©Journal of Sports Science and Medicine (2012) **11**, 669-675
http://www.jssm.org

Research article

Acute effects of two different warm-up protocols on flexibility and lower limb explosive performance in male and female high level athletes

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Abstract
This study examined the effects of two different warm-up protocols on lower limb power and flexibility in high level athletes. Twenty international level fencers (10 males and 10 females) performed two warm-up protocols that included 5-min light jogging and either short (15s) or long (45s) static stretching exercises for each of the main leg muscle groups (quadriceps, hamstrings and triceps surae), followed by either 3 sets of 3 (short stretching treatment), or 3 sets of 5 tuck jumps (long stretching treatment), in a randomized crossover design with one week between treatments. Hip joint flexion was measured with a Lafayette goniometer before and after the 5-min warm-up, after stretching and 8 min after the tuck jumps, while counter movement jump (CMJ) performance was evaluated by an Ergojump contact platform, before and after the stretching treatment, as well as immediately after and 8 minutes after the tuck jumps. Three way ANOVA (condition, time, gender) revealed significant time ($p < 0.001$) and gender ($p < 0.001$) main effects for hip joint flexion, with no interaction between factors. Flexibility increased by 6.8 ± 1.1% ($p < 0.01$) after warm-up and by another 5.8 ± 1.6% ($p < 0.01$) after stretching, while it remained increased 8 min after the tuck jumps. Women had greater ROM compared with men at all time points (125 ± 8° vs. 94 ± 4° $p<0.01$ at baseline), but the pattern of change in hip flexibility was not different between genders. CMJ performance was greater in men compared with women at all time points (38.2 ± 1.9 cm vs. 29.8 ± 1.2 cm $p < 0.01$ at baseline), but the percentage of change CMJ performance was not different between genders. CMJ performance remained unchanged throughout the short stretching protocol, while it decreased by 5.5±0.9% ($p < 0.01$) after stretching in the long stretching protocol However, 8 min after the tuck jumps, CMJ performance was not different from the baseline value ($p = 0.075$). In conclusion, lower limb power may be decreased after long periods of stretching, but performance of explosive exercises may reverse this phenomenon.

Key words: Countermovement jump, stretching, post-activation potentiation, fencing.

Introduction

Athletes competing in speed/power sports are often required to have both high leg muscle power and flexibility in order to perform explosive and wide movements and avoid injuries during training and competition (Baechle et al., 2008; Behm and Chaouachi, 2011). Prior to training and competition, athletes perform a warm-up routine, aiming to prepare their muscles to attain maximal power and coordination as well as to increase joint range of motion. These are attained by increasing muscle temperature, usually through light exercise, and by performing kinetic patterns that mimic movements of the sport (Baechle et al., 2008; Shellock and Prentice, 1985). A typical warm-up contains both stretching exercises and maximal or near maximal muscle actions, so that ample and explosive movements can be performed in the training or competition that follows (Young and Behm, 2002). However, several studies have shown that static stretching exercises that are commonly used by athletes prior to training or competition may impair muscle power, sprint speed, agility and balance (Bacuraeu et al., 2009; Mac Millian et al., 2006; Winchester et al., 2008). The duration of static stretching seems to play a critical role in these performance impairments (Behm and Chaouachi, 2011).

On the other hand the dynamic general or specific explosive movements that are typically performed during warm-up may induce a phenomenon called post-activation potentiation (PAP) that enhances muscle power in the following 3-20 minutes (Gelen, 2010; Hilficker et al., 2007; Hodgson et al., 2005; Kilduff et al., 2007). Although the effects of stretching and dynamic muscle actions on consequent explosive movements are opposing (decrease and increase muscle power, respectively), most previous studies have examined their effects separately. For example, Thompsen et al. (2007) reported lower vertical and long jump performance following static stretching, compared with another condition where dynamic exercises with or without an external load (vest) were used. Furthermore, Gellen, (2010) and Vetter (2007), demonstrated the negative effects of static stretching on jumping, sprint, and specific soccer drills performed after general warm-up, while Chaouachi et al. (2010) in their study conducted in highly trained sprinters, asserted that static stretching exercises to point of discomfort applied 5 min after a general warm-up did not adversely affect sprinting and jumping performance. Interestingly, dynamic stretching can reduce or even reverse the detrimental effects of static stretching (Gelen 2010; Behm and Chaouachi, 2011; Turki et al., 2011).

Only a few studies have examined the acute effects of different warm-up methods on power and sport-specific performance. For example, Tsolakis et al. (2010a) did not find any significant differences on flexibility, jumping ability and leg functional characteristics of fencing performance after either static or ballistic stretching of the lower limbs in international level fencers, suggesting that both types of stretching can be used during pre-competition warm-up of a speed/power sport However, there is a lack of studies examining the effects of a realistic pre-competition warm-up, containing both stretching and potentiating exercises, on flexibility and muscle

Received: 14 August 2012 / Accepted: 05 September 2012 / Published (online): 01 December 2012

power.

Therefore, the aim of this study was to examine the combined effect of stretching and muscle potentiating exercises that are used in a speed/power sport warm-up, on leg muscle power and flexibility. More specifically, the effect of two different stretching durations (long and short) was studied in combination with pre-conditioning tuck jumps, used to enhance muscle power. It was hypothesized that the longer static stretching protocol would adversely affect power performance (Behm and Chaouachi, 2011), but the plyometric exercises (tuck jumps) would counteract the detrimental effects of static stretching (Tillin and Bishop, 2009).

Methods

Subjects

The participants were 20 speed/power athletes (10 male and 10 female fencers), all members of the National team, with considerable experience of international competitions. The physical characteristics of the subjects are shown in Table 1. The participants trained 5-6 times a week (~120 minutes per session) and participated in competitions approximately every second week. The daily training programs were typical of the fencing training and were devoted to specific exercises and skills for the lower limbs and to technical and tactical development at moderate to high intensities (Tsolakis and Katsikas, 2006). The specific conditioning part aimed to improve aerobic and anaerobic fitness of the fencers was performed twice a week and contained alternatively weight training, circuit training, sprint and jumping plyometric drills. Prior to data collection, informed consent was obtained from each participant, after a thorough description of the risks being involved. The study was approved by the local Institutional Review Board and all procedures were in accordance with the Helsinki declaration of 1975, as revised in 1996. The fencers were free of injury and the testing was performed during the transitional training period.

Table 1. Descriptive characteristics of the participants. Data are means (±standard errors).

	Males (n=10)	Females (n=10)
Age (yrs)	24.3 (2.7)	22.1 (1.3)
Height (m)	1.80 (.02)	1.69 (.03)**
Weight (kg)	77.1 (2.2)	61.1 (2.8)**
Body fat (%)	15.9 (1.3)	22.2 (1.8)*

* $p < 0.05$ and ** $p < 0.01$ from males

Experimental design and procedures

This study was designed to investigate the effects of two different warm-up protocols on legs power performance in high level speed/power athletes of both genders. More specifically, a repeated measure, within subject randomized designed was used to compare the effects of two different warm-ups on hip joint flexion range of motion (ROM) and counter-movement jump (CMJ) performance. The warm-up procedures contained either a short or a longer static stretching treatment combined with either a moderate or high volume of plyometric jumps. In order to evaluate the possible interaction between fatigue and PAP, performance tests were executed immediately after and at the end of the 8^{th} min of recovery following interventions. The results of this study were expected to provide additional information concerning the effectiveness of the combination of those warm-up components and to suggest the most appropriate warm-up procedures for speed/power athletes.

In the 24-hour period before performing the tests, the subjects did not engage in any fatiguing activity. Each fencer was instructed and verbally encouraged during each test to perform maximally at each trial.

Participants visited the fencing hall of the Athens Olympic complex three times. On the first day (familiarization session) each participant's height body mass and body fat were measured and they were familiarized with the warm-up procedures, stretching, plyometric exercises and the performance tests. The participants were instructed to execute each CMJ with maximal effort while minimizing the ground contact time during tuck jumps. The remaining two testing sessions were conducted at the same time of the day (16:00 -20:00 pm), with 2-4 days in between. Within each session, participants were first tested for ROM of the dominant leg. In elite fencers leg dominance was defined with regard to the armed hand (Poulis et al 2009).

Main tests

Before the standardized warm-up the hip flexion range of motion (ROM) of the dominant leg was measured with a Lafayette goniometer. Participants laid supine on a standard gymnastics plinth with the opposite lower extremity held firmly down by an assistant, so that there was no flexion at the hip joint. Another experienced investigator placed one hand on the front of the tested leg, slightly below the knee and the other hand on the heel. The extended leg was then lifted as far as possible without the pelvis lifting off the plinth. At the point of maximum stretch, a second investigator fixed the goniometer halfway between the greater trohanter and the lateral epicondyle of the thigh (Heyward, 2005). Two separate measurements were taken and the best was used for analysis.

Then participants performed 5 min of light jogging followed by the baseline measurement of CMJ and another measurement of hip ROM. Counter movement jump (CMJ) performance was measured using an Ergojump contact platform (Ergojump, Psion XP, MA.GI.CA., Rome, Italy) as described by Bosco et al, (1983). All participants were instructed to leave the mat with the knees and ankles extended and land at the same spot in an upright position. The best of two trials, separated by 30 s rest, was used for analysis. The ICC for the ROM and CMJ were 0.989, ($p < 0.001$) and 0.985 ($p < 0.001$), respectively.

Stretching interventions

Before the static stretching interventions (either 15 s or 45 s to the point of discomfort), participants undertook a 3 min of seated recovery. Static stretching included three different stretching exercises: unilateral standing quadriceps stretch, unilateral standing hamstring stretch, unilateral standing calf stretch, executed for 15 s (short) or 45 s (long) for each leg and each exercise, to the point of discomfort. For the unilateral standing quadriceps, the

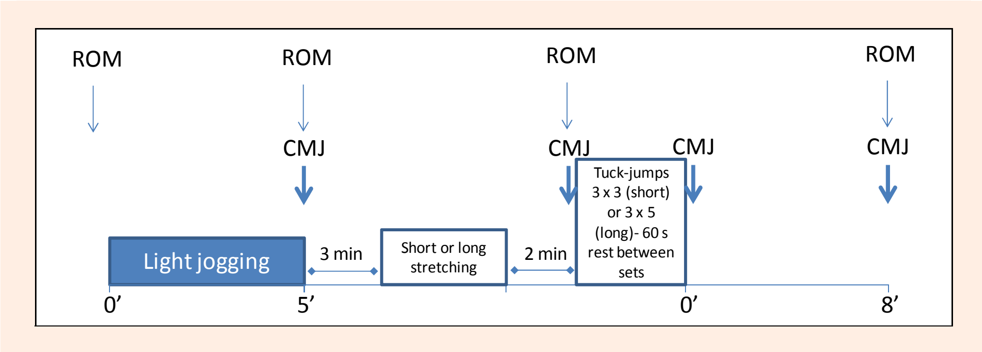

Figure 1. Experimental protocol of the study.

participants grabbed the ankle with the ipsilateral hand making sure not to pull the leg into abduction while performing the stretch. For the unilateral standing hamstring stretch the heel of the foot was placed on an adjustable obstacle slightly below the hip level with the knee fully extended, while for the standing calf stretch the hands were placed against a wall and the foot was planted on the floor approximately 1 meter from the wall with the heel touching the ground (Alter, 1988). The subjects were then instructed to lean forward making sure that the stretched foot was flat on the floor. Participants were asked to maintain the stretching position where they felt discomfort throughout the required stretching time period. The participants were familiar with the stretching protocols, since they routinely performed these exercises in every day training and competition.

PAP interventions

Two min after the end of the static stretching exercises CMJ and the ROM of the dominant leg were measured again as described above. Then, the three sets of tuck jumps (PAP intervention) were executed (3x3 tuck jumps for the short stretching or 3x5 tuck jumps for the long stretching protocol). The three sets of tuck jumps were separated by 60 s or rest. This plyometric drill results in high muscle fiber recruitment (Masamoto et al., 2003; Till and Cooke, 2009) and many speed/power athletes, including fencers, empirically use as a part of warm-up activities just before competition to enhance their performance. Immediately after and at the 8th minute of recovery following the PAP treatment the CMJ was measured again. ROM was measured only after the 8th min of recovery (Figure 1).

Statistical analysis

All statistical analysis was performed using the STATISTICA v.8.0 software (StatSoft Inc., Tulsa, OK, USA). Data are presented as means and standard error of the mean. A 3-way repeated measures ANOVA (gender x condition x time) was used to examine differences in ROM and CMJ performance between the two genders, the two conditions and over time. A Tuckey post–hoc was performed whenever appropriate ($p < 0.05$) to locate differences between means. Effect size for main effects and interaction was estimated by calculating partial eta squared (η^2) values using the STATISTICA v.8.0 software. Effect sizes were classified as small (0.2), medium (0.5) and large (0.8). Relationships between variables were examined by calculating the Pearson Product-Moment correlation coefficient (r). Statistical significance was accepted at $p < 0.05$.

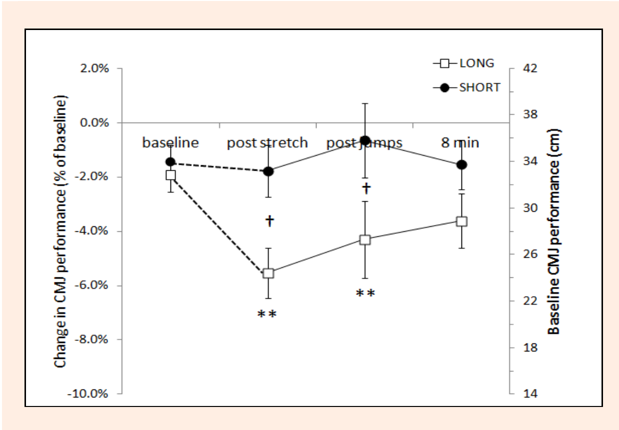

Figure 2. Countermovement jump (CMJ) performance in the two conditions (short and long duration stretching). Data are expressed in absolute values (cm) only at baseline (after the 5 min run), while CMJ performance at the other time points is expressed as a percentage of the corresponding baseline value. Time points: after the stretching protocols (post stretch), immediately after (post jumps) and 8 min following the tuck jumps (8 min). **: $p < 0.01$ from baseline only in the LONG condition; †: $p < 0.05$ between LONG and SHORT CMJ performance at the corresponding time point.

Results

CMJ performance

The 3-way ANOVA (condition x time x gender) revealed significant main effects for time ($p = 0.01$, $n^2 = 0.18$, "small"), gender ($p < 0.001$, $n^2 = 0.55$, "medium"), as well as a condition x time interaction ($p = 0.01$, $n^2 = 0.18$, "small"). Post hoc comparisons showed that CMJ performance remained unchanged throughout the short stretching protocol (Figure 2), while it decreased by 5.5±0.9% ($p < 0.01$) after stretching in the long stretching protocol. CMJ performance in the long stretching condition remained depressed after the tuck jumps (by 4.3 ± 1.4%; $p < 0.01$ from baseline, Figure 2). However, 8 min after the tuck jumps, CMJ performance was not different from the baseline value ($p = 0.075$, Figure 2). CMJ performance was greater in men compared with women at all time points (38.2 ± 1.9 cm vs. 29.8 ± 1.2 cm $p < 0.01$ at baseline), but the percentage of change CMJ performance was not different between genders. Since the percent changes of CMJ performance were not different between males and females, data were pooled for the two genders at each condition and time point. Figure 2 shows the relative changes in CMJ performance over time for the two experimental conditions.

There was not any significant correlation between changes in ROM and changes in CMJ performance at all time points.

ROM

The 3-way ANOVA (condition x time x gender) revealed significant main effects for time ($p < 0.001$, $n^2 = 0.79$, "large") and gender ($p<0.001$, $n^2 = 0.51$, "medium"), with no interaction between factors. Post hoc comparisons showed that ROM of the hip joint increased by 6.8 ± 1.1% ($p < 0.01$) after warm-up and by another 5.8 ± 1.6% ($p < 0.01$) after stretching, while it remained increased 8 min after the tuck jumps. Women had greater ROM compared with men at all time points (125 ± 8° vs. 94 ± 4° $p < 0.01$ at baseline), but the percentage of change in hip flexibility was not different between genders. Figure 3 shows the relative changes in ROM over time for the two experimental conditions. Since the percent changes of ROM were not different between males and females, data were pooled for the two genders at each condition and time point.

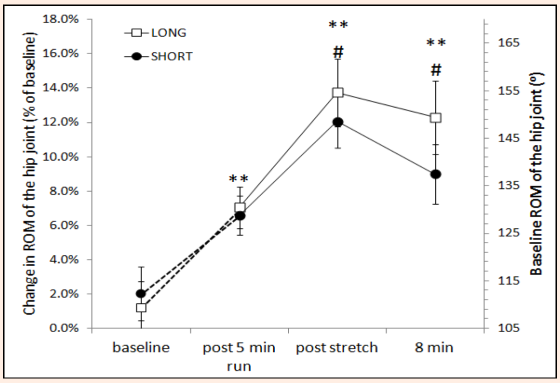

Figure 3. Hip joint flexion range of motion (ROM) in the two conditions (short and long duration stretching). Data are expressed in absolute values (°) only at baseline (before the 5 min run), while ROM at the other time points is expressed as a percentage of the corresponding baseline value. Time points: after the 5 min run (post 5 min run), after the stretching protocols (post stretch) and 8 min following the tuck jumps (8 min). **: $p < 0.01$ from baseline; #: $p < 0.01$ from post 5 min run.

Discussion

The main finding of the present study was that although both stretching durations (long and short) resulted in a similar increase in hip flexion ROM (~12.6%), CMJ performance was significantly reduced by about 5.5% only after the longer duration static stretching protocol. This reduction was maintained immediately after the tuck jumps, but CMJ performance returned to baseline values 8 min following the tuck jumps.

The fact that there was no statistically significant impairment in CMJ performance following the short stretching protocol is in contrast with findings of other studies that showed considerable decreases in jump height after static stretching of similar duration (<=15 s; Behm and Chaouachi, 2011; Fletcher and Monte-Colombo, 2010; Gonzalez-Rave et al., 2009; Holt and Lambourne, 2008). The lack of a decreased CMJ performance after stretching in the short stretching condition coincided in time with a large increase in hip flexion ROM (Figure 3). However, this acute "elongation" of the muscle-tendon unit did not cause any decreases in explosive performance, as might have been expected due to a possible altered length-tension relationship (Rassier et al., 1999) or possible neural inhibitory effects (Guissard et al., 2001). It should be noted that stretching in the present study was performed at high intensity (to the point of discomfort), that seems to have a detrimental effect on neuromuscular activation (Behm et al., 2001). Therefore, it may be argued that short duration stretching during warm-up can increase flexibility without causing any negative effects on subsequent explosive performance. However, the fact than no post activation potentiation of jump performance was observed following the tuck jumps in the short stretching protocol, may either be interpreted as a failure of the 3 x 3 tuck jumps to cause PAP, or as a counterbalance between muscle potentiation due to the jumps and decrease in performance due to stretching. In support of the first explanation, Till and Cooke (2009) also reported a failure of 5 double-legged tuck jumps to enhance the excitability of the fast twitch motor units and to cause a PAP effect. Unfortunately in the present study, as well as in other similar studies (Esformes et al., 2010; Masamoto et al., 2003) electromyography was not performed, hence a mechanism by which plyometric exercises may enhance CMJ performance was not provided.

Another possible explanation for the lack of a decrease in CMJ performance after short duration stretching during warm-up is the training level of the participants, who were international fencers with long training histories and adaptations. Some authors have proposed that well-trained athletes may be less susceptible to the stretch-induced decrements in explosive performance compared to untrained individuals (Unick et al., 2005). Studies using athletic populations reported no effect of static stretching on subsequent performance of well trained female basketball players (Egan et al., 2006), female volleyball players (Dalrymple et al., 2010), elite sprinters (Little and Williams, 2006) highly trained University students (Chaouachi et al., 2010) as well as fencers (Tsolakis et al., 2010a). It is possible that greater flexibility or more training to achieve greater ROM, may result in specific adaptations such as maintenance of stiffness after stretching (Magnusson et al., 1996). However, it must be noted that this is not always the case and decreases in sprint, and jump performance have been observed after stretching in well-trained athletes (Fletcher and Jones, 2004; Vetter, 2007)

The finding that CMJ performance was significantly decreased (by about 5.5%) immediately after the long duration stretching protocol is not uncommon. Several studies reported static stretching-induced impairments of subsequent explosive performance (Fletcher and Jones, 2004; McMillan et al., 2006; Yamaguchi and Ishi, 2005; Young and Behm 2003), or specific kinetic patterns such as fencing movements (Tsolakis et al., 2010a). Although it is not always possible to compare the findings of studies using different mode, intensity, frequency and duration of stretching exercises, it seems that stretch duration as well as intensity is key variable (Behm and Chaouachi, 2011). When intensity is standardized to high levels, as in the present study, the longer duration static stretching causes a greater decrement in performance (Siatras et al., 2008; Ogura et al., 2007; Wong et al., 2011). Longer duration static stretching protocols may cause a decrease in jumping performance making the muscle more compliant (Magnuson et al., 1996; Power et al., 2004). Several studies have argued that an increase in muscle compliance reduces storage and utilization of elastic energy, impairs force transmission (Turki et al., 2012), and intramuscular coordination and proprioception (Fletcher and Jones, 2004). A large increase in hip flexion ROM has been observed following the long stretching protocol in the present study, and one may argue that this increased muscle compliance may contribute to the drop of CMJ performance. However, as also noted above, a similar increase in ROM was also observed in the short stretching protocol, without any change in subsequent explosive performance. Furthermore, no correlation was found between the increase in ROM and the decrease in CMJ performance at any time point. These findings would suggest that a mechanism causing this decrement in CMJ following long duration stretching was neural. It has been suggested that motoneuron excitation may be decreased following stretching, due to a reduction of the excitatory drive from the Ia afferents onto the alpha motoneuron, which is, in turn, caused by a decreased resting discharge of the muscle spindles (Avela et al., 1999). A possible decrease in the responsiveness of muscle spindles could result in a reduction of motor unit recruitment (Beedle et al., 2008) and subsequent explosive performance.

Interestingly, the decrease in CMJ performance following the long stretching protocol recovered relatively quickly. Previous studies have reported long-lasting performance decreases after similar and/or larger stretching durations. For example, Power et al. (2004) reported a mean decrease in quadriceps maximal force of 9.5%, coupled with a 5.4% decrease in muscle activation and a 7.4% increase in ROM, that lasted for about 2 hours after stretching. An important factor determining the magnitude and possibly the duration of performance impairment after static stretching is stretch duration. In the present study, the duration of static stretching in the long stretching protocol was 3 x 45= 135 s. Behm and Chaouachi (2011) in a review of the relevant literature argued that when the duration of stretching exceeds 90 s, then subsequent performance impairments are evident and large.

The plyometric exercises used in the present study (tuck jumps) were chosen because they are commonly used at the end of the warm-up before training or competition. It was hypothesized that the greater volume of tuck jumps performed after the long duration stretching would not only reduce but would reverse the adverse effects of static stretching on explosive power generation (Gellen, 2010; Chaouachi et al., 2010). The fact that in the present study CMJ performance recovered towards the baseline values so fast (8^{th} min) may be attributed to the PAP effect of the 3 x 5 tuck jumps, which probably outweighed the negative effect of stretching (Figure 2). From a practical viewpoint, this finding suggests that the negative effect of long duration stretching may be reversed by using this type of plyometric exercise. As expected from the time course of explosive performance after an exercise aiming to induce PAP, there is initially a decrement (fatigue outweighing PAP) followed by an increase (PAP dominating over fatigue; Behm, 2004). As seen in Figure 2, CMJ performance returned to baseline values 8 min after the tuck jumps. However, there was no potentiation of CMJ performance above the baseline values after both stretching and tuck jump combination warm-up protocols. In practical terms, both ROM and muscle power should be increased following an “optimal” warm-up. While the first aim was attained after both warm-up protocols used in the present study the second aim, i.e. the increase in CMJ performance was not achieved. An increase of lower limb explosive performance would allow athletes to perform fast and powerful sport-specific movements (Caplan et al., 2009; Tsolakis et al., 2010b). Thus, it may be argued that none of these combinations of stretching duration and tuck jumps should be used for competition. A novelty of the present study was that the effects of stretching and PAP activities were not examined in isolation, but under real-life training and competition conditions. Elite speed/power athletes, such as fencers, use similar warm-up protocols and modify stretch duration and muscle activation contractions by experience, i.e. trial and error. The results of the present study may shed some light onto the optimum combination of stretching and PAP activities for a successful warm-up in speed/power sports. It seems possible that in the short duration stretching protocol, the number of tuck jumps was too low and thus no potentiation of jumping performance was seen. On the other hand, the duration of stretching was too long in the other stretching protocol, while a possible increase in the number of tucks jumps to induce a greater PAP effect would result in fatigue and not in performance enhancement (Tsolakis et al., 2011). A suggestion for future research would be to combine the short stretching protocol with the increased number of tuck jumps (3 x 5).

Conclusion

The results of the present study showed that following a warm-up similar to that used by elite speed/power athletes in training and competition, flexibility of the hip joint is increased at the same degree after both short and long duration stretching. However, lower limb power is decreased when performing longer duration stretching, but this is reversed when three sets of a PAP exercise are performed following stretching. The failure of both warm-up protocols to increase CMJ above baseline suggests firstly that the long duration stretching used in the present study should be avoided and possibly that a greater volume of PAP exercises is needed to optimize warm-up in athletes of speed/power sports.

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Key points

- Stretching of the main leg muscle groups for 45 s results in a relatively large decrease (by 5.5%) in subsequent jumping performance
- Stretching of the main leg muscle groups for only 15 s results in an increase in flexibility similar to that of the longer duration stretching (by 12.6%), with no change in subsequent jumping performance
- Performance of a PAP exercise such as tuck jumps may reverse the negative effects of long duration stretching on leg muscle power. However, jumping performance is not increased above baseline
- Speed/power athletes should be advised against using long duration stretching. The number of repetitions of a PAP exercise such as the tuck jumps, should be further examined in order to induce an increase in explosive performance during competition

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