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# Acute effects of dynamic versus foam rolling warm-up strategies on physical performance in elite tennis players

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**ABSTRACT:** To date, there is a lack of information about the optimal conditions of the warm-up to lead to a better performance in elite tennis players. The aim of this study was to compare the effects of two different warm-up protocols (dynamic vs. self-myofascial release with foam rolling) on neuromuscular variables associated with physical determinants of tennis performance. Using a crossover randomised experimental design, eleven professional men tennis players (20.6 ± 3.5 years) performed either a dynamic warm-up (DWU) or a self-myofascial release with foam rolling (SMFR) protocol. DWU consisted of 8 min of dynamic exercises at increasing intensity and SMFR consisted of 8 min of rolling on each lower extremity unilaterally. Just before (baseline) and after completing warm-up protocols, players performed a countermovement jump (CMJ), the 5-0-5 agility test, a 10-m sprint test and the Straight Leg Raise and Thomas tests to assess range of motion. Compared to baseline, the DWU was more effective to reduce the time in the 5-0-5 test than SMFR (-2.23 vs. 0.44%, respectively, $p = 0.042$, $\eta p^2 = 0.19$). However, both warm-up protocols similarly affected CMJ (2.32 vs. 0.61%, $p = 0.373$, $\eta p^2 = 0.04$) and 10-m sprint time changes (-1.26 vs. 1.03%, $p = 0.124$, $\eta p^2 = 0.11$). Changes in range of motion tests were also similar with both protocols (p = 0.448–1.000, $\eta p^2 = 0.00$–$0.02$). Overall, both DWU and SMFR were effective to prepare well-trained tennis players for highly demanding neuromuscular actions. However, DWU offered a better preparation for performing change of direction and sprint actions, and hence, in high-performance tennis players, the warm-up should include dynamic exercises.

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## INTRODUCTION

Tennis is an intermittent sport characterised by short bouts of high-intensity exercise (4–10 s) during a variable period of time that ranges from ~1 to ~5 h [1]. Overall, tennis entails multiple running accelerations/decelerations and changes of direction, together with several types of groundstrokes performed all over the tennis court [2]. The organisation of tennis scoring by points, games and sets implies, at the same time, the performance of very high-intensity actions during play due to its intermittent nature and incomplete recovery between actions because of the short duration of the pauses [3]. Before training and competition, elite tennis players perform warm-up routines to increase their readiness to perform these tennis-specific actions [4]. However, to date, there is no consensus about what type of exercise should be included in a tennis warm-up to optimise players' preparation to train and compete.

Tennis players normally perform different types of warm-up routines prior to formal training and competitions aiming to achieve high levels of explosive force before the beginning of the competitive activity [4]. Thus, apart from a reduction in the injury risk, increases in intra-muscular temperature and nerve conductance velocity through warm-up exercises can enhance physical performance [5]. In this regard, traditional warm-up protocols in tennis typically involve low-to-moderate intensity aerobic activities (e.g., jogging at a self-selected pace), dynamic stretching exercises to enhance joint range of motion (ROM), coordination exercises and sport-specific drills executed at, or just below, game intensity [6]. A recent study showed that warming up with low intensity running followed by dynamic stretching led to greater improvements in jumping, sprinting and other tennis performance variables than the use of running plus

static stretching [4]. Similarly, other studies incorporating dynamic stretching exercises in the warm-up have also shown improved agility values and better 20-m sprint times in tennis players [7]. Mechanisms explaining such improvements after dynamic stretching strategies can be related to post-activation potentiation and greater activation of the myotatic reflex induced by the dynamic movements [8]. Thus, these previous investigations have been helpful in evolving the traditional warming up strategies in tennis to achieve a more effective warm-up that includes dynamic exercises. However, it is still unknow whether other warming up strategies used in other sports may have a greater impact on tennis performance.

In recent years, other options of warm-up have been proposed, among which the use of self-myofascial release with foam rolling (SMFR) is worthy of mention. This technique is a therapeutic practice usually employed to treat soft-tissue restrictions [9]. SMFR is commonly used by therapists and fitness professionals as a recovery tool to promote the process of soft-tissue healing [10, 11] and is normally applied in periods of 5–10 minutes duration [12, 13]. Previous studies have demonstrated the efficacy of SMFR in reducing muscle soreness and improving joint ROM after intense exercise [11, 12]. However, the utility of SMFR prior to sports training/competitions remains controversial. With SMFR, the musculature is rolled and compressed utilising a foam rolling device producing an increase in myogenic and endothelial dilation that may facilitate performance [14]. However, only the targeted musculature is affected by these potential effects, and thus several muscular structures must be foam-rolled. On the one hand, improvements in jump, speed and power performance and in flexibility have been found when comparing an SMFR warm-up vs. more traditional warm-up protocols with dynamic exercises [15, 16]. However, greater jump performance has also been reported with the use of dynamic stretching after a warm-up protocol of 5 min of cycling when compared to the same warm-up protocol followed by SMFR [17]. The discrepancies among studies could be attributed to the diverse methodologies used, such as the combination of SMFR with other warm-up exercises and differences in warm-up lengths and foam rolling devices. For this reason, the aim of this study was to examine and compare the acute effects of two different warm-up protocols that only differed in the inclusion of dynamic stretching exercises or self-myofascial release with foam rolling on neuromuscular variables associated with physical determinants of tennis performance.

## MATERIALS AND METHODS

### *Participants*

Eleven high performance men tennis players (age: 20.64 ± 3.56 years; body mass: 75.55 ± 5.03 kg; height: 1.83 ± 0.05 m) volunteered to participate in the study. Participants were ranked in the Association of Tennis Professionals (ATP) and they were among the 300 best national tennis players in Spain. In addition, all participants were active competitors in tournaments of the International Tennis Federation (ITF) world tour. At the time of the study, participants averaged 19.00 ± 4.24 h of training (i.e., on-court) per week, focused on the development of on-court technical/tactical tennis skills, as well as the enhancement of tennis-specific physical fitness. The exclusion criteria set for the study sample were: having had a musculoskeletal injury in the three months previous to the study and the presence of delayed onset muscle soreness at the testing session or the day before. Prior to the start of this investigation, all players were fully informed about the testing protocols and the risks associated with the study and written informed consent was obtained from them or their parents/guardians (3 participants were under 18 years old). The study was approved by the institutional ethics review committee of the University Miguel Hernandez (2016.348.E.OEP) and conformed to the code of ethics of the World Medical Association (Declaration of Helsinki).

### *Experimental protocol*

The research was conducted during the preparatory phase of the 2017 tennis season. Throughout the investigation, participants were requested to maintain their normal life habits and their regular diets and normal hydration state, not to take any nutritional supplementation or anti-inflammatory medications, and to refrain from caffeine intake in the 24 hours before each testing session [18]. Participants were also requested to avoid strenuous activities 24 hours before each test session. All trials were performed at the same time of the day to avoid any effect of circadian variations on the results of the study [19]. Participants were enrolled in a crossover-study design, in which they acted as their own controls by taking part in two identical experimental sessions. Before the onset of the experimental sessions, tennis players underwent two familiarisation sessions carried out 1 week before the experiment (separated by 48 hours), which included measurements of all tests employed in the experimental sessions and the different warm-up protocols.

Participants participated in two identical experimental sessions, except for the characteristics of the warm-up. In each experimental session, and in a randomised order, tennis players performed either a warm-up including dynamic exercises (DWU) or the same warm-up including SMFR. The experimental trials were separated by at least 48 hours to allow full recovery. During each experimental trial, the players performed a 10-minute general warm-up. This general warm-up routine included running at moderate intensity (self-rated), forward/backward movements, sidestepping and general dynamic exercises. Afterwards, players performed a battery of neuromuscular tests that included a countermovement jump, a modified version of the 5-0-5 test, a 10 m sprint test, and two flexibility tests: the straight leg raise test and the Thomas test. There was set 5-min recovery period between tests. The results of these tests, performed before DWU and SMFR protocols, were considered as the baseline performance. After completing these baseline measurements, participants performed 8 minutes of DWU or SMFR. After the warm-up protocols had been completed, the battery of neuromuscular measurements was replicated following the protocols of the baseline measurement, including order and recovery between tests (Figure 1). All protocols were

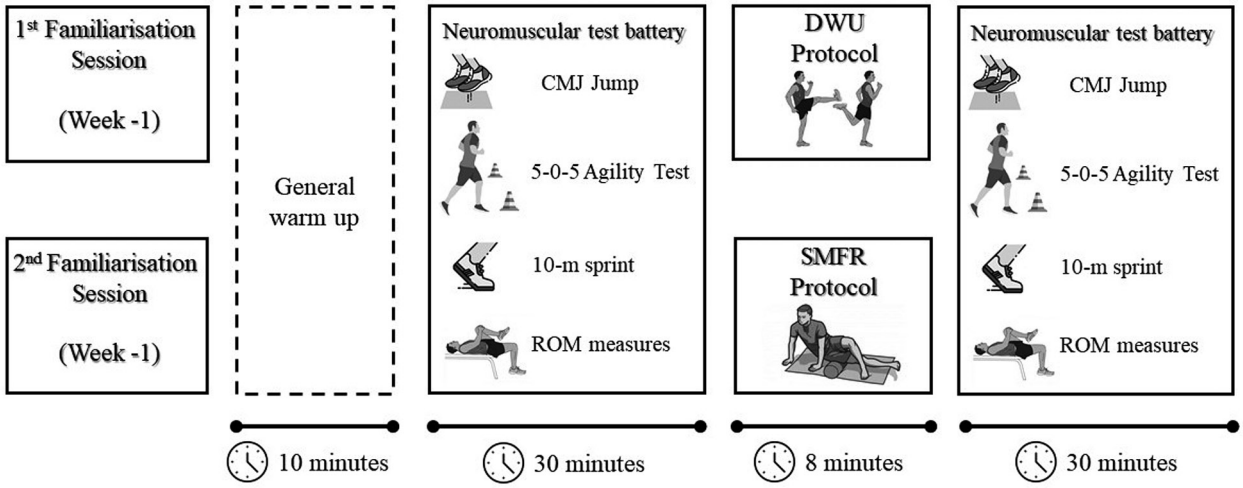


**FIG. 1.** Experimental design.
Participants performed two pre-experimental familiarisation sessions. In each experimental session, tennis players performed either a warm-up including dynamic exercises (DWU) or the same warm-up including self-myofascial release with foam rolling (SMFR). During each experimental session, the players performed a 10-minute general warm-up including running at moderate intensity, forward/backward movements, sidestepping and general dynamic exercises. Afterwards, players performed a battery of neuromuscular tests that included a countermovement jump (CMJ), a 10 m sprint test, a modified version of the 5-0-5 test and two flexibility tests: the straight leg raise test and a modified version of the Thomas test (ROM measures). After completing these baseline measurements, participants performed 8 minutes of DWU or SMFR. After the protocols of warm-up had been completed, the battery of neuromuscular measurements was replicated.

conducted in a training club centre and environmental temperature (14.3 ± 3.4°C) and relative humidity (40 ± 8%; WMR 108, Mextech, India) were similar in both experimental sessions.

*Dynamic warm-up (DWU).*

Participants performed 8 min of dynamic exercises which consisted of straight leg march, forward lunge with opposite arm reach, forward lunge with elbow to instep, lateral lunge, trunk rotations and multi-directional skipping exercises following a previously described protocol [20]. Each participant performed 3 sets of increasing exercise intensity (from low to high), with 15 s rest between sets. Participants were informed that the velocity of movement had to be progressively increased from 50 to 90% of their maximal velocity for each exercise [21].

*Self-myofascial release with foam rolling*

Participants performed 8 min of SMFR consisting of rolling on each extremity (leg) unilaterally. Specifically, SMFR was performed once on the quadriceps, hamstrings, gluteus and gastrocnemius for 60 s in both legs to complete a total of 8 min, following the protocols described by Behara et al. [13]. The SMFR was performed with a foam rolling device of medium density (Grid Foam Roller, Trigger Point, USA), although the density of the foam roller has little impact on the results of the technique [22].

*Testing Procedures*

*Vertical jumping (CMJ)*

Bilateral countermovement jumps (CMJs) were performed on an infrared jump system (Optojump, Microgate, Italy) according to standard methodology previously described [23]. During the jump, hands were held at the hips to remove the influence of the upper body on the jump. From a standing position with straight knees, players squatted down to ~90º before jumping as high as possible. Each player performed three maximal attempts interspersed with 45 s of passive recovery, and the best height jumped was recorded and used for statistical analysis as previously reported. The ICC for this test was 0.90 [19].

*Modified 5-0-5 agility test (5-0-5)*

The ability of the athletes to perform a single, rapid 180° change of direction over a 5 m distance was measured using a modified version (stationary start) of the 5-0-5 agility test [24]. Players started in a standing position with their preferred foot 50 cm behind the starting line. On command, they accelerated forwards to the line placed at 5 m, pivoted on either the left or right foot and then returned to the start line. The time to complete the modified 5-0-5 test was recorded to the nearest 0.01 s (Smartspeed, Fusion Sport, Australia). Participants performed one repetition pivoting on each foot. Two minutes of rest were allowed between attempts. The ICC for this test was 0.92 [25].

**TABLE 1.** Changes in neuromuscular performance and hip range of motion after a warm-up protocol that included dynamic exercises (DWU) or self-myofascial foam rolling (SMFR) in elite tennis players.

| | DWU | | | | SMFR | | | | ANOVA | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Baseline** | **Post warm-up** | **Δ (%)** | ***d*** | **Baseline** | **Post warm-up** | **Δ (%)** | ***d*** | ***Time*** | ***Proto-col*** | ***Interac-tion*** |
| **CMJ (cm)** | 34.78 ± 5.13 | 35.59 ± 5.19 | 2.32 ± 3.73 | 0.16 | 34.24 ± 6.77 | 34.42 ± 7.07 | 0.61 ± 5.54 | 0.02 | 0.173 | 0.716 | 0.373 |
| **10-m sprint (s)** | 2.22 ± 0.11 | 2.20 ± 0.12 | -1.26 ± 2.02 | -0.19 | 2.12 ± 0.08 | 2.14 ± 0.08 | 1.03 ± 4.33 | 0.25 | 0.860 | 0.052 | 0.124 |
| **5-0-5 Agility Test (s)** | 2.86 ± 0.14 | 2.79 ± 0.13 | -2.63 ± 3.55 | -0.52 | 2.75 ± 0.18 | 2.76 ± 0.13 | 0.44 ± 3.94 | 0.06 | 0.097 | 0.236 | 0.042* |
| **SLRT dominant (º)** | 76.55 ± 6.07 | 78.18 ± 6.23 | 2.12 ± 2.76 | 0.27 | 77.27 ± 5.75 | 79.09 ± 4.13 | 2.45 ± 2.50 | 0.36 | 0.001* | 0.732 | 0.836 |
| **SLRT non-dominant (º)** | 75.64 ± 5.78 | 76.36 ± 5.71 | 0.97 ± 3.02 | 0.14 | 77.09 ± 5.47 | 78.36 ± 4.97 | 1.68 ± 2.64 | 0.24 | 0.041* | 0.461 | 0.558 |
| **TT dominant (º)** | 0.91 ± 3.39 | 1.82 ± 3.52 | 17.33 ± 60.22 | 0.26 | 0.00 ± 2.69 | 0.36 ± 2.80 | 20.27 ± 28.67 | 0.13 | 0.115 | 0.348 | 0.448 |
| **TT non-dominant (º)** | 2.18 ± 3.16 | 2.55 ± 3.24 | 8.11 ± 52.08 | 0.12 | 0.73 ± 2.24 | 1.09 ± 3.02 | 27.47 ± 33.82 | 0.14 | 0.395 | 0.232 | 1.000 |

Data are presented as mean ± SD. Abbreviations: ANOVA: Analysis of variance with two ways: time and warm-up protocol; CMJ = Countermovement jump; SLRT = Straight Leg Raise Test; TT = Thomas Test. *Significant differences at $p < 0.05$.

*Sprint test (10-m sprint)*

A 10-m sprint test (with 5-m split times) was performed in a straight line while running time was measured using beam photocell gates placed 1.0 m above the ground level (Smartspeed, Fusion Sport, Australia). Each sprint was initiated 50 cm behind the photocell gate as previously reported [5]. Each player performed two maximal 10-m sprints with 2 min of passive recovery between the attempts. The best performance was recorded and used for the statistical analysis. The ICC for this test was 0.90 [19].

*ROM measures*

Passive hip flexion (passive straight leg raise test; SLRT) and a modified version of the Thomas test were measured using an inclinometer (Isomed, Portland, OR, USA) with a telescopic arm to assess the effect of the warm-up protocols on hip ROM [26]. Prior to each assessment, the inclinometer was calibrated to 0° with either the vertical or horizontal axis. Participants were instructed to perform two maximal attempts for each test and for each limb (30 s rest between attempts) The ICC of ROM measurements were 0.94 for the SLRT and 0.87 for the Thomas test [26].

*Statistical analysis*

Data are presented as mean ± standard deviation (SD). The Shapiro-Wilk test revealed that data were normally distributed. A two-way analysis of variance (ANOVA) with time (pre-test vs. post-test) × and protocol (DWU vs. SMFR) was performed to examine the effects of the different warm-up protocols on performance and ROM variables. After a significant F test, the Bonferroni post hoc test was applied to identify pairwise differences. The significance level ($\alpha$) was set at 0.05. Statistical significance was set at $p < 0.05$. Cohen's d and partial eta squared ($\eta p^2$) for ANOVA were calculated to estimate the effect size [27]. All procedures were performed using SPSS software (v. 24, IBM, Armonk, NY, USA).

## RESULTS

Table 1 shows the results obtained in the baseline and post warm-up measurements with the two warm-up protocols investigated. There was no difference in the baseline values between DWU and SMFR for any of the variables investigated (all $p > 0.05$). There were no overall effects of time or protocol, and no interaction, for countermovement jump height (Table 1; $\eta p^2 = 0.04$). Compared to baseline, neither DWU ($p = 0.055$) nor SMFR ($p = 0.782$) improved countermovement jump height. There was a main effect of the protocol in the time to complete the 10 m sprint test but there was no main effect of time and no interaction for this performance variable ($\eta p^2 = 0.11$). However, the post-hoc analysis revealed that neither DWU ($p = 0.076$) nor SMFR ($p = 0.443$) significantly reduced the time to complete the 10 m sprint test. There was a statistically significant time × protocol interaction for the time to complete the 5-0-5 agility test, although the main effects did not reach statistical

significance ($\eta p^2 = 0.19$). In comparison to baseline values, tennis players significantly reduced their time to complete the 5-0-5 test with DWU ($p = 0.032$) while the time in this test was unchanged with SMFR ($p = 0.782$).

There was a main effect of time for SLRT in the dominant and non-dominant limbs although there was no main effect of the protocol and no interaction ($\eta p^2 = 0.00$ and 0.01) respectively). When compared to ROM baseline values, both DWU ($p = 0.031$) and SMFR ($p = 0.010$) warm-up protocols improved the values in the SLRT in the dominant limb with no significant differences between protocols ($p = 0.836$). However, no differences were reported in the SLRT test in the non-dominant limb with DWU ($p = 0.307$) or SMFR ($p = 0.067$). Lastly, there were no overall effects of time or protocol, and no interaction, for the Thomas test in the dominant and non-dominant limbs ($\eta p^2 = 0.02$ and 0.00). Specifically, there were no pre-to-post changes in the values for the Thomas test in the dominant and non-dominant limb for DWU ($p = 0.176$ and 0.588) or SMFR ($p = 0.441$ and 0.506).

## DISCUSSION

To the best of our knowledge, this is the first study to compare the efficacy of dynamic warm-up and self-myofascial release foam rolling to enhance neuromuscular variables associated with physical determinants of tennis performance. While previous studies have investigated the effect of including different types of stretching exercises on tennis-specific performance [4, 7, 28] this investigation is novel because it assesses the effect of foam rolling to enhance the readiness of tennis players to complete highly demanding neuromuscular actions. Overall, the statistical analysis revealed that the effect of both DWU and SMFR to enhance hip ROM was similar when compared to baseline values, but DWU was superior to SMFR to improve agility (Table 1). In addition, there was a tendency for time × protocol interaction in the sprint test, suggesting a better pre-to-post warm-up improvement in 10-m sprint times with DWU in comparison to SMFR. Last, the pre-to-post warm-up change in jump height almost reached statistical significance with DWU. Thus, the results of this investigation indicate that both dynamic warm-up and self-myofascial release with foam rolling may be considered effective to prepare high-performance tennis players for actions that demand a large ROM in the hip. However, the dynamic warm-up offered a better preparation for performing agility exercises and changes of direction and it was likely more beneficial to perform sprint and jump actions.

The larger effect of DWU to improve agility over SMFR might be related to the different changes that each protocol produces within the muscle. On one hand, DWU increases muscle temperature and induces neural activation such as post-activation potentiation and activation of the myotatic reflex [4]. These changes have been repeatedly related to improved physical readiness to perform high-intensity exercise actions [8], and for this reason, DWU is considered the most recommended type of warm-up protocol in tennis. By contrast, the musculature compressed during the SMFR is subjected to endothelial dilation and reduction in tissue adhesion [14, 29], but the effect on muscle activation is minimal [10]. In fact, a recent meta-analysis on the effect of foam rolling prior to exercise concluded that its influence on jump and strength performance was negligible [30]. Thus, DWU may have greater value than SMFR when preparing players to perform high-intensity actions that require changes of directions and agility, and hence it should be performed before workouts that include this type of routines. Moreover, as the average sprint distance performed by tennis players during competition is 4–7 m in the course of a rally or point, with an average of 4 changes of direction (COD) [31], these data might indicate that the use of SMFR shows no benefits in physical performance of elite tennis players, at least during the first phases of the competition. In this regard, DWU should be recommended as the warm-up of choice before a tennis competition.

A similar tendency was found for jump and sprint performance, with greater changes in terms of magnitude after DWU vs. SMFR, although the effect of the warm-up protocols on these tennis-specific performances did not reach statistical significance. In tennis, muscle strength/power in the lower extremities is essential to produce explosive actions such as in the tennis serve [32]. In this regard, countermovement jump height was improved by 2.32% after DWU and by 0.61%, after SMFR. These findings are similar to other studies that have found 2.0–3.9% improvements in vertical jump following DWU [33, 34]. In addition, DWU enhanced sprint time (i.e., reducing it by -1.26%) while the time in the sprint test was longer than the baseline value with SMFR (+1.03%). Again, there is evidence showing the benefits of DWU to improve sprint performance [4] while the effect of SMFR is usually lower [30]. From a practical perspective, the performance effect found with DWU might entail a higher jump and sprint capacity in tennis players that suggests the adequacy of this type of warm-up over SMFR for performing lower limb power actions.

Concerning hip ROM, the present results suggest that both warm-up protocols were equally effective to improve hip flexion in the dominant limb. Although no statistically significant differences were found for the effect of DWU and SMFR on the hip ROM change, the mechanism that the effect of the warm-up entailed were probably different between DWU and SMFR. The increase in flexibility after DWU may be explained by the incorporation of multi-dimensional activities with wide movements such as skipping, directional running, shuffling, and various calisthenics. This type of dynamic exercise may favour ROM through a positive effect on the stretch-shortening cycle [35]. On the other hand, the improvements in the ROM with the SMFR technique could be explained by altered tissue stiffness, change in the thixotropic property of the fascia and the analgesic effects of the technique by mediating pain-modulatory systems [36, 37]. Specifically, SMFR involves small undulations back and forth over a mild-density foam roller which places direct and sweeping pressure on the soft tissue to stretch it and generate friction between the soft tissue of the body and the foam, resulting in higher flexibil-

ity [10, 38]. Independently of the mechanism, both warm-up protocols may be considered equally effective to increase hip ROM before tennis-specific routines. However, due to their low efficacy to produce statistically significant changes over baseline – which was recorded after a general warm-up – it should be pointed out that both DWU and SMFR will produce low-magnitude changes in ROM compared to a general warm-up.

Aside from its strengths, the current experiment presents some potential limitations. The first limitation is the small sample size. For this reason, we should be careful when drawing any definitive conclusions as small samples are more prone to other hidden biases, such as population stratification and cryptic relatedness, both of which may lead to increased type I error rates. A second limitation is that we only studied the effect of including dynamic exercises or foam rolling in isolation, while both techniques may have an additive or even synergistic effect on tennis specific performance. Future research should study the effects of applying DWU and SMFR in combination and compare the benefits to other forms of warm-up before exercise.

In summary, the present study showed that a warm-up protocol that includes dynamic exercises seems to be a better option to increase performance in some neuromuscular parameters with relevance for tennis performance. Specifically, the dynamic warm-up offered better enhancements of performance in agility/changes of direction actions and there were tendencies for better improvements in sprint and jump actions. In this regard, high-performance tennis players' warm-up should include dynamic exercises, especially before high-demanding practices and competition. However, both dynamic warm-up and the use of self-myofascial release with foam rolling may be equally effective to increase hip ROM in high-performance tennis players, and perhaps they may be useful for workouts focused on enhancing muscle flexibility.

### *Practical applications*

Based on the results of this study, DWU should be recommended over SMFR in order to achieve high neuromuscular performance levels (e.g., change of direction ability, sprint and jump actions) before training or matches. Both warm-up protocols were equally effective to enhance ROM and muscle flexibility, although their effects were of low magnitude when compared to a general and unspecific warm-up.

## CONCLUSIONS

The use of self-myofascial release likely will not offer performance benefits during the warm-up section of a training routine or before a tennis competition. However, both dynamic warm-up and the use of self-myofascial release with foam rolling may be equally effective to increase hip ROM in high-performance tennis players, and perhaps they may be useful for workouts focused on enhancing muscle flexibility.

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