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Acute Effects of Combining Dynamic Stretching and Vibration Foam Rolling Warm-up on Lower-Limb Muscle Performance and Functions in Female Handball Players

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Abstract

Chen, CH, Chiu, CH, Tseng, WC, Wu, CY, Su, HH, Chang, CK, and Ye, X. Acute effects of combining dynamic stretching and vibration foam rolling warm-up on lower-limb muscle performance and functions in female handball players. *J Strength Cond Res* XX(X): 000–000, 2021—The purpose of this study was to compare the acute effects of 3 warm-up protocols on knee flexor and extensor muscles performance in elite female collegiate handball players. Ten female handball players with poor hamstring flexibility completed 3 randomly sequenced experimental visits. During each visit, a different warm-up protocol (general running warm-up [GW], dynamic stretching [DS], or DS combined with vibration foam rolling [DS + VR]) was delivered before the subsequent tests: quadriceps and hamstring muscle stiffness, knee extension and flexion range of motion (ROM), knee joint position sense, knee extension and flexion isokinetic strength with hamstring-quadriceps strength ratio, and muscle endurance during fatiguing exercise. Relative to the GW, the DS + VR protocol resulted in significantly greater knee flexion ROM (mean ± *SD*: DS + VR = 79.4° ± 7.7°; GW = 69.3° ± 9.6°) and lower hamstring muscle stiffness (DS + VR = 253.33 ± 36.20 $N \cdot m^{-1}$; GW = 292.89 ± 24.28 $N \cdot m^{-1}$). In addition, the DS + VR protocol also yielded greater hamstring muscle endurance than the other 2 protocols did (fatigue percentage: DS + VR = 30.24% ± 10.84%; GW = 41.40% ± 8.98%; DS = 42.22% ± 9.42%). Therefore, the results of this experiment suggest that it can be more beneficial for the female handball players to warm-up with the DS + VR, rather than the GW and DS protocols.

Key Words: hamstring strain, knee joint, preconditioning, fatigue, recovery, flexibility

Introduction

A handball match involves numerous sprints, accelerations, pivots, changes of direction, and jumps (24,28). The most common injuries in handball players are around the knee joint (8–26%) (1,30), especially to the anterior cruciate ligament (ACL). Of all the risk factors, neuromuscular fatigue is a factor that weighs progressively more during a competition or training session because fatigue results in a deficit in knee flexor and extensor muscle strength as well as the increased muscle strength imbalance (17). Comparing with men, the risk of ACL injury is higher in female handball players (14,25).

Stretching is a common warm-up exercise for a variety of athletic populations. It not only enhances flexibility and athletic performance but also helps prevent sports injury (7,38). Studies have revealed that compared with static stretching (SS), dynamic stretching (DS) increases core muscle temperature and blood flow rate and enhances athletic performance (3,26,32). However, controversial findings have also been reported (9,15,31). For example, DS (for approximately 12 minutes) reportedly reduced the muscular endurance performance of the lower limbs (31). In addition, general running warm-up ([GW] running for 15 minutes on the treadmill at a velocity equivalent to 70% $\dot{V}O_2max$) combined with DS immediately reduced endurance running performance when compared with GW alone (39). Regarding muscular strength, DS had no effect on hamstring strength (37). However, it is worth mentioning that the influence of DS on dynamic isokinetic strength is velocity dependent, with impairment in low velocity ($60° \cdot s^{-1}$) but enhancement in high velocity ($300° \cdot s^{-1}$) (15). Finally, DS reduced knee extensor and flexor muscle imbalance (e.g., hamstring-quadriceps ratio) and had a greater negative effect on hamstring concentric and eccentric strength (9). Thus, current research results on the effect of DS on athletic performance and muscle functions remain inconsistent (26).

Recently, vibration foam rolling (VR) has increasingly become popular and has been used as a component in warm-up exercises. Studies have revealed that VR alone and VR combined with other warm-up modalities could improve athletic performance (16,18–20). However, relevant research is still limited, and results have been inconclusive regarding the efficacy of VR on athletic performance. For example, VR (3 sets of 20 seconds) on the ankle plantar flexor muscles significantly increased ankle range of

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motion (ROM) but had no effect on ankle maximal voluntary isometric contraction (13). However, Lee et al. (18) showed different findings: the VR significantly increased the quadriceps muscle strength. When combined with other warm-up exercises, VR may add some benefits. For example, DS followed by VR was effective improving the lower-limb flexibility, agility, as well as the explosive power of both the upper and lower limbs (16). Another study comparing DS alone vs. DS + VR suggested that the combination warm-up was not superior to DS alone in improving flexibility, power, and agility of the lower limbs in badminton athletes (19). However, DS + VR was more effective in decreasing quadriceps muscle stiffness. This, therefore, suggests that adding the VR portion to the warm-up protocol may potentially reduce the risk of sports injury.

Few studies have examined the effects of DS with and without VR on knee muscle functions and lower-limb muscle endurance during fatiguing exercises. Considering neuromuscular fatigue is a risk factor that progressively increases during a competition or training session, it is important to design special warm-up or preconditioning exercises to minimize this factor. Therefore, the purpose of this study was to investigate the acute effects of GW, DS, and DS + VR on knee joint ROM, quadriceps and hamstring muscle stiffness, knee joint position sense, knee extensions and flexion isokinetic strength, and muscle endurance in female handball athletes with poor hamstring flexibility. The results of the current study may help coaches or trainers select more beneficial warm-up modalities to reduce the risk of sport injury and potentially to improve athletic performance.

Methods

Experimental Approach to the Problem

To compare the effects of the 3 warm-up protocols (i.e., GW, DS, and DS + VR) on knee joint flexibility, muscle stiffness, joint position sense, isokinetic strength, and muscle endurance, a counterbalanced crossover design with repeated measurements was conducted. The subjects performed 3 separate warm-up conditions with a randomized order, and a 1-week interval was provided between consecutive experimental visits. During each experimental visit, the subjects completed one warm-up protocol and the subsequent measurement tests. Based on the effect sizes observed from a previous study (4), a priori power analysis (G*Power 3.1.9.7) suggested a minimum number of 9 subjects were required for this experiment.

Subjects

Ten collegiate female handball players (age = 21 ± 1 years; height = 162.7 ± 6.8 cm; body mass = 61.67 ± 7.30 kg; mean ± *SD*) with poor hamstring flexibility (passive straight leg raise ≤70°) (12) from the Taiwanese collegiate national champion team volunteered to participate in this study. On average, they trained 5 times a week (3–4 hours per session). Before any experimental testing, all subjects completed and signed the written informed consent forms. All the experimental procedures in this investigation were in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Jen-Ai Hospital (approval number: IRB-108-61). All subjects were requested to refrain from vigorous physical activities and training for at least 72 hours before all the experimental visits. On all experimental visit days, subjects were instructed not to consume alcohol or caffeine. In addition, extra effort was taken to ensure the tests were conducted at around the same time of day for each subject, and the subjects were asked to maintain their hydration, sleep, and nutritional levels as much as they could during the entire study.

Procedures

Before the first testing day, all subjects attended an introductory session, during which they were fully familiarized with the experimental and testing procedures.

General Running Warm-up. During the GW visit, all subjects began by jogging for 5 minutes on a treadmill at 6.4 km·h^{-1} with a 1% incline. Subsequently, they performed a stretching protocol that consisted of 8 minutes of SS and 8 minutes of DS, which was used in a study by Sekir et al. (32). This protocol was designed to stretch both the quadriceps and hamstring muscles of each leg. Both the SS and DS exercises were performed to the threshold of mild discomfort, without feeling pain. For the SS, 4 exercises were performed rotationally (see details in Sekir et al. (32)), and the subjects were instructed to hold each stretch position for 30 seconds, with 15 seconds of rest period between consecutive stretch positions. For the DS, the subjects performed 4 sets of different dynamic stretch exercises targeting both quadriceps and hamstring muscles for each limb. Each dynamic stretch repetition was performed every 2 seconds and was repeated 5 times slowly, followed by 10 times as quickly and powerfully as possible without bouncing (32). Fifteen seconds of rest period was provided between consecutive stretches.

Dynamic Stretching. After the 5-minute jogging exercise, without any SS exercises, all subjects performed 4 sets of DS exercises (8 minutes) as they did during the GW for the quadriceps and hamstrings for each leg.

Dynamic Stretching Combined With Vibration Foam Rolling. After the 5-minute jogging exercise, all players performed 4 sets of DS (8 minutes), followed by 4 sets of VR (8 minutes). This study used a commercial vibration foam roller (Vyper 2.0, Hyperice, Irvine, CA) with the vibration frequency set at 45 Hz. The subjects performed the VR on the floor by actively rolling back and forth on the quadriceps and hamstring muscles. Each set of VR was performed for 30 seconds at a rate of 30 rolls per minute (1 second up, 1 second down) using a metronome. The rolling was applied to the hamstrings and quadriceps muscles of both limbs in a predetermined randomized order.

Measurement of Dependent Variables. The measurement tests were always conducted in the following order: muscle stiffness, joint ROM, joint position sense, isokinetic strength, and fatiguing exercise. In addition, all measurement tests were performed in the dominant thigh of the subjects, based on their kicking preference. All subjects in the current study are right-leg dominant. All the measurement tests were conducted by trained research staffs, who were also supervised by a certified strength and conditioning specialist (CSCS).

Muscle Stiffness. The vastus lateralis and the biceps femoris muscle stiffness were measured in a relaxed state by using a handheld myometer (Myoton PRO; Myoton AS, Tallinn, Estonia), which applies a brief (duration: 15 ms; force: 0.4 N) mechanical impulse to elicit damped oscillations of the muscle. The myometer has been reported to have high-to-excellent reliability (2). The muscle stiffness was calculated as follows: Stiffness = $a_{max} \times m_{probe}/\Delta l$, where a denotes acceleration of the damped oscillation, m_{probe} refers to probe mass, and Δl denotes the maximal displacement of the tissue. One measurement series of 2 single trials was completed at each muscle site (vastus lateralis: 1/2 of the distance between the lateral edge of the patella and the anterior superior iliac spine; biceps femoris: the longitudinal axis of the dominant biceps femoris muscle at 50% of the distance from the ischial tuberosity to the medial epicondyle of the tibia), with a 1-second interval between each measurement. The average value of 2 trials was recorded.

Knee Flexion Range of Motion. The knee flexion ROM was evaluated using passive straight leg raises, consistent with previous studies (5,40). The subjects remained in a supine position on a padded plinth. Both their waist and the nonstretched leg were fixed by a strap. The examiner aligned a digital inclinometer (Model # 122 A800; JIN-BOMB Inc, Kaohsiung, Taiwan) over the distal tibia of the dominant leg. The dominant leg was then passively lifted to a position where the subjects felt a mild tightness but not pain. The average measurement value of 2 trials was recorded. This test has an intraclass correlation coefficient (ICC) greater than 0.8 (6).

Knee Extension Range of Motion. The knee extension ROM was evaluated using passive knee flexion, consistent with a previous study (19). The subjects laid prone on the padded plinth. The examiner stabilized the subject's pelvis by placing one hand on the sacrum and then lifted the ankle of the dominant leg to passively flex the leg to a point where the subjects felt a mild tightness but not pain. Subsequently, the angle between the thigh and the lower leg was measured. The average measurement value of 2 trials was recorded. This test has an ICC of 0.91, suggesting high test-retest reliability (29).

Knee Joint Position Sense. The knee joint position sense (JPS) measurement was performed on the isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY). All subjects had the "hold" button in one hand, enabling them to stop the dynamometer's lever arm when they reached the target angle, which they held for approximately 2 seconds. The starting position was at the full knee extension, and the subjects actively moved their leg to the target angles (30° and 70° knee flexion, in a random order). In each trial, the dominant leg was passively moved to the target position at a slow angular velocity ($10°\cdot s^{-1}$), and the position was maintained for 10 seconds, followed by returning the leg to the starting position. Subsequently, the subjects were blindfolded and instructed to actively move their leg to the target positions. Each testing position was repeated 5 times. The repositioning absolute angular error was obtained by calculating the difference between the target angle and chosen position angle (34).

Isokinetic Strength Testing. Concentric isokinetic peak torque (PT) for knee extension and flexion of the dominant leg was measured using a Biodex System 3 dynamometer (Biodex Medical Systems, Inc., Shirley, NY) at randomly ordered velocities of $60°\cdot s^{-1}$ and $240°\cdot s^{-1}$. The subjects were seated upright on the dynamometer with a comfortable position. The mechanical axis of the dynamometer was aligned with the lateral epicondyle of the knee, and the trunk, waist, thigh, and chest were stabilized with belts to avoid compensatory movements during the strength test. The knee ROM was set before the warm-up exercises for the strength test. All subjects performed a standardized warm-up involving 4 submaximal concentric contractions for each velocity before each test session. After a 2-minute rest period, they were instructed to perform 3 alternating maximal concentric knee extensions and knee flexions. The highest PT of the 3 maximal contractions for each velocity was collected for subsequent analysis. The hamstring-quadriceps (H:Q) strength imbalance ratios were calculated by dividing the concentric knee flexion PT by the concentric knee extension PT.

Muscle Endurance. The subjects performed a modified Thorstensson test (33), which consisted of 50 consecutive maximal alternating concentric knee extension and flexion exercises on the isokinetic dynamometer at an angular velocity of $180°\cdot s^{-1}$. The PT of the knee extension and knee flexion was measured every 10 repetitions. The mean PT of the knee extension and the knee flexion from the final 10 repetitions were compared with the those from the first 10 repetitions, and the difference was then divided by the mean of the first 10 repetitions to obtain the fatigue percentage (%).

Statistical Analyses

Data are presented as mean ± *SD*s. After the variables passed the Shapiro-Wilk test for normality, they were analyzed using SPSS (version 25; IBM, Armonk, NY). Separate one-way repeated measures analysis of variance (ANOVA) tests were used to test the effects of different conditions (GW vs. DS vs. DS + VR) for quadriceps and hamstring stiffness, knee joint ROM, knee JPS, isokinetic strength, H:Q ratio, and muscle endurance (fatigue percentage). If a significant condition effect was found, pairwise comparisons with Bonferroni correction were then used to compare the potential difference between any 2 conditions. In addition, separate two-way (repetition interval [1–10 vs. 11–20 vs. 21–30 vs. 31–40 vs. 41–50] × condition [GW vs. DS vs. DS + VR]) repeated measures ANOVA tests were used to analyze the knee extension and flexion PTs during the fatiguing exercise. Statistical significance was set to $p < 0.05$. The effect size (Cohen's d) ($d = M1-M2/\sigma$ pooled) (8) was calculated to examine the magnitude of the effects between 2 different warm-up conditions.

Results

Table 1 presents the mean and *SD*s of the knee extension and flexion ROM and quadriceps and hamstring muscle stiffness after 3 different warm-up protocols. The one-way ANOVAs showed significant differences among 3 warm-up protocols for the hamstring muscle stiffness ($F = 4.53$, $p = 0.02$) and knee flexion

Table 1
Mean ± *SD* of knee joint range of motion (ROM) and muscle stiffness after 3 warm-up protocols (GW, DS, and DS + VR).*

	ROM (degree)		Stiffness ($N\cdot m^{-1}$)	
	Knee flexion	Knee extension	Hamstring	Quadriceps
GW	69.3 ± 9.6	130.5 ± 6.0	292.89 ± 24.28	254.00 ± 23.78
DS	75.8 ± 8.4	132.1 ± 6.8	276.34 ± 26.68	250.54 ± 25.94
DS + VR	79.4 ± 7.7†	133.5 ± 5.1	253.33 ± 36.20†	257.09 ± 12.50

*GW = general running warm-up; DS = dynamic stretching; DS + VR = dynamic stretching with vibration foam rolling.
†Statistically significant difference between GW and DS + VR ($p < 0.05$).

ROM ($F = 3.59$, $p = 0.04$). The pairwise comparisons revealed that hamstring stiffness ($d = 1.28$, $p = 0.006$) was significantly lower in the DS + VR than in the GW protocol, and the knee flexion ROM ($d = 1.17$, $p = 0.01$) was significantly greater in the DS + VR than the GW protocol. However, no significant differences were observed among the 3 warm-up conditions for both the knee extension ROM ($F = 0.62$, $p = 0.55$) and quadriceps muscle stiffness ($F = 0.23$, $p = 0.80$).

For the knee JPS, no significant difference was observed among 3 warm-up protocols (JPS 30°: $F = 0.70$, $p = 0.51$; JPS 70°: $F = 0.17$, $p = 0.84$). In addition, no significant differences were observed in the PT ($60°\cdot s^{-1}$ knee flexion PT: $F = 0.31$, $p = 0.74$; $60\cdot s^{-1}$ knee extension PT: $F = 1.13$, $p = 0.34$; $240°\cdot s^{-1}$ knee flexion PT: $F = 0.11$, $p = 0.89$; $240°\cdot s^{-1}$ quadriceps PT: $F = 0.03$, $p = 0.97$) and H:Q ratios ($60°\cdot s^{-1}$ H:Q ratio: $F = 0.54$, $p = 0.59$; $240°\cdot s^{-1}$ H:Q ratio: $F = 0.08$, $p = 0.92$) among the warm-up protocols at both contraction velocities for both muscles (Table 2).

For the modified Thorstensson test, the ANOVA revealed that the knee flexor muscle fatigue (%) was significantly different among 3 protocols ($F = 3.37$, $p = 0.04$), with significantly lower percentage in the DS + VR than in the GW and DS protocols (DS + VR vs. GW: $d = 1.12$, $p = 0.03$; DS + VR vs. DS: $d = 1.17$, $p = 0.02$, respectively). No significant difference was noted in the knee extensor muscle fatigue (%) for the 3 warm-up conditions ($F = 0.34$, $p = 0.71$; Figure 1). For the knee flexion PT throughout the fatigue test, no 2-way interaction ($p = 0.53$) was observed; however, significant main effects were noted for repetition interval ($p < 0.001$) and condition ($p = 0.03$). When collapsed across repetition interval, the combined knee flexion PT for DS + VR was significantly greater than those for both GW ($d = 0.83$, $p = 0.03$) and DS ($d = 0.91$, $p = 0.02$) (Figure 2). For the knee extension PT throughout the fatigue test, the only significant main effect was observed for repetition interval ($p < 0.001$), but there was no 2-way interaction ($p = 0.66$) or main effect for the condition ($p = 0.34$).

Discussion

To the best of our knowledge, the current experiment is one of the few studies to compare the acute effects of different warm-up protocols (i.e., GW, DS, and DS + VR) on knee joint flexibility, muscle stiffness, knee JPS, lower-limb strength, and muscle endurance in elite collegiate female handball players. The main findings are as follows: (a) The knee flexion ROM after performing the DS + VR was significantly greater than the GW warm-up protocol. This result was accompanied by the lower hamstring muscle stiffness after the DS + VR, when compared with the GW warm-up protocol; (b) No differential warm-up effects were observed for the knee extension ROM and quadriceps muscle stiffness; (c) The knee flexor muscles exhibited greater muscle endurance after performing the DS + VR than those after performing the GW and DS warm-up protocols. This was reflected by the greater overall knee flexion concentric PT (repetitions merged) after the DS + VR than those after the GW and DS warm-up protocols; (d) No differential warm-up effects were observed in knee JPS, knee extension and knee flexion concentric isokinetic strength, and H:Q ratios.

Regarding the differential effects of different warm-up protocols on lower-limb ROM and muscle stiffness, Lin et al. (19) compared DS and DS + VR (at 28 Hz) and reported that DS + VR did not improve knee flexion ROM, whereas DS (3.7°) and DS + VR (4.1°) significantly improved knee extension ROM, with no significant difference between the 2 protocols (19). The different findings on knee flexion ROM between our study and Lin et al. (2020) may be attributed to the poor hamstring flexibility of the subjects recruited in the current study, which the warm-up protocol might have induced a larger decrement in the hamstring muscle stiffness in these subjects. An interesting finding of this study is the enhancement effect on knee flexion ROM when adding the VR component to the DS in the current study. Previously, Lee et al. (18) found that knee flexion (3.0°) and extension (3.7°) ROM were both improved after the VR alone (at 28 Hz) warm-up intervention. In addition, Lin et al. (19) revealed that DS alone significantly increased quadriceps stiffness, but with the VR added, the quadriceps stiffness was reduced. The authors (19) further suggested that DS + VR was superior to DS in muscle stiffness reduction. Taken together, these findings support our results.

Less is known regarding the effects of warm-up interventions such as DS + VR on proprioception, and the results from previous studies are inconsistent. In this study, the 3 types of warm-up protocols did not influence the knee JPS differently. This finding is consistent with a similar study, where nonvibrating foam rolling reduced knee joint proprioception at 45° of knee flexion position, but the VR had no such effect. By contrast, another study revealed that foam rolling on the hamstring muscle improved knee JPS for at least 20 minutes, but it had no effect on the hip JPS or knee joint force sense (10). Different from the current study and Lee et al. (18), David et al. (10) used different measurement method by adopting weight-bearing joint position matching tasks (e.g., forward lunge stance) to test knee and hip JPS. In addition, the rolling speed of foam rolling in that study was slower (3–4 repetitions$\cdot$min^{-1}), which could also be an influencing factor because steady and slow rolling is likely to relax muscle tissue, whereas a faster rolling speed tends to increase tissue tension (36).

In this study, all 3 warm-up protocols had no differential effects on the absolute isokinetic muscular strength (both knee flexion and knee extension). This result is within our expectation. Although SS can be detrimental to strength performance (3), our subjects performed bouts of short duration (30 s) of static stretches, followed by dynamic stretches (GW protocol), which should not be an impairing factor to the isokinetic strength. In addition, foam rolling intervention has rarely been shown to affect strength performance (35). Interestingly, during the fatiguing

Table 2
Mean ± *SD* of isokinetic strength, hamstring: quadriceps (H: Q) ratio and knee joint position sense (JPS) after 3 warm-up protocols (GW, DS, and DS + VR).*

	GW	DS	DS + VR
Hamstring strength (Nm)			
$60°\cdot s^{-1}$	51.52 ± 8.89	47.90 ± 13.30	51.39 ± 12.28
$240°\cdot s^{-1}$	48.33 ± 10.65	48.10 ± 11.67	50.57 ± 15.48
Quadriceps strength (Nm)			
$60°\cdot s^{-1}$	107.47 ± 14.29	95.36 ± 17.69	100.16 ± 21.76
$240°\cdot s^{-1}$	61.40 ± 11.46	59.94 ± 13.78	60.68 ± 13.58
H:Q ratio			
$60°\cdot s^{-1}$	0.47 ± 0.05	0.50 ± 0.10	0.52 ± 0.09
$240°\cdot s^{-1}$	0.81 ± 0.24	0.83 ± 0.26	0.86 ± 0.27
Joint position sense (degree)			
30°	3.2 ± 2.6	4.3 ± 3.7	2.9 ± 1.5
70°	4.7 ± 3.3	5.3 ± 4.3	4.4 ± 2.8

*GW = general running warm-up; DS = dynamic stretching; DS + VR = dynamic stretching with vibration rolling.

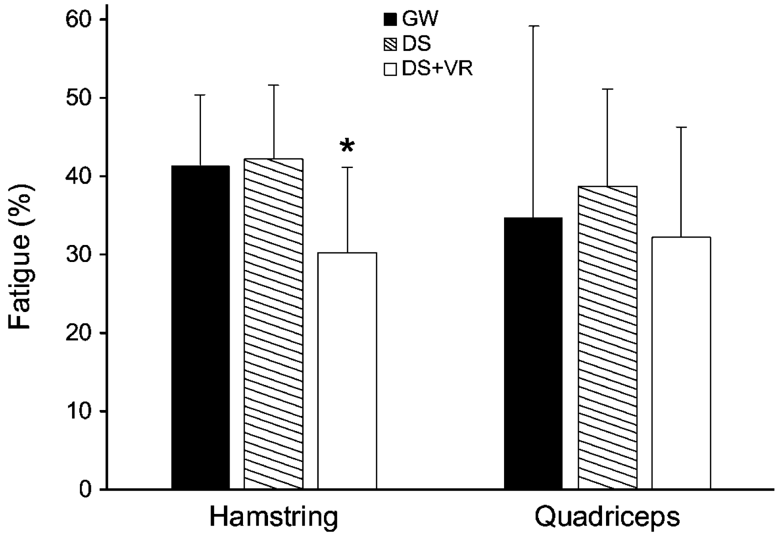

Figure 1. Fatigue percentage (%) of both muscle groups (hamstring and quadriceps) during the modified Thorstensson fatigue test after all 3 warm-up protocols. *Significant differences between DS + VR and GW and between DS + VR and DS. DS = dynamic stretching warm-up; DS + VR = dynamic stretching combined with vibration foam rolling warm-up; GW = general running warm-up.

exercise (modified Thorstensson test), the knee flexor muscle group became more fatigue resistant after the DS + VR than after the GW and DS warm-up protocols. Regarding the effects of stretching exercises on the fatiguing exercise, a related study revealed that SS significantly reduced knee flexion muscle strength endurance (23). However, short-duration active stretching (approximately 5–8 minutes) of the lower limbs had no effect on muscular endurance, whereas long-duration active stretching (approximately 11–13 minutes) resulted in reduced muscular endurance (31). Thus, short-duration DS alone does not seem to affect muscle endurance. In addition, foam rolling or vibration interventions might improve muscular endurance in the lower limbs. For example, a study revealed that vibration intervention on quadriceps muscle significantly increased the quadriceps muscle time to fatigue (27). Moreover, after a foam rolling intervention, the magnitude of the knee extension maximal isometric voluntary force reduction after fatiguing exercise was lower than that in the control intervention (11). However, cautions must be taken because longer rolling bouts may impair muscular endurance. For example, 4 sets of knee extension to

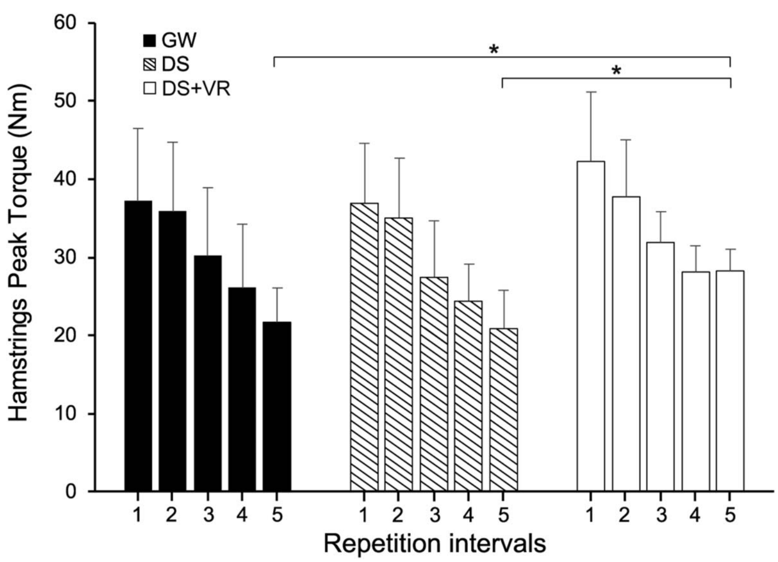

Figure 2. Hamstring muscle's mean peak torque for each 10 repetitions during the modified Thorstensson fatigue test after all 3 warm-up protocols. Repetition interval 1: first 10 repetitions; repetition interval 2: Repetitions 10–20; repetition interval 3: Repetitions 20–30; repetition interval 4: Repetitions 30–40; repetition interval 5: last 10 repetitions. *Significant differences (all repetition intervals merged) between DS + VR and GW and between DS + VR and DS. DS = dynamic stretching warm-up; DS + VR = dynamic stretching combined with vibration foam rolling warm-up; GW = general running warm-up.

concentric failure exercises along with relatively long durations of foam rolling (60, 90, and 120 seconds) on the anterior thigh before each set yielded fewer repetitions when compared with the passive rest group (22). Another related study indicated that after 60 or 120 seconds of FR interventions on the anterior thigh, knee extensor muscle endurance decreased (21).

This study has some limitations. First, the current subjects were healthy female elite college handball players with limited hamstring flexibility. Results may differ in other athletic populations or individuals with normal hamstring flexibility. Further research is required to determine the effectiveness of DS + VR in individuals with symptoms that may be related to hamstring or knee injury. Second, a true control condition (subjects do not receive any warm-up protocol, but passively rest) and the baseline (before any warm-up intervention) were not included in this study. Thus, it is impossible for us to know if or how much each warm-up protocol altered the measurement variables. In addition, the current experimental setup did not allow us to examine the effects of having SS alone or having vibration alone as the warm-up intervention. It would be more beneficial if future research can identify the effects of each warm-up component, so the practitioners may choose or combine warm-up exercises for their specific purposes. Finally, caution must be taken when interpreting the results, although limited joint ROM and muscle fatigue are risk factors in sports-related injuries, our results should not simply be used to prescribe interventions to reduce the risk of sports injury during exercise and sports competitions. In conclusion, this study demonstrated that although the effect of the DS + VR warm-up on lower-limb muscular strength and proprioception did not differ from those of the GW and DS warm-up protocols, superior effects were found for the knee flexion ROM and hamstring muscle stiffness, as well as the knee flexor muscle endurance, after the DS + VR warm-up protocol.

Practical Applications

For female collegiate athletes who are more susceptible to hamstring muscle injuries due to the limited joint flexibility and greater muscle stiffness, DS combined with VR warm-up can be considered as a potential replacement for conventional warm-up (SS combined with DS), and DS warm-up. Although the superior effects of DS + VR warm-up on muscle strength and proprioception are not evident, relative to GW and DS, it resulted in a greater increase in knee flexion ROM and decrease in hamstring muscle stiffness. In addition, the DS + VR also has superior effect on the knee flexor muscle endurance.

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