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Original Article

Effects of traditional stretching versus self-myofascial release warm-up on physical performance in well-trained female athletes

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Abstract

Objective: The purpose of this study was to compare the acute effects of self-myofascial release (SMR) versus traditional stretching used as a part of warm-up on physical performance in well-trained female athletes. **Methods**: Twenty-three participants (age, 21.8±1.73 years; experience in sport, 114.8±30.5 months) were recruited. Isokinetic peak torque and muscle endurance ratio were measured during knee extension and flexion at 60°/s and 180°/s. Jump height, reactive strength index, and leg stiffness were measured using a jump mat during a counter-movement jump. Hamstring flexibility was measured using a sit-and-reach test. Three interventions were performed by all athletes randomly within 72 hours intervals. **Results**: The jump height and hamstring flexibility test scores improved significantly more after dynamic stretching (DS) as compared to SMR and static stretching (SS). The DS and SMR exercises were more effective than the SS exercises in terms of right and left knee muscle isokinetic strength both at 60°/s, and 180°/s. With regard to keeping muscular endurance ratio (%), SS exercises were found more effective than DS and SMR exercises for only the right knee at 180°/s, but not left knee muscle. **Conclusion**: Dynamic stretching and SMR showed better flexibility, strength, and jump performance than SS. Trainers and players may replace SS with DS and SMR to acutely improve muscle power, strength, and flexibility.

Keywords: Foam rolling, Flexibility, Isokinetic strength, Muscle endurance ratio, Jump height

Introduction

Traditionally, athletes perform warm-up routines before any training and competition for best performance and to prevent sports-related injuries. A warm-up routine generally consists of submaximal aerobic exercise (running, cycling, etc.) and subsequent stretching exercises, such as static stretching (SS), dynamic stretching (DS), ballistic stretching (BS), proprioceptive neuromuscular facilitation (PNF), or a combination of these stretching exercises[1,2]. Static stretching exercises include holding the muscle for 15-60 s below pain or discomfort (POD) limits to reduce muscle tension, increase joint range of motion (ROM), and decrease the injury risk of the muscle-tendon unit (MTU)[3].

Although SS exercises are preferred over other stretching exercises[3], a considerable number of studies[2,4-6] reported that when a muscle is stretched for more than 90 s (3 × 30 s), performance decrement (jumping, sprinting, agility, change of direction, etc.) is dependent on reducing MTU stiffness (tendon slack), inverse myotatic stretch reflex (autogenic inhibition), firing rate of the muscle spindle, and reduction in the number of muscle fibers that are subsequently activated[1-3].

Owing to possible performance decrement after the SS, athletes and trainers have started using the DS exercises instead of the SS in their warm-up routine. Dynamic stretching was defined by Fletcher & Jones[7] as "controlled movement through the active range of motion for each joint." During DS exercises, the joint or limb is stretched with a

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movement that resembles that of a sports skill[1,6]. Dynamic stretching exercises are generally performed in couple sets of 10-20 s duration at a velocity of 50-100 bpm[9]. It is generally accepted that DS effectively increases flexibility, muscle strength, sprint performance, jump performance, and agility performance[9-11].

Performance enhancement after DS exercises is attributed to movement rehearsal, increased motor unit activation or reflex sensitivity, producing post-activation potentiation (PAP), increasing muscle and core temperature, decreasing MTU viscosity, depending on muscle and core temperature, lowering resistance to stretch, and increasing joint ROM[2,9].

In the last decade, a massage type called self-myofascial release (SMR) has been considered as an alternative to DS or SS exercises for increasing performance, recover from exhausting exercise, restore fascia, and as a sport-specific warm-up tool[12,13]. Self-myofascial release can be applied using a foam roller massage bar with different densities, sizes, lengths, and materials. The SMR is believed to have effects similar to those of massage, according to the American Massage Therapy Association[14]. During foam rolling (FR), individuals use their own body mass on a foam roller to exert pressure on soft tissues. The motions place both direct and sweeping pressure on the soft tissue, stretching it and generating friction between it and the foam roller[15].

It has been reported that SMR can be used safely because it increases ROM, alleviates muscle pain, supports recovery, and increases strength[16,17]. After the SMR, increasing performance is attributable to changing a muscle's viscoelastic properties, decreasing fascial tenderness by activating golgi tendon organs and mechanoreceptors (Ruffini's corpuscles, Pacinian corpuscles, etc.), increasing mitochondrial biogenesis, and increasing blood flow, possibly by increasing angiogenesis and vascular endothelial growth factor[15], as well as psychological benefits by decreasing anxiety and enhancing mood and relaxation[18].

There are contradictory results obtained by studies that compared the effects of DS, SS, and FR on physical performance[4,8,19,20]. Su et al.[8] reported that FR is more effective than static and dynamic stretching in acutely increasing the flexibility of the quadriceps and hamstring muscles. Su et al.[8] also reported that FR is more effective than dynamic stretching in increasing the knee extension peak torque (ES: 0.59 vs. ES: 0.45). However, a recent systematic review and meta-analysis revealed no significant differences in the overall effects on performance (maximum voluntary contractions, jumping performance, and sprinting performance) between stretching and FR in healthy participants[4]. To the best of our knowledge, only a few studies compared the effect of SMR versus SS or DS on the physical performance of athletes. Perhaps the only study comparing the effect of SS and DS versus SMR on the physical performance of athletes together is the study by Su et al[8]. As far as we know, the current study may be the second study aiming at comparing the effectiveness of SS and DS versus SMR together. The results of the current study will provide new scientific support for using self-myofascial release versus traditional stretching among athletic populations.

Based on contradictory results of traditional stretching (static stretching and dynamic stretching) versus FR on acute effects of physical performance, this study aimed to examine and compare acute effects of SMR, SS, and DS used as a part of warm-up on flexibility, isokinetic strength (60°/s and 180°/s), muscle endurance ratio (180°/s), vertical jump height (VJH), reactive strength index (RSI), and leg stiffness (K_{leg}) of well-trained female athletes.

Material and Methods

Subjects

Twenty-three well-trained female athletes (age, 21.8±1.73 years; weight, 62.2±6.0 kg; height, 169.9±6.1 cm; experience in sport, 114.8±30.5 months; and weekly training, 8.4±2.1 h) recruited from the Turkey Women's Handball Super League (n=11) and Turkey regional women's basketball leagues (n=12). The upper age limit for inclusion was determined as 40 years. Prior to the start of the study, all the players were fully informed about the study protocols and risks associated with the study. Written informed consent was obtained from all the players. Inclusion criteria were: a) absence of musculoskeletal injuries for at least six months before the study; b) age of 18 years or above; c) at least three years of experience in sports; d) a sports license for the 2021-2022 sport seasons; and e) active participation in sport training (≥4-6 times per week). Exclusion criteria were: a) reporting usage of any ergogenic supplements, such as creatine, amino acids, and protein powder, b) a history of orthopedic problems, such as hamstring-quadriceps injuries, fractures, surgery, or pain in the spine or hamstring-quadriceps muscle over the past 6 months. Sample size required was estimated to be 21, with an alpha level of 0.05, power of 0.80, and effect size of 0.59 derived from the study of Su et al.[8] to detect the differences between conditions in relative knee extensor torque after FR (pre: 2.17±0.44 $N.m.Kg^{-1}$ versus post: 2.34±0.31 $N.m.Kg^{-1}$). The study protocol was approved by the Eskişehir Technical University Ethics Committee (protocol number: 44505). This study was conducted in accordance with the principles of the Declaration of Helsinki.

Procedures

This study was conducted between January and February 2022 at the Human Performance Laboratory of Eskişehir Technical University Sports Science Faculty. All trials were performed at the same time of the day to avoid any effect of circadian variations on the study results. The players were informed about avoiding strenuous physical activity 24 h before each session, and also requested to maintain their regular sleep and nutritional habits and avoid the intake of excessive caffeine (more than two cups of coffee) 6 h before the testing and alcohol intake 24 h before the testing. The players performed one of three different exercise protocols (SS, DS, and SMR) for an equal duration in each session in a randomized, balanced order. The exercise protocols were

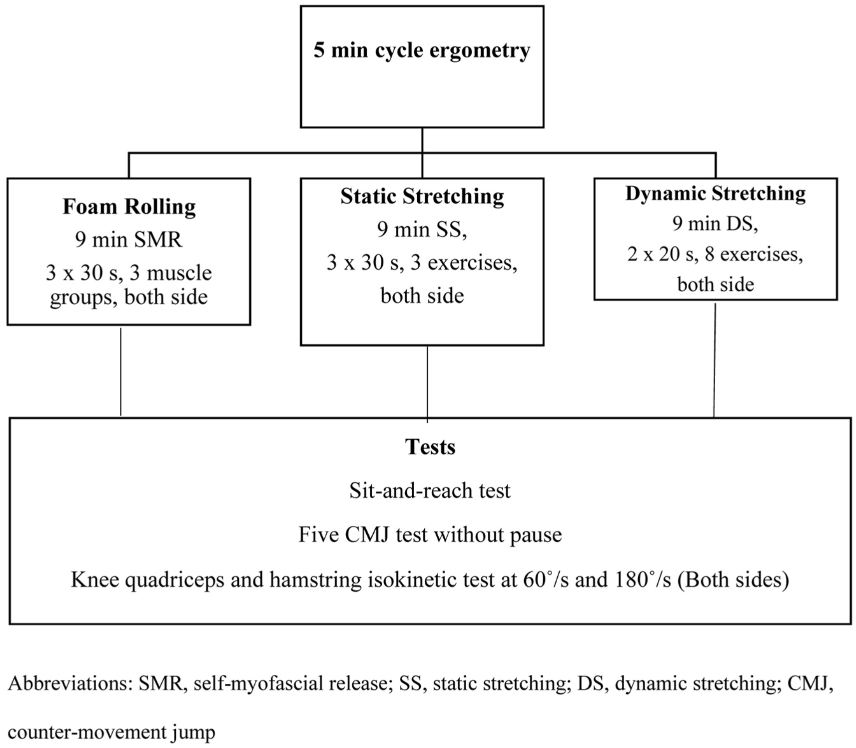

Figure 1. Summary of study design.

separated by at least 72 h to allow recovery. At the beginning of each session, the participants warmed-up for 5 min on a cycle ergometer (834 E, Monark, Vansbro, Sweden) at 60–80 rpm and a resistance of 50 W. After 2 min, the players performed one of the exercise protocols in a randomized order. Each exercise session was 9 min. After 2 min, the players performed the sit and reach, countermovement jump, and knee isokinetic strength tests 2 min apart. Flowchart of the study is presented in Figure 1. Body mass and height of the players were measured to the nearest 0.5 kg and 0.5 cm, respectively (Seca 710; Seca, Birmingham, United Kingdom) with the participant wearing sports tights and barefooted.

Exercise Protocols

SS exercises

During the SS exercise, the participants performed three different exercises (quadriceps stretch, semi-straddle stretch, and spinal twist-pretzel). Each exercise was performed for each limb for 3 x 30 s to the point of discomfort. The participants rested for 30 s between the exercises.

DS exercises

During the DS exercise, the participants performed eight different exercises (straight leg kick, back kick, butt kick, high knee skipping, knee-to-chest, leg cradles, karaoke right and left, and walking lunge). Each exercise lasted for 20 s and was performed in two sets with a 15 s inter- set 30 s inter-exercise rest intervals. Each DS exercise was performed, as quickly as possible.

SMR exercises

The participants rolled a grid foam roller cylinder (height: 13 inches; diameter: 5.5 inches; Trigger Point, USA) from the top of the selected muscle to the bottom, and then returned to the starting position[13]. For the foam roller session, they were instructed to use an application rate of five rolls per 30 s of targeting the area with as much pressure as they could[8]. The SMR exercises were applied to each side of the hamstring, quadriceps, and hip at 3 × 30 s with a 15-s passive rest. The participants were allowed 30 s of rest between the exercises.

Measures

Sit-and-reach test

The sit-and-reach test was used to assess lower body flexibility. A sit-and-reach box (Lafayette Instrument Company, Lafayette, IN, USA) with a scale marked on the upper side was placed against the wall. The test was performed according to the study by Belkhir et al.[21]. The players removed their shoes and sat on the floor with their legs fully extended and feet against the box. Placing one hand on top of the other and keeping their legs straight, the players reached forward, as far as possible, while

Table 1. Results of pairwise comparison of hamstring flexibility, jumping height, reactive strength index, and leg stiffness.

Treatments	Flexibility (cm) (n=23)				Jumping Height (cm) (n=23)			
	Mean ± SD				Mean ± SD			
	SS 36.4±5.7	DS 38.3±6.2	SMR 36.9±5.9		SS 22.3±3.0	DS 25.0±3.7	SMR 23.8± .0	
	MD	SE	p	ES	MD	SE	p	ES
SS -DS	- 1.89	0.22	<0.01*	1.1^{d}	- 2.68	0.46	<0.01*	1.0^{d}
SS - SMR	- 0.48	0.34	0.534	0.5^{d}	- 1.47	0.43	0.002*	4^{d}
DS - SMR	1.41	0.34	0.001*	1.0^{d}	1.21	0.53	0.03*	1.1^{d}
Treatments	RSI (n=23) Mean ± SD				Leg Stiffness (kN/m) (n=23) Mean ± SD			
	Mean ± SD				Mean ± SD			
	SS 0.528±0.275	DS 0.50±0.27	SMR 0.57± 0.33		SS 6.92±6.40	DS 6.50±6.81	SMR 7.07±7.10	
	M [Min Max]	Z	p	ES	M [Min Max]	Z	p	ES
SS - DS	0 [-0.02 - 0.06]	-0.5	0.651	0.1^{r}	0.37 [-0.22 - 1.29]	-1.4	0.176	0.2^{r}
SS - SMR	-0.01 [-0.09 - 0.06]	-1.0	0.305	0.1^{r}	0.06 [-0.76 - 1.43]	-0.2	0.867	0.03^{r}
DS - SMR	-0.03 [-0.08 - 0.02]	-1.4	0.148	0.2^{r}	-0.28 [-1.28 - 0.09]	-1.5	0.144	0.2^{r}

*cm, centimeters; ES, effect size; SS, static stretching; DS, dynamic stretching; SMR, self-myofascial release; RSI, Relative Strength Index; M, Median; MD, Mean difference; kN/m, kilonewton-meter; SD, standard deviation; Min, minimum; Max, maximum; M, mean difference; SE, standard error. *p<0.05.*

sliding their fingers along the measurement scale on top of the box. The players were asked to hold the final position for 3 s, and the measurements were recorded to the nearest centimeter. After familiarization, each player performed two trials with the best score being recorded for the analysis[21].

Counter movement jump test

Vertical jump height, RSI, and K_{leg} stiffness were assessed using the counter-movement jump test (CMJ). The VJH was recorded to the nearest millimeter using a flight-time based jump mat (Fusion Sport Smart Jump mat, Australia). At the start of test, the participants stood in the center of the jump mat and their body mass was recorded to the device. When performing the five CMJ tests without a pause, the participants were asked to: 1) keep the trunk as vertical as possible, and the hands were placed on the hips; and 2) flex their knees at ~90° in the transition between the eccentric concentric phases[22]. All the participants performed one trial. The mean value of the five CMJ tests was accepted as VJH and used for statistical analysis. The RSI and K_{leg} were determined to be the same as the average VJH.

Knee flexor and extensor isokinetic tests

Isokinetic knee extensor and flexor muscle strength was assessed using a Cybex isokinetic dynamometer (Humac Norm Testing & Rehabilitation System, USA). Participants sat in an upright position on a Cybex dynamometer chair with their trunk and limb stabilized by straps to minimize extraneous body movements[8]. The limb to be assessed was then placed on a dynamometer. The lateral femoral condyle was used as the bony landmark to align the axis of the knee rotation with that of the dynamometer[8]. The dominant side of the knee extensor and flexor muscles were defined as the preferred leg used to kick a soccer ball[23]. Testing at each velocity consisted of three submaximal repetitions for the warm-up[24]. Participants were asked to perform knee extension and immediate knee flexion, as fast as they could, five times at an angular velocity of 60°/s[8], and 30 repetitions at 180°/s to determine the muscular endurance ratio of the quadriceps and hamstring muscles[2]. The peak torque in five trials for each muscle group at 60°/s was recorded. After the testing at 180°/s, the muscular endurance ratio was determined automatically using the Cybex dynamometer software. The endurance ratio (%), defined as the work performed in the last five repetitions, was divided by the work performed in the first five repetitions and expressed as a percentage to obtain an endurance ratio[25]. This provides an indication of the participant's ability to maintain the initial workload. All measurements were converted to Newton-meters[23]. Each participant was provided with 5 min of rest between the dominant and non-dominant sides, as well as 60°/s and 180°/s isokinetic test sessions[23].

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 23.0 software (IBM Corp., Armonk, NY, USA). Data are expressed as mean ± standard deviation (SD) or median and interquartile range (25th and 75th percentiles)

Table 2. Results of pairwise comparison for knee extensor-flexor peak torques at 60°/s isokinetic measurement.

Treatments	Right Knee Extensor (Nm) (n=23)				Right Knee Flexor (Nm) (n=23)			
	Mean ± SD				Mean ± SD			
	SS 132.4±28.9	DS 140.4±25.6	SMR 138.0±24.6		SS 90.0±15.5	DS 94.9±18.5	SMR 94.7±17.1	
	M [Min Max]	Z	p	ES	MD	SE	p	ES
SS-DS	-10 [-32 - 31]	-2.3	0.024*	0.4^{r}	-4.83	1.65	0.023*	0.7^{d}
SS-SMR	-7 [-30 - 37]	-2.1	0.038*	0.3^{r}	-4.65	1.33	0.006*	0.9^{d}
DS-SMR	1 [-14 - 22]	-1.5	0.140	0.2^{r}	0.17	1.16	0.998	0.04^{d}
Treatments	**Left Knee Extensor (Nm) (n=23)**				**Left Knee Flexor (Nm) (n=23)**			
	Mean ± SD				Mean ± SD			
	SS 125.0±24.0	DS 130.7±21.9	SMR 131.9±22.7		SS 88.3±13.5	DS 89.7±12.9	SMR 91.0±15.0	
	MD	SE	p	ES	MD	SE	p	ES
SS-DS	-5.67	2.88	0.182	0.8^{d}	-1.39	1.79	0.999	0.5^{d}
SS-SMR	-6.87	2.93	0.086	1.2^{d}	-2.74	2.08	0.603	0.6^{d}
DS-SMR	-1.17	2.28	0.998	0.3^{d}	-1.35	1.50	0.998	0.2^{d}

*ES, effect size; SS, static stretching; DS, dynamic stretching; SMR, self-myofascial release; SD, standard deviation; MD, mean difference; SE, standard error; M, Median; Min, minimum; Max, maximum; Nm, Newton-meter. *p<0.05.*

Table 3. Results of pairwise comparison for knee extensor-flexor peak torques (Newton-meter) at 180°/s isokinetic measurement.

Treatments	Right Knee Extensor (Nm) (n=23)				Right Knee Flexor (Nm) (n=23)			
	Mean ± SD				Mean ± SD			
	SS 87.7±22.1	DS 86.4±25.5	SMR 89.7±14.2		SS 63.5± 1.7	DS 68.3±15.1	SMR 65.2±14.3	
	M [Min Max]	Z	p	ES	MD	SE	p	ES
SS-DS	-4 [-18 - 102]	-1.4	0.153	0.21^{r}	-4.83	1.76	0.035*	0.7^{d}
SS-SMR	-2 [-20 - 15]	-1.2	0.243	0.18^{r}	-1.74	1.60	0.870	0.3^{d}
DS-SMR	2 [-102 - 15]	-0.5	0.588	0.07^{r}	-3.09	1.66	0.228	0.9^{d}
Treatments	**Left Knee Extensor (Nm) (n=23)**				**Left Knee Flexor (Nm) (n=23)**			
	M ± SD				M ± SD			
	SS 81.5±15.9	DS 85.2±15.9	SMR 85.2±17.0		SS 63.3±11.2	DS 65.8±12.7	SMR 66.5±13.4	
	M [Min Max]	Z	p	ES	M [Min Max]	Z	p	ES
SS-DS	-3 [-22 - 10]	-1.7	0.082	0.25^{r}	-3 [-12 - 15]	-1.9	0.055	0.3^{r}
SS-SMR	-4 [-17 - 13]	-2.4	0.014*	0.35^{r}	-3 [-14 - 16]	-2.2	0.026*	0.3^{r}
DS-SMR	-1 [-15 - 22]	-0.1	0.935	0.01^{r}	-1 [-12 - 14]	-0.7	0.497	0.1^{r}

*ES, effect size; SS, static stretching; DS, dynamic stretching; SMR, self-myofascial release; SD, standard deviation; MD, mean difference; SE, standard error; M, Median; Min, minimum; Max, maximum; Nm, Newton-meter. *p<0.05.*

in parametric or non-parametric tests, respectively. The normality assumption of the related data was checked using the Shapiro-Wilk test, and the sphericity assumption of the data was examined using the Mauchly's test of sphericity. A one-way repeated-measures analysis of variance (ANOVA) or Friedman test was used to compare each variable between the mean scores of the three different measures from stretching exercises according to the normality test results. Descriptive statistics are reported as median [$25–75^{th}$ percentile] for non-parametric values in related Tables. The effect sizes of the differences were also reported [Wilcoxon signed rank test (r; 0.1=small, 0.3=medium, and 0.5=large

Table 4. Results of pairwise comparison for knee extensor-flexor endurance ratio at 180°/s isokinetic measurement.

Treatments	Right Knee Extensor (%) (n=23)				Right Knee Flexor (%) (n=23)			
	Mean ± SD				Mean ± SD			
	SS 76.0±13.1	DS 71.4±13.3	SMR 71.8±10.8		SS 83.7±16.4	DS 76.7±12.4	SMR 77.1±11.2	
	M [Min Max]	Z	p	ES	M [Min Max]	Z	p	ES
SS-DS	-3 [-9 - 26]	-2.42	0.015*	0.4^{r}	5 [-18 - 33]	-2.37	0.018*	0.3^{r}
SS-SMR	-2 [-6 - 31]	-2.01	0.044*	0.3^{r}	4 [-12 - 26]	-2.37	0.018*	0.3^{r}
DS-SMR	-1 [-14 - 20]	-0.37	0.708	0.05^{r}	0 [-16 - 10]	-0.13	0.896	0.02^{r}
Treatments	Left Knee Extensor (%) (n=23)				Left Knee Flexor (%) (n=23)			
	Mean ± SD				Mean ± SD			
	SS 134.7±28.9	DS 139.9±27.1	SMR 139.7±29.3		SS 79.4±10.4	DS 76.4±9.02	SMR 76.5±7.34	
	M [Min Max]	Z	p	ES	M [Min Max]	Z	p	ES
SS-DS	-3 [-12 - 15]	-1.5	0.139	0.2^{r}	5 [-13 - 30]	-1.17	0.242	0.2^{r}
SS-SMR	2 [-12 - 15]	-1.3	0.184	0.2^{r}	0 [-17 - 38]	-1.08	0.279	0.1^{r}
DS-SMR	-1 [-13 - 9]	-0.6	0.530	0.09^{r}	0 [-13 - 18]	-0.07	0.944	0.01^{r}

*ES, effect size; SS, static stretching; DS, dynamic stretching; SMR, self-myofascial release; SD, standard deviation; MD, mean difference; SE, standard error; M, Median; Min, minimum; Max, maximum. *p<0.05.*

effect size) and ANOVA (Cohen's effect size d; 0.2=small, 0.5=medium, and 0.8=large effect size)]. A p value of <0.05 was considered statistically significant.

Results

A pairwise comparisons of the SS, DS, and SMR in terms of hamstring flexibility, VJH, RSI, and K_{leg} are presented in Table 1. The pairwise comparison of the treatments showed that the DS was more effective than the SS (p<0.01), and the DS exercises were more effective than the SMR exercises in terms of hamstring flexibility (p=0.01) and VJH (p<0.05) (Table 1). Based on these results, we conclude that the DS exercises are more effective than the SS and SMR exercises, and the least effective treatments are the SS exercises in terms of hamstring flexibility and VJH.

Table 2 shows that the DS and SMR exercises were more effective than the SS exercises in terms of right knee extensor (p<0.05) and flexor muscle isokinetic strength at 60°/s, but the DS and SMR treatments were not superior to each other (p>0.05). When it comes to the isokinetic strength of the left knee muscles at 60°/s, no statistical differences were found among the treatments in terms of the left knee muscle isokinetic strength values at 60°/s (p>0.05) (Table 2). When the knee extensor and flexor muscles were tested at 180°/s, statistical differences were found only in the right knee flexor muscle peak torque in favor of the DS exercises in the pairwise comparison of the DS and SS exercises (p<0.05) (Table 3). On the other hand, for the left knee flexor and extensor muscles tested at 180°/s, statistical differences were found in a pairwise comparison of SS-SMR measurements in favor of SMR treatments (p<0.05). There were no statistical differences in the pairwise comparison of SS-DS and DS-SMR treatments in terms of the left knee flexor and extensor muscle test values at 180°/s (Table 3) (p>0.05). Table 4 has shown that the SS exercises were more effective than the DS and SMR exercises in keeping high muscular endurance ratio (%) of the right knee flexor and extensor muscles at 180°/s (p<0.05). A pairwise comparison of DS and SMR exercises showed no statistical differences in the muscular endurance ratio of the right knee flexor and extensor muscles (Table 4). At the same time, there were no statistical differences among the treatments when the left knee flexor and extensor muscles were tested for keeping high muscular endurance ratio at 180°/s (p>0.05) (Table 4).

Discussion

The purpose of this study was to evaluate and compare the acute effects of SMR, SS, DS used as a part of warm-up on flexibility, isokinetic strength (60°/s and 180°/s), muscle endurance ratio (180°/s), VJH, RSI, and K_{leg} in well-trained female athletes. The main findings of this study are as follows: (a) DS produces better hamstring flexibility than SMR, and SS is not effective in increasing flexibility, acutely; b) DS is more effective than SMR and SS in increasing VJH, acutely; c) DS and SMR exercises are more effective than SS exercises in terms of right knee extensor and flexor muscle isokinetic strength at 60°/s, but the DS and SMR treatments are not superior to each other; d) right knee flexor muscle peak torque improved only after DS, when a pairwise comparison of SS-DS at 180°/s was made; e) left knee flexor and extensor muscle torque only improved after SMR, when a pairwise comparison of SS-SMR at 180°/s was made; and f) SS exercises seem to be more effective than DS and SMR in keeping high muscle endurance ratio (%) of the right knee flexor and extensor muscles at 180°/s. Besides, DS and SMR exercises have no any effect in maintaining high muscle endurance ratio of the right knee flexor and extensor muscles. At the same time, there were no statistical differences among treatments when the left knee flexor and extensor muscles were tested to maintain a high muscular endurance ratio at 180°/s.

Flexibility or ROM is one of the fitness components, and it has been considered an essential performance in team sports and should therefore be incorporated into the warm-up routine[26]. Although it has been considered as an important warm-up component in sports because of its potentially positive effect on flexibility or ROM and musculotendinous injury prevention[27]. There is no agreement on what kind of stretching exercises produce better flexibility or ROM performance[2,9,27]. Some studies have indicated that SS produces better flexibility or ROM performance[26,28-30], while others indicated that DS has demonstrated improved flexibility or ROM performance rather than SS[9,31-33], or no differences between DS and SS in increasing flexibility or ROM performance acutely[34-37]. Studies have reported that SS produces greater flexibility or ROM than DS; they attributed flexibility enhancement to decreased MTU stiffness, and SS increases viscoelasticity, decreases stiffness of muscular and connective tissues, and increases tolerance to stretch[2,9,38].

With regard to the DS mechanism, flexibility increase after DS is explained by movement rehearsal, increasing muscle and body temperature, decreasing the viscous resistance of muscles, and increasing blood flow to the muscles, with the latter resulting in enhanced oxygen delivery and waste removal and faster nerve-impulse conduction[2,9,36].

Another exercise modality used to increase flexibility is SMR, which is performed using foam roll and various massagers[16,17]. However, there are conflicting results regarding the effectiveness of SMR on flexibility and muscle performance[17,20,35,39,40]. Konrad et al.[35] reported that SMR had no significant effect on increasing flexibility or ROM compared to DS and SS. Sağıroğlu et al.[40] also reported that SMR had no advantage over SS in terms of hamstring flexibility. In contrast to the study by Konrad et al.[35] and Sağıroğlu et al.[40], the study by Smith et al.[39] reported that FR produces better hamstring flexibility than the control group, but FR does not differ from foam DS in increasing hamstring flexibility. Behara and Jacobson[20] also reported that hip flexibility scores were significantly higher after DS and SMR; however, DS and SMR treatments did not differ from each other. Even if there was no pairwise comparison of SS and SMR, or DS and SMR, Macdonald et al.[17] reported improvement in knee joint ROM after SMR compared to pre-test and control measurements. Flexibility or ROM increase is generally attributed to changes in the thixotropic property of the fascia, which means promoting the fascia to take on a more fluid-like form, leading to the restoration of soft tissue extensibility and greater flexibility[8,41]. The increased flexibility may also be attributed to the vigorous pressure placed on the soft tissue during FR. When pressure is applied to the soft tissue, cutaneous receptors located in the fascia may be activated to produce stretch tolerance and reciprocal inhibitions, which can lead to decreased tension and increased fascia flexibility[8,42,43].

To the best of our knowledge, this study is one of the few that aimed to evaluate the DS, SS, and SMR in terms of flexibility and ROM[8,34,44]. One study reported that there was no significant increase in hip ROM after SMR, but SS and DS improved hip ROM at the same rate[34]. Another study also reported that SMR produced better flexibility than either DS or SS[44]. Similar to the results of Nichol et al.[44], Su et al.[8] reported that SMR was more effective than SS and DS in increasing flexibility of the quadriceps and hamstring muscles.

Regarding the effect of DS and SS on jumping performance, Perrier et al.[36] concluded that DS has a greater effect than SS in improving CMJ performance. Meerits et al.[45] concluded that squat jump performance improved after DS, but it decreased after SS in male track and field athletes. Similar to Meerits et al.[45], Galazoulas[46] also concluded that CMJ height scores decreased after SS, but improved after DS. Some researchers have reported conflicting results regarding the effects of DS and SS on jump performance[47,48]. Paradisis et al.[47] reported that jump performance decreased after DS and SS in adolescent boys and girls. Dalrymple et al.[48] also reported no significant difference between SS and DS in female collegiate volleyball players. Performance improvement after DS is attributed to elevated muscle and body temperatures, stimulation of the nervous system, and/or decreased inhibition of antagonist muscles and PAP[2,9,27]. However, performance decrement after SS is generally explained by increased muscle compliance to stretch, lower motor unit activation, lower MTU stiffness, and viscosity[2,28]. However, some authors have argued that SS for less than 90 s did not exhibit subsequent performance impairments[2,9,27,28]. Another factor affecting the performance decrement after SS is the training level of the participants. Egan et al.[49] reported that trained athletes may be less susceptible to stretching than are untrained individuals. Babault et al.[50] also suggested that SS could be performed with smaller and shorter detrimental effects during warm-up in individuals with high flexibility than in individuals with low flexibility.

Regarding the comparison of the effects of SMR to SS or DS on jump performance, Kopec et al.[51] reported that neither DS nor FR significantly or practically affects the VJH performance. Smith et al.[39] reported that FR does not seem to enhance VJH, either alone or in combination with DS. Contrastingly, Årneby[52] concluded that DS is more effective than SMR in terms of improving VJH.

Considering the pairwise comparison of SS and SMR, results obtained from literature Wärnström[53] concluded that both SMR and SS were equally effective at eliciting acute bilateral standing long jump performance enhancement in healthy recreational athletes. Contrastingly, Sağıroğlu et al.[40] argued that SS leads to statistically significant decrements in CMJ, whereas SMR has a statistically insignificant CMJ decrement.

In the present study, RSI and K_{leg} were also evaluated. Although the present study did not find any positive or negative changes after the treatment with SMR, DS, and SS. Werstein and Lund[54] reported that DS is more effective than SS in improving RSI in female Division I soccer players and female club rugby players. However, Abels et al.[55] reported no statistical difference in RSI score after FR.

Regarding the comparison of SMR to SS or DS effect on isokinetic strength, Ayala et al.[56] reported that short and contextualized lower limb static and DS routines have no stretching-induced strength and power deficit or improvement effects on concentric and eccentric knee flexion and extension isokinetic movements at three different speeds (60, 180, and 240°/s) in recreational athletes. Alp et al.[57] also reported that SS and/or DS had no any effect on concentric strength at 60°/s and 180°/s of the knee and ankle flexor and extensor muscles in well-trained male taekwondo athletes. In contrast to the findings of Ayala et al.[56] and Alp et al.[57], the study by Fekhfekh et al.[58] reported a decrease in knee flexor and extensor muscles when they were tested at 60°/s and 180°/s after the SS exercises when it was compared to DS exercises. However, Şekir et al.[59] concluded that significant decreases following SS and significant increases following DS during quadriceps and hamstring muscle actions in both concentric and eccentric testing modes at 60°/s and 180°/s in well-trained female athletes. Contrastingly, as far as the effects of SMR on isokinetic strength is concerned, Li[60] concluded that SMR had no effect on performance of the leg quadriceps isokinetic strength at 60°/s. Another study aimed to evaluate the effect of myofascial release (MFR), which was applied by a therapist as different from self-myofascial release. The study reported that MFR had no acute effect on knee extensor peak torque, total work, and mean power at 60°/s and 120°/s.[61] Cornell and Ebersole[62] reported that SMR does not influence the peak knee extension force output in recreationally active participants.

To evaluate the acute effects of SMR, SS, and DS on VJH and isokinetic strength performance, we were able to perform only two studies[8,44]. Nichol et al.[44] reported that DS produces a better VJH than either DS or SS, similar to the current study. Additionally, Su et al.[8] reported improvements in knee extension peak torque after FR and DS, but not after SS. In the present study, the DS and SMR exercises were more effective than the SS exercises in terms of the isokinetic strength of the right knee extensor and flexor muscles at 60°/s. We can say that the results of the study are similar to the results of Su et al.[8].

In the current study, isokinetic knee flexor and extensor muscle performance was evaluated on both the right and left sides, but significant differences were only found for the right knee extensor and flexor muscles after the DS and SMR at 60°/s. This result may have been obtained because the dominant side of all the participants was on the right side. They use their right extremities much more than their left extremities in both daily and sports life. However, when the right and left knee extensor and flexor muscles were tested at 180°/s, complicated results were obtained. For example, the peak torque of the right knee flexor muscle improved only after DS. The left knee flexor and extensor peak torques improved only after the SMR.

In the present study, the muscle endurance ratio was also evaluated (30 reps for each side at 180°/s). In the pairwise comparisons, SS was found to be more effective in maintaining a high muscle endurance ratio than SMR or DS for the right knee flexor and extensor muscles. We could not find any manuscript to compare the results of the present study. As we understand, this result requires further research to interpret it.

Studies that examined the above have reported contradictory results, regarding the effectiveness of different treatments on flexibility and muscle performance. As explained in the studies presented above, these contradictory results may be caused by the age and sex of participants, participants' fitness level (strength, flexibility, etc.), participants' status (amateur, professional or recreational athletes, etc.), or volume, intensity, and type of treatment.

This study has several limitations. The major limitation is that evaluation was not carried out before and after individual interventions in the study. In future studies, all variables should be evaluated before and after each intervention to be able to obtain more reliable results. Other limitations are: a) the study had no familiarization sessions, b) the players lacked experience in using a foam roller, and c) the players in the study were all active players in the mid-competition season. Although we asked them to participate in all sessions in full rest, this may not have been possible because of their match and training schedule.

Although the obtained results are not enough to clarify the research objective, the study results deserve consideration when it comes to comparing the effectiveness of SS and DS versus SMR in terms of improving the physical performance of athletes. As is explained in the introduction section, the current study may be only the second study aiming at comparing the effectiveness of SS and DS versus SMR together.

Conclusion

Dynamic stretching produces better hamstring flexibility and VJH than SMR or SS does. Dynamic stretching and SMR exercises were more effective than SS exercises in terms of the isokinetic strength of the right knee extensor and flexor muscles at 60°/s and 180°/s. Static stretching is only superior to DS and SMR in maintaining a high muscle endurance rate for the dominant leg's knee flexor and extensor muscles. Based on the results of the present study, trainers and players may replace SS with DS and SMR to improve muscle power, muscle strength, and flexibility.

Authors' contributions

Data collection: Barış Gürol; methodology: Cem Kurt, Barış Gürol, İlbilge Özsu Nebioğlu; fund collection: Barış Gürol; writing-original draft preparation: Cem Kurt; writing-review and editing: Barış Gürol, İlbilge Özsu Nebioğlu. All authors read and approved the final version of the manuscript

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