamstring elasticity. Mallmann *et al.* reported that PNF contract–relax and SS applied for 32 s improved elasticity similarly [26]. As a result of the stretching exercises that they applied for 30 s using the PNF contract–relax exercise, O'Hora *et al.* showed that PNF stretching increased elasticity more in comparison to SS [29]. In contrast to other studies, the authors wanted to see the construction of the agonist muscle during the PNF contract–relax exercise they applied on the hamstring muscle. They reported that agonist muscle contraction applied in addition to stretching may be a more effective technique than antagonist contraction, and this situation may be responsible for the higher increase in elasticity by PNF. While it is known that PNF exercises increase elasticity through reciprocal and autogenic inhibitions, the mechanism responsible for inhibition varies based on the technique used. In the PNF CRAC exercise, which was used in this study, by the contraction of

the antagonist muscle, 'autogenic inhibition' in this muscle and 'reciprocal inhibition' in the agonist muscle are expected [42]. While the total stretching duration in our study while applying PNF CRAC was 30 s, each stretching was applied for 5 s in six sets. As the stretching was reciprocally applied on the hamstring muscles, the resting breaks given between the sets may have been the reason for the reduction in the effectiveness of the PNF CRAC exercise. The effect of stretching exercises on flexibility occurs mechanically as well as neurological pathways. SG contains viscoelastic properties of muscle that stretch beyond normal range of motion, mechanically terminating in muscle fibers and connective tissue elongation [12,58]. In the PNF technique, the viscoelastic properties and neuromuscular facilitation effects created by the contraction of the muscles cause an increase in flexibility. The contracted muscle contributes to the improvement of flexibility by extending the noncontractile elements, causing the muscle tendon unit to relax and the passive tension in the muscle to decrease [12,59]. In our study, the mechanical advantages of both techniques may have resulted in similar improvement of flexibility in both immediate and long-term intergroup.

Proprioceptors that are found in joints, muscles, tendons and ligaments are sensitive to the perception of tension and motion in these structures [60]. It is thought that especially the stretching of the hamstring muscles, which affect the knee joint and whose shortness is prevalently encountered, affects proprioceptive sense. In the intragroup comparisons of this study, neither of the techniques led to a significant improvement in proprioception. On the other hand, in the intergroup comparison, it was seen that the PNF CRAC exercise was more effective in improving motion sense in the long term.

In previous studies, although not comparative ones, there are studies examining the immediate effects of PNF and SS on proprioceptive sense. In a study that investigated the effects of PNF on proprioceptive sense indirectly via postural control, the PNF CRAC exercise was applied on the hamstring, quadriceps, iliopsoas and plantar flexor muscles, and at the end of the study, it was seen that postural control improved [10]. This study attributed the improvement in postural control to the three factors. One of them is warm-up exercises' effects, second is neurological facilitation from the contract–relax and third one is irradiation overflow from the antagonist–contract phase. Although Ryan *et al.* used the Biodex Balance System™ (NY, USA) to assess the postural control of the extremity [10]. In the study, proprioceptive sensation was indirectly evaluated, and stretching exercises were applied on three more muscles in addition to the hamstring muscle. Streepey *et al.*, who investigated the effects of PNF on isolated knee proprioception sensation, showed that the PNF contract–relax exercise they applied on the hamstring and quadriceps muscles lowered motion sense in comparison to the control group [11]. The study mentioned that the reduction in knee joint motion sensation to an increase in the slack built up in the muscle. In addition, it was reported that the PNF technique used in the study may be due to the leg fully suspended in a nonweight bearing position and with the knee being moved passively.

In the study where a stretching duration of 90 s was applied in total, motion sense was assessed from a 135° knee flexion to the direction of extension and at an angular velocity of 0.4°/sec. The fact that a much shorter stretching duration than that in the study by Streepey *et al.* was used in our study may have been the reason that no intragroup was observed in the PNF CRAC exercise group. Another reason may be the knee position angle where the angular velocity that was used and motion sense were measured. Although there is no gold standard in the literature in terms of the angular velocities reported for measurement of motion sense [50], it has been stated that angular velocities under 0.5°/s cannot be distinguished, and angular velocities in the range of 0.5°/s to 1.5°/s should be used in tests of the passive motion perception threshold [46,47]. In the literature, passive movement is perceived better because more motor responses are facilitated due to the increase in tension in the antagonist muscles while going to terminal extension in the knee joint, for this reason, it is reported that passive motion sense should be measured while moving from 30° flexion position to extension [48,49]. We think that the test position used in our study is one of the reasons for the significant improvement in motion sense in the long term.

Proprioceptors or mechanoreceptors around and within the joint (muscle spindles, Golgi tendon organs, Ruffini nerve endings, Pacinian corpuscles, Meissen's corpuscles and Merkel's discs) provide afferent information [61,62]. PNF exercises consist of stretching, isometric contraction, agonist or antagonist concentric contractions that can stimulate the proprioceptors and increase their sensitivity. PNF exercises can increase the receptors of proprioceptive sensory organs such as the muscle spindle and the Golgi tendon organ, thereby increasing homocentric stimulation in muscle length or tensile strength [63]. Our study may have contributed to the improvement of motion sense by improving the sensitivity of the receptors to motion with 8-week PNF CRAC exercises.

In the literature, there are a few studies that have examined the immediate effects of SS exercises on only position sense, whereas their results are conflicting. Haffarinejad *et al.*, who applied stretching for a total of 90 s on the hamstring, quadriceps, adductor and gastrocnemius muscles, reported that SS improved position sense, whereas

a different study using the same duration applied SS on only the quadriceps and hamstring muscles and showed that stretching did not have an effect on position sense [15,16]. Haffarinejad *et al.* attributed the improvement in position sense to the structure of muscle spindles and stated that with the tension effect of muscle spindles which have a thixotropic characteristic, the positional sensitivity of muscle receptors may be adjusted, and a new balance may be created in the tendon [15]. Larsen *et al.*, on the other hand, reported that the thixotropic contraction and relaxation behavior of the muscle spindle will be present for a very short time when the muscle is extended, and this effect will not be reflected on the results [16]. The common feature of the studies by Haffarinejad *et al.* and Larsen *et al.* was that they did not look for hamstring shortness in the individuals they included. In this study, a much shorter duration of stretching was applied in comparison to the aforementioned studies, and though not statistically significant, there was a tendency of SS to improve position sense. As Haffarinejad *et al.*, we thought that SS exercises may stimulate muscle spindle receptors in especially individuals with hamstring shortness.

Although there are no studies comparing the effect of PNF and SS exercises on proprioception in individuals with short hamstring in the literature, there are studies comparing the effect on flexibility [33,37–40]. Several studies investigating the immediate effect of stretching exercises on flexibility have reported that single session PNF contract–relax and SS exercises increase flexibility equally [38–40]. The immediately effects of stretching exercises used in our study on flexibility are consistent with the literature.

In a study investigating the long-term effects of stretching exercises, it was observed that after a 12-session (3 days a week for 4 weeks) exercise program, PNF contract–relax and SS exercises improved hamstring flexibility, but no technique was superior [33]. In another study comparing the same techniques, it was shown that PNF contract–relax exercise improved more flexibility than SS at the end of 20 sessions (5 days a week for 4 weeks) [37]. PNF exercises seem to be more effective than SS in improving flexibility. Also, according to previous studies, CRAC technique is superior to PNF contract–relax in the long-term effects of stretching exercises [21,41,42]. The similar long-term effects of both exercises in this study may be due to the differences in applications. In the study of Kaur *et al.*, PNF contract–relax technique was applied in five repetitions with 7 s hamstring stretching time, 3 s isometric hamstring contraction and 20 s rest period [37]. Youdas *et al.* applied the PNF contract–relax and CRAC technique single repetition with 10 s cycles [22]. In our study, PNF CRAC exercises were performed three-times with 5 s of hamstring stretching, 3 s of isometric hamstring contraction, 5 s of rest and 7 s of concentric quadriceps contraction. As explained above, PNF techniques in the studies were used in different session numbers, different stretching and contraction times.

Limitations

This study is a pilot study. For this reason, the numbers of the individuals in our groups were limited. Additionally, the results of our study are only applicable to healthy male individuals with hamstring shortness. Therefore, our results may not be generalized to individuals without hamstring muscle shortness or with orthopedic disorders. One of the limitations is that it is neither a single- nor a double-blind study.

Conclusion

SS and PNF CRAC are equally effective for improving elasticity in males suffering from hamstring shortness. The PNF CRAC exercise was more effective than SS in improving the motion sense. Our study was conducted on sedentary male individuals with hamstring muscle shortness. Further studies need to be repeated in populations including both sexes with different activity levels. To be able to obtain clear information on proprioceptive sense in clinical practice, there is a need for randomized controlled studies to be conducted on orthopedic and sports injuries.

Summary points

- This study was conducted on male individuals with hamstring shortness.
- Static stretching and proprioceptive neuromuscular facilitation contract–relax–antagonist–contract exercises are successful methods of improving muscular flexibility.
- Moreover, proprioceptive neuromuscular facilitation contract–relax–antagonist–contract exercises more effective method to enhancing proprioceptive sense than static stretching in the long term.

Author contributions

All the authors participated in literature review and topic identification, and contributed to writing phase of the article. E Mani and B Kirmizigil were involved in the screening of people to be included in the research. E Mani contributed to application phase of the study.

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The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

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Ethical conduct of research

This randomized comparative study was conducted at the Athlete's Health Unit of the Health Sciences Faculty of Eastern Mediterranean University after the ethical approval was obtained with the decision of Eastern Mediterranean University Scientific Research and Publication Ethics Committee dated 19 March 2019 and numbered 2019/09-13. The participants were informed about study and their written informed consent was obtained before conducting the study.

Data sharing statement

The authors certify that this manuscript reports original clinical trial data. All data collected as part of the study, including de-identified, individual data that underlie the results, study protocol, exercise programs and statistical analysis plan will be available upon request. Clinical trial registration number: NCT04026646.

References

Papers of special note have been highlighted as: • of interest; •• of considerable interest

1. Tuthill JC, Azim E. Proprioception. *Curr. Biol.* 28(5), R194–R203 (2018).
2. Marini F, Ferrantino M, Zenzeri J. Proprioceptive identification of joint position versus kinaesthetic movement reproduction. *Human Mov. Sci.* 62, 1–13 (2018).
3. Röijezon U, Clark NC, Treleaven J. Proprioception in musculoskeletal rehabilitation. Part 1: basic science and principles of assessment and clinical interventions. *Manual Ther.* 20(3), 368–377 (2015).
4. Macefield VG. Physiological characteristics of low-threshold mechanoreceptors in joints, muscle and skin in human subjects. *Clin. Exp. Pharmacol. Physiol.* 32(1–2), 135–144 (2005).
5. Bigongiari A, Francica JV, Franciulli PM, Mochizuki L, Hamill J, Ervilha UF. Aerobic training in aquatic environment improves the position sense of stroke patients: a randomized clinical trial. *Motriz: Revista de Educação Física* 24(1), 1–7 (2018).
6. Cho S-H, Bae C-H, Gak H-B. Effects of closed kinetic chain exercises on proprioception and functional scores of the knee after anterior cruciate ligament reconstruction. *J. Phys. Ther. Sci.* 25(10), 1239–1241 (2013).
7. Kalirathinam D, Hashim HA, Ismail MSB. A 12-weeks multimodal exercise training on ankle joint position sense in lateral ankle ligament injury of athletes. *Res. J. Pharm. Technol.* 11(9), 4074–4083 (2018).
8. Walsh GS. Effect of static and dynamic muscle stretching as part of warm up procedures on knee joint proprioception and strength. *Human Mov. Sci.* 55, 189–195 (2017).
9. Takasaki H, Okubo Y, Okuyama S. The effect of proprioceptive neuromuscular facilitation on joint position sense: a systematic review. *J. Sport Rehab.* 29(4), 488–497 (2019).
10. Ryan EE, Rossi MD, Lopez R. The effects of the contract-relax-antagonist-contract form of proprioceptive neuromuscular facilitation stretching on postural stability. *J. Strength Cond. Res.* 24(7), 1888–1894 (2010).

•• **Investigates the effects of proprioceptive neuromuscular facilitation (PNF) exercises.**

11. Streepey JW, Mock MJ, Riskowski JL, VanWye WR, Vitvitskiy BM, Mikesky AE. Effects of quadriceps and hamstrings proprioceptive neuromuscular facilitation stretching on knee movement sensation. *J. Strength Cond. Res.* 24(4), 1037–1042 (2010).

•• **Investigates the effects of PNF exercises.**

12. Weerapong P, Hume PA, Kolt GS. Stretching: mechanisms and benefits for sport performance and injury prevention. *Phys. Ther. Rev.* 9(4), 189–206 (2004).
13. Osternig LR, Robertson RN, Troxel RK, Hansen P. Differential responses to proprioceptive neuromuscular facilitation (PNF) stretch techniques. *Med. Sci. Sports Exercise* 22(1), 106–111 (1990).
14. Hindle K, Whitcomb T, Briggs W, Hong J. Proprioceptive neuromuscular facilitation (PNF): its mechanisms and effects on range of motion and muscular function. *J. Hum. Kinet.* 31(2012), 105–113 (2012).

15. Ghaffarinejad F, Taghizadeh S, Mohammadi F. Effect of static stretching of muscles surrounding the knee on knee joint position sense. *Brit. J. Sports Med.* 41(10), 684–687 (2007).

•• **Examines the effects of static stretching (SS) exercises on proprioceptive sense.**

16. Larsen R, Lund H, Christensen R, Røgind H, Danneskiold-Samsøe B, Bliddal H. Effect of static stretching of quadriceps and hamstring muscles on knee joint position sense. *Brit. J. Sports Med.* 39(1), 43–46 (2005).

•• **Examines the effects of SS exercises on proprioceptive sense.**

17. Ogura Y, Miyahara Y, Naito H, Katamoto S, Aoki J. Duration of static stretching influences muscle force production in hamstring muscles. *J. Strength Cond. Res.* 21(3), 788 (2007).

18. Robin K, Raj YL. Impact of PNF stretching on muscular flexibility in football. *Int. J. Yogic Hum. Mov. Sports Sci.* 4(1), 686–688 (2019).

19. Singh AK, Nagaraj S, Palikhe RM, Neupane B. Neurodynamic sliding versus PNF stretching on hamstring flexibility in collegiate students: a comparative study. *Int. J. Phys. Educ. Sports Health* 1(1), 29–33 (2017).

20. Ün N, Yüktaşır B, Ergun N. Statik germe süresinin hamstring kas esnekliği üzerine etkisi. *Fizyoterapi Rehabilitasyon* 13(2), 72–76 (2002).

21. Ford GS, Mazzone MA, Taylor K. The effect of 4 different durations of static hamstring stretching on passive knee-extension range of motion. *J. Sport Rehab.* 14(2), 95–107 (2005).

22. Youdas JW, Haeflinger KM, Kreun MK, Holloway AM, Kramer CM, Hollman JH. The efficacy of two modified proprioceptive neuromuscular facilitation stretching techniques in subjects with reduced hamstring muscle length. *Physiother. Theory Pract.* 26(4), 240–250 (2010).

23. Sivagnanam R, Paul J, Natarajan SK, Sudhakar S. Comparative effect of PNF stretching technique on hamstring flexibility. *Int. J. Med. Exercise Sci.* 4(1), 443–447 (2018).

24. López-Bedoya J, Vernetta-Santana M, Robles-Fuentes A, Ariza-Vargas L. Effect of three types of flexibility training on active and passive hip range of motion. *J. Sports Med. Phys. Fitness* 53(3), 304–311 (2013).

25. Davis DS, Ashby PE, McCale KL, McQuain JA, Wine JM. The effectiveness of 3 stretching techniques on hamstring flexibility using consistent stretching parameters. *J. Strength Cond. Res.* 19(1), 27 (2005).

•• **Uses the same stretching volume in PNF and SS exercises.**

26. Mallmann JS, Moesch J, Tomé F, Vieira L, Ciqueleiro RT, Bertolini GRF. Comparação entre o efeito imediato e agudo de três protocolos de alongamento dos músculos isquiotibiais e paravertebrais. *Rev. Bras. Clin. Med.* 9(5), 354–359 (2011).

•• **Uses the same stretching volume in PNF and SS exercises.**

27. Magnusson SP, Simonsen EB, Aagaard P, Dyhre-Poulsen P, McHugh MP, Kjaer M. Mechanical and physiological responses to stretching with and without preisometric contraction in human skeletal muscle. *Arch. Phys. Med. Rehabil.* 77(4), 373–378 (1996).

28. Miyahara Y, Naito H, Ogura Y, Katamoto S, Aoki J. Effects of proprioceptive neuromuscular facilitation stretching and static stretching on maximal voluntary contraction. *J. Strength Cond. Res.* 27(1), 195–201 (2013).

29. O'Hora J, Cartwright A, Wade CD, Hough AD, Shum GL. Efficacy of static stretching and proprioceptive neuromuscular facilitation stretch on hamstrings length after a single session. *J. Strength Cond. Res.* 25(6), 1586–1591 (2011).

30. Wicke J, Gainey K, Figueroa M. A comparison of self-administered proprioceptive neuromuscular facilitation to static stretching on range of motion and flexibility. *J. Strength Cond. Res.* 28(1), 168–172 (2014).

31. Yıldırım M, Ozyurek S, Tosun O, Uzer S, Gelecek N. Comparison of effects of static, proprioceptive neuromuscular facilitation and Mulligan stretching on hip flexion range of motion: a randomized controlled trial. *Biol. Sport* 33(1), 89 (2016).

32. Yıldırım MŞ, Tuna F, Kabayel DD, Süt N. The cut-off values for the diagnosis of hamstring shortness and related factors. *Balkan Med. J.* 35(5), 388 (2018).

33. Haji Hasani A, Bakhtiari AH, Amoozadeh Khalili M. Comparative study of static stretch and hold relax on increasing the motion range of knee extension and flexibility of shortened hamstring muscles of male students in semnan. *Middle East J. Rehab. Health* 1, 2 (2014).

34. Bolívar YA, Munuera PV, Padillo JP. Relationship between tightness of the posterior muscles of the lower limb and plantar fasciitis. *Foot Ankle Int.* 34(1), 42–48 (2013).

35. White LC, Dolphin P, Dixon J. Hamstring length in patellofemoral pain syndrome. *Physiotherapy* 95(1), 24–28 (2009).

36. Mistry GS, Vyas NJ, Sheth MS. Comparison of hamstrings flexibility in subjects with chronic low back pain versus normal individuals. *J. Clin. Exp. Res.* 2(1), 85 (2014).

37. Kaur M, Paul R, Kumar S, Arora R, Arora L. A randomized controlled trial to compare the effectiveness of static stretching versus PNF stretching of hamstring muscles following superficial heat in athletes. *Int. J. Sci. Res. Pub.* 4(7), 1–4 (2014).

38. Lim K-I, Nam H-C, Jung K-S. Effects on hamstring muscle extensibility, muscle activity, and balance of different stretching techniques. *J. Phys. Ther. Sci.* 26(2), 209–213 (2014).

39. Ramanand CJ. A study to compare the effect of scapular taping along with stretching and stretching alone in patients with postural neck pain – randomised control trial. *Indian J. Physiother. Occ. Ther.* 9(3), 1–6 (2015).

40. Ahmed H, Iqbal A, Anwer S, Alghadir A. Effect of modified hold-relax stretching and static stretching on hamstring muscle flexibility. *J. Phys. Ther. Sci.* 27(2), 535–538 (2015).
41. Ramachandran S, Paul J, Senthilkumar N, Sudhakar S, Tamilselvi. Comparative effect of pnf stretching techniques on hamstring flexibility. *Int. J. Med. Exercise Sci.* 4(1), 443–447 (2018).
42. Nagarwal A, Zutshi K, Ram C, Zafar R, Hamdard J. Improvement of hamstring flexibility: a comparison between two PNF stretching techniques. *Int. J. Sports Sci. Engineer.* 4(1), 25–33 (2010).
43. Youdas JW, Krause DA, Hollman JH, Harmsen WS, Laskowski E. The influence of gender and age on hamstring muscle length in healthy adults. *J. Orthopaed. Sports Phys. Ther.* 35(4), 246–252 (2005).
44. Drust B, Waterhouse J, Atkinson G, Edwards B, Reilly T. Circadian rhythms in sports performance: an update. *Chronobiol. Int.* 22(1), 21–44 (2005).
45. Davis DS, Quinn RO, Whiteman CT, Williams JD, Young CR. Concurrent validity of four clinical tests used to measure hamstring flexibility. *J. Strength Cond. Res.* 22(2), 583–588 (2008).
46. Stillman BC. *An investigation of the clinical assessment of joint position sense [PhD thesis]*. The University of Melbourne, Victoria, Australia (2000).
47. Ogard WK. Proprioception in sports medicine and athletic conditioning. *Strength Cond. J.* 33(3), 111–118 (2011).
48. Pincivero DM, Bachmeier B, Coelho AJ. The effects of joint angle and reliability on knee proprioception. *Med. Sci. Sports Exerc.* 33(10), 1708–1712 (2001).
49. Erden Z. Dizin farklı açılarında eklem pozisyon hissi farklı mıdır? *Joint Dis. Rel. Surg.* 20(1), 47–51 (2009).
50. Relph N. *The measurement of knee joint position sense [PhD thesis]*. University of Salford, Salford, UK (2015).

• **Indicates that there is no gold standard in proprioceptive sense evaluation.**

51. Kotteeswaran K, Snigdha J, Alagesan J. Effect of proprioceptive neuromuscular facilitation stretching and dynamic soft tissue mobilization on hamstring flexibility in subjects with low back ache-single blinded randomised controlled study. *Int. J. Pharma Bio Sci.* 5(3), 228–233 (2014).
52. Rosenthal R, Cooper H, Hedges L. Parametric measures of effect size. *Handbook Res. Synth.* 621(2), 231–244 (1994).
53. Minshull C, Eston R, Bailey A, Rees D, Gleeson N. The differential effects of PNF versus passive stretch conditioning on neuromuscular performance. *Eur. J. Sport Sci.* 14(3), 233–241 (2014).
54. Chen C-H, Chen TC, Chen H-L, Lin M-J, Wu C-J, Tseng K-W. Effects of 8-week static stretch and PNF training on the angle-torque relationship. *J. Med. Biol. Engineer.* 29(4), 196–201 (2009).
55. Chen C-H, Nosaka K, Chen H-L, Lin M-J, Tseng K-W, Chen TC. Effects of flexibility training on eccentric exercise-induced muscle damage. *Med. Sci. Sports Exerc.* 43(3), 491–500 (2011).
56. Maddigan ME, Peach AA, Behm DG. A comparison of assisted and unassisted proprioceptive neuromuscular facilitation techniques and static stretching. *J. Strength Cond. Res.* 26(5), 1238–1244 (2012).
57. Puentedura EJ, Huijbregts PA, Celeste S *et al.* Immediate effects of quantified hamstring stretching: hold-relax proprioceptive neuromuscular facilitation versus static stretching. *Phys. Ther. Sport* 12(3), 122–126 (2011).
58. McNair PJ, Dombroski EW, Hewson DJ, Stanley SN. Stretching at the ankle joint: viscoelastic responses to holds and continuous passive motion. *Med. Sci. Sports Exerc.* 33(3), 354–358 (2001).
59. Taylor DC, Brooks DE, Ryan JB. Viscoelastic characteristics of muscle: passive stretching versus muscular contractions. *Med. Sci. Sports Exerc.* 29, 1619–1624 (1997).
60. Oliver KM, Florez-Paz DM, Badea TC, Mentis GZ, Menon V, de Nooij JC. Molecular development of muscle spindle and Golgi tendon organ sensory afferents revealed by single proprioceptor transcriptome analysis (2020). www.biorxiv.org/content/10.1101/2020.04.03.023986v1
61. Alter MJ. *Science of Flexibility.* Human Kinetics, IL, USA (2004).
62. Barrett KE, Barman SM, Boitano S, Brooks HL, Gökbel H. *Ganong'un Tıbbi Fizyolojisi.* Nobel Tıp Kitabevleri, İstanbul, Turkey (2015).
63. Sharman MJ, Cresswell AG, Riek S. Proprioceptive neuromuscular facilitation stretching. *Sports Med.* 36(11), 929–939 (2006).