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Research article

Effects of Baseline Levels of Flexibility and Vertical Jump Ability on Performance Following Different Volumes of Static Stretching and Potentiating Exercises in Elite Gymnasts

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Abstract
This study examined the effects of baseline flexibility and vertical jump ability on straight leg raise range of motion (ROM) and counter-movement jump performance (CMJ) following different volumes of stretching and potentiating exercises. ROM and CMJ were measured after two different warm-up protocols involving static stretching and potentiating exercises. Three groups of elite athletes (10 male, 14 female artistic gymnasts and 10 female rhythmic gymnasts) varying greatly in ROM and CMJ, performed two warm-up routines. One warm-up included short (15 s) static stretching followed by 5 tuck jumps, while the other included long static stretching (30 s) followed by 3x5 tuck jumps. ROM and CMJ were measured before, during and for 12 min after the two warm-up routines. Three-way ANOVA showed large differences between the three groups in baseline ROM and CMJ performance. A type of warm-up x time interaction was found for both ROM ($p = 0.031$) and CMJ ($p = 0.016$). However, all athletes, irrespective of group, responded in a similar fashion to the different warm-up protocols for both ROM and CMJ, as indicated from the lack of significant interactions for group (condition x group, time x group or condition x time x group). In the short warm-up protocol, ROM was not affected by stretching, while in the long warm-up protocol ROM increased by 5.9% ± 0.7% ($p = 0.001$) after stretching. Similarly, CMJ remained unchanged after the short warm-up protocol, but increased by 4.6 ± 0.9% ($p = 0.012$) 4 min after the long warm-up protocol, despite the increased ROM. It is concluded that the initial levels of flexibility and CMJ performance do not alter the responses of elite gymnasts to warm-up protocols differing in stretching and potentiating exercise volumes. Furthermore, 3 sets of 5 tuck jumps result in a relatively large increase in CMJ performance despite an increase in flexibility in these highly-trained athletes.

Key words: Gymnastics, countermovement jump, stretching, post-activation potentiation.

Introduction

One of the main purposes of a warm-up prior to training and competition is to maximize performance and prevent injuries (Chaouachi, et al., 2010; Fradkin, et al., 2010; O' Sullivan et al., 2009; Safran et al., 1989; Shellock and Prentice, 1985). Warm-up is typically composed of a submaximal aerobic activity, stretching of the major muscle groups, as well as general and sport specific exercises performed at or near competition intensities (Taylor et al., 2008). Low to moderate aerobic activity increases body and muscle temperature, muscle compliance and efficiency of physiological responses (Bishop, 2003). Stretching, following submaximal aerobic activity, has been shown to further increase range of motion (Bandy et al., 1998; Magnusson and Renström, 2006; Magnusson et al., 1996) and to enhance performance (Young and Behm, 2002) while it may also reduce the incidence of injury (Cross and Worell, 1999; Hartig and Henderson, 1999; McHugh and Cosgrave, 2010). However, there is evidence that pre-exercise stretching may not decrease the risk of injury (Pope et al., 2000; Small et al., 2008; Thacker, et al., 2004) or may even be harmful (Shrier, 1999; Weldon and Hill, 2003). Thus, although pre-exercise stretching is common practice for many athletes, its effects have been questioned (Shrier, 2004; Haff, 2006).

Previous studies, reported that static stretching may temporarily decrease the ability of the stretched muscles to generate power output (Behm et al., 2001, 2004; Fowles et al., 2000; Nelson et al., 2001). This has been attributed to both neuromuscular inhibition and a decrease in muscle stiffness due to alterations of the viscoelastic properties of the musculotendinous unit (Alter, 1996; Knudson et al., 2011). The duration and intensity of the static stretching exercises seem to play a critical role in these impairments, with long lasting, intense stretching exhibiting a greater decrease in subsequent power generating ability (Behm and Chaouachi, 2011).

The final part of a typical warm-up involves general and sport specific explosive movements that may induce a phenomenon called post-activation potentiation (PAP), (Gelen, 2010; Hilficker et al., 2007). PAP is characterized by increased muscle force and power output in the next 4-20 minutes following voluntary conditioning contractions performed at high intensities (Tillin and Bishop, 2009). PAP is greater in individuals with high levels of muscle power, who also have a higher proportion of type II fibers (Hamada et al., 2000; Young et al., 1995) and shorter twitch contraction time (Vandenboom et al., 1995).

The acute effects of stretching and potentiating exercises in warm-up routines are opposing, i.e. stretching exercises decrease and PAP exercises increase muscle power. However, there is limited information on the combined effects of stretching and PAP exercises during warm-up. In a recent study, Tsolakis and Bogdanis (2012) examined the combined effect of static stretching and potentiating exercises in elite fencers. The main finding of their study was that although short (15 s) and long (45 s) durations of stretching resulted in a similar increase in hip flexion ROM by 12.6%, subsequent countermovement

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jump (CMJ) performance was significantly reduced by 5.5% only after the long duration static stretching protocol. In contrast, Chaouachi et al. (2010) reported that static stretching to the point of discomfort did not affect sprint and jumping performance in elite athletes and attributed it to their high training status. These data suggest that there may be different responses to stretching and PAP protocols, depending on the training status, baseline flexibility and muscular power.

In most studies, static stretching may increase compliance and thus reduce the stiffness of the muscle-tendon unit (Bacuraeu et al., 2009, Winchester et al., 2008), but this effect is transient (Magnusson and Renström, 2006) and depends on the duration (Yamaguchi and Ishii, 2005), and intensity of the stretching protocols. This reduction in stiffness of the muscle-tendon unit results in a decreased performance during subsequent explosive muscle actions. On the other hand, according to "sarcomere give' theory stretching of an active muscle causes a rapid increase of force after the onset of stretch, followed by a sudden yielding of the sarcomeres, which may affect subsequent muscle performance (Flitney and Hirst, 1978).

The combined effects of stretching and conditioning exercises during warm-up may be influenced by the flexibility and muscle power of the performer, as well as by the volume of exercise. Gymnastics is a sport that is generally characterized by high levels of strength and power relative to body weight, as well as high flexibility (Arkaev and Sutsilin, 2004). Interestingly, athletes of the different gymnastics disciplines are characterized by varying levels of flexibility and muscle power. Artistic gymnasts are much stronger than rhythmic gymnasts, while rhythmic gymnasts are mainly characterized by their flexible joints and compliant muscles (Smolefski and Gaverdofski, 1999).

This led us to investigate the hypothesis that the different levels of flexibility and muscle power of those groups of athletes influence their responses to warm-up protocols containing different volumes of stretching and conditioning exercises. Therefore, the aim of the present study was to manipulate the volumes of stretching and muscle potentiating exercises and examine their combined effects on counter-movement jump performance (CMJ) and straight leg raise range of motion (ROM). Two different stretching durations (short and long) were used in combination with conditioning tuck jumps, commonly used to induce PAP (Masamoto et al., 2003; Till and Cooke, 2009; Tsolakis and Bogdanis, 2012). One of the advantages of using three subgroups of elite level gymnasts (male and female artistic and female rhythmic gymnasts) is that each group is characterized by different levels of flexibility and CMJ performance. Thus, the effect of differences in baseline level of CMJ performance and flexibility on the responses to the two warm-up programs was examined.

Methods

Participants

Thirty-four rhythmic and artistic gymnasts (10 male, 14 female artistic gymnasts and 10 female rhythmic gymnasts), all members of the Greek national team took part in this study. The physical characteristics of the participants are shown in Table 1. All gymnasts had long competing experience of official international F.I.G (Fédération Internationale de Gymnastique) competitions: Olympic Games, World Championships, European Championships. Nine gymnasts were Olympic Games qualifiers and 15 participated in World Championships. Rhythmic and artistic gymnasts were training for six days a week (two training sessions per day) for approximately 48 and 34 hours per week respectively and participated in competitions according to the national and the international calendar of the F.I.G. The training sessions of artistic gymnastics included specific physical conditioning, as well as general and specific technical preparation on the apparatuses six times per week. The physical conditioning part aimed to improve strength, flexibility, anaerobic fitness, muscular endurance. It contained resistance training, strength exercises using body weight, strength oriented gymnastic skills and combinations of the skills (Jemni et al., 2006). Static and dynamic flexibility exercises were performed in every training session for 20 min as part of the warm-up. In addition, dynamic flexibility training (with light weights and elastic bands) was performed as part of the physical conditioning for 30-35 min in the end of every morning training session and static flexibility exercises for 20-30 min in the end of every afternoon training session focusing especially on the individual needs of every gymnast. Rhythmic gymnastics training incorporated special physical conditioning for static and dynamic flexibility before and after training, strength skills, balance training, speed capacities and technical preparation with and without apparatuses six times a week. Static and dynamic flexibility exercises were performed for 30 min in every training session as part of the warm-up. Dynamic flexibility training (with and without light weights and elastic bands) was performed as part of the physical conditioning for 40-45 min in the end of every morning training session and static flexibility exercises for 30-35 min in the end of every afternoon training session.

The gymnasts were free of injury and testing was performed during the competitive training period. Adult gymnasts, gave consent to participate in the study while written parental consent was provided for non-adult gymnasts. The study was approved by the University's Institutional Review Board and all procedures were in accordance with the Helsinki declaration of 1975, as revised in 1996.

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

	Age (y)	Height (m)	Weight (kg)	Training experience (y)
Male artistic gymnasts (n = 10)	24.4 (4.3)	1.67 (.03)	64.3 (4.4)	17.2 (4.8)
Female artistic gymnasts (n = 14)	18.1 (2.6)	1.60 (.05)	49.9 (5.4)	10.7 (3.6)
Female rhythmic gymnasts (n = 10)	18.6 (1.6)	1.67 (.04)	48.8 (1.1)	10.4 (1.2)

Table 2. Baseline values of straight leg raise range of motion (ROM), countermovement jump (CMJ) performance and leg peak power of rhythmic and artistic gymnasts. Data are means (±standard error).

	Male Artistic Gymnasts (n=10)	Female Artistic Gymnasts (n=14)	Rhythmic Gymnasts (n=10)
ROM (°)	122 (3)	169 (2) *	182 (1) *†
CMJ (cm)	38.5 (0.9)	29.5 (1.1) *	24.0 (.7) *†
Leg peak power (W/kg)	49.7 (0.8)	40.0 (1.3) *	33.0 (.9) *†

* $p < 0.001$ from male artistic gymnasts; † $p < 0.001$ from female artistic gymnasts

Experimental design and procedures

The present study examined the effectiveness of two different warm-up protocols on counter movement jump performance (CMJ) and straight leg raise range of motion (ROM) in 10 male, 14 female artistic and 10 female rhythmic international level gymnasts with different initial flexibility and counter-movement jump performance (Table 2). A repeated measures randomized design was used. The two conditions included two different warm-up protocols containing either a short (15 s) or a long (30 s) static stretching followed by either a low (1x5) or high volume (3x5) of plyometric (tuck) jumps. The duration of the stretches was chosen based to scientific and practical evidence; there are several investigations supporting that 30 s of static stretching can improve muscle flexibility (Bandy and Irion, 1994; Odunaiya et al., 2006; Yamaguchi and Ishii, 2005). On the other hand, 15 s of static stretching is a stretch duration that is often used in warm-up before training and especially before competition. Furthermore, evidence supports the notion that even relatively brief durations of stretching (15-30 s) can reduce strength and power production of the stretched muscle group (Gonzalez-Rave et al., 2009; Hough et al., 2009). The effects of each protocol on ROM and CMJ were examined before and after stretching and the tuck jumps (Figure 1).

Gymnasts visited the installations of the Gymnastics High Performance Centre three times. Prior to performing the treatment protocols, each participant underwent a first familiarization session, performing the warm-up procedures, stretching, and plyometric exercises. In addition, each participant's height and body mass were measured.

Twenty-four hours prior to performing the main testing conditions, the gymnasts were asked to avoid any strenuous activity. These two testing sessions were performed 5-7 days apart, in a balanced random order at the same time of the day (at around 16:00 hours).

Main tests

Prior to a five-minute moderate intensity jogging (50-60% of maximal heart rate), the straight leg raise range of motion (ROM) of the preferred leg was measured with a Lafayette goniometer, to assess the functional excursion of the hamstrings. The gymnasts lay in a supine position on a gymnastics plinth with their lower back flat on the plinth to prevent possible pelvic rotation. The opposite leg was held firmly down by an assistant so that there was no flexion at the hip joint. An 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 lifted as far as possible while maintaining the knee fully extended, without the pelvis lifting off the plinth and with the ankle joint in a neutral position. The pressure was progressively applied on the leg to the point that each subject could tolerate, without changing the predetermined stretching position. At the point of maximum stretch, a second investigator fixed the goniometer on the subject to measure ROM. One lever of the goniometer was land marked on the lateral midline of the pelvis, while the pivot was placed on the lateral aspect of the hip joint, at the greater trochanter. The other lever was positioned on the lateral midline of the femur on the line connecting the greater trohanter and the lateral epicondyle of the thigh (Heyward, 2005). These anatomical landmarks were located by manual palpation and marked with a permanent marker so that they could be used during all measurements. The same investigators performed all tests. Two measurements were taken and the largest value was used for analysis. The ICC for ROM was 0.989, ($p < 0.001$). Then participants performed the 5 min light jogging followed by the baseline measurement of CMJ and another measurement of ROM. CMJ performance was measured using an Ergojump contact platform (Ergojump, Psion XP, MA.GI.CA., Rome, Italy) as described by Bosco et al. (1983). Peak leg power was calculated using the following equation: Peak Power (W) = 60.7 x jump

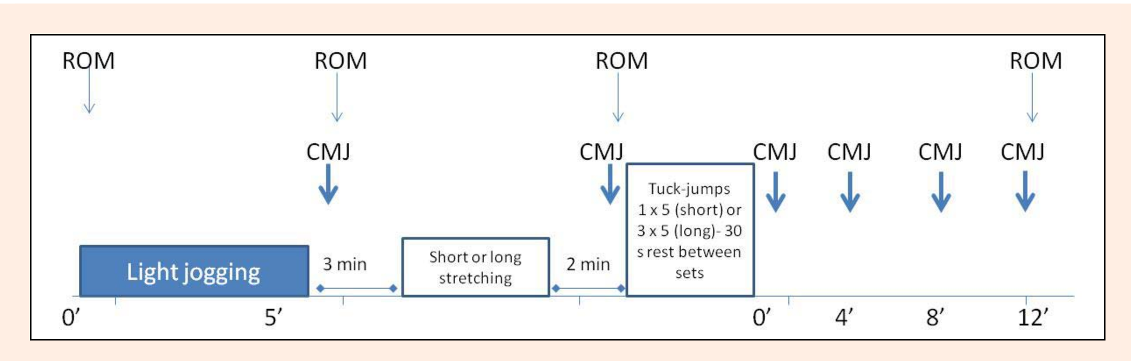

Figure 1. Schematic representation of the study protocol. Measurements of straight leg raise range of motion (ROM) and countermovement jump (CMJ) performance are indicated by arrows. Two separate conditions were performed: short (15 s) and long (30 s) stretching, followed by 1x5 or 3x5 tuck jumps, respectively.

height (cm) + 45.3 x body mass (kg) – 2055, (Sayers et al., 1999). Gymnasts were instructed to perform a countermovement until the knees were bent at approximately 90 degrees, and then immediately jump as high as possible with maximal effort. Athletes were instructed to land at the same spot in an upright position. The largest value of two trials, separated by 30 s rest, was used for analysis. The ICC for CMJ was 0.985 ($p < 0.001$).

Stretching and PAP interventions

Three minutes after a seated recovery, gymnasts undertook static stretching interventions including three different stretching exercises: unilateral standing quadriceps stretch, unilateral standing hamstring stretch, unilateral standing calf stretch, executed for 15 s (short) or 30 s (long) for each leg. Participants stretched one leg, followed by the other without any rest period. For the unilateral standing quadriceps stretch, the participants stood straight, bent one leg at the knee and held the ankle with the ipsilateral hand and brought their heel towards their buttock while making sure not to pull the leg into abduction during the stretch. For the unilateral standing hamstring stretch, the participants placed the heel of the foot to be stretched on an adjustable obstacle slightly below the hip level, allowing the knee to remain fully extended and the hip joint to flex until a stretch was felt in the posterior thigh. Then they leaned forward while keeping their upper body straight and extended as far as they could with their hands grabbing their toes. For the standing calf stretch, the participants placed both hands against a wall, extended one foot behind them while keeping their heel on the ground approximately 1 meter from the wall. The participants were then instructed to lean towards the wall with their hips making sure that the stretched foot was flat on the floor. Participants were asked to maintain all stretching positions where they felt discomfort throughout the required stretching time period. The gymnasts were familiar with the stretching protocols, since they performed these exercises in every day training and competition.

CMJ and ROM of the preferred leg were measured again two min after the end of the static stretching exercises. Then, the tuck jumps (PAP intervention) were executed (1x5 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 of rest. This plyometric exercise results in high muscle fiber recruitment (Masamoto et al., 2003; Till and Cooke, 2009) and it is a widespread warm-up activity among athletes just before competition to enhance performance. Immediately after and at the 4th, 8th and 12th minute of recovery following the PAP treatment the CMJ was measured again (single measurement). Finally, ROM was measured after the 12th min of recovery (Figure 1.)

Statistical analysis

All statistical analyses were 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 three-way repeated measures ANOVA (condition x time x group) was used to examine differences in ROM and CMJ between the three group of gymnasts (male and female artistic and female rhythmic), the two conditions and over time. A two-way ANOVA with repeated measures on one factor (condition) was used to compare the baseline values of CMJ and ROM between the three groups of athletes. A Tukey's post–hoc test was performed whenever appropriate ($p < 0.05$) to locate differences between means. Effect sizes for main effects and interaction were estimated by calculating partial eta squared (η^2) values using the STATISTICA v.8.0 software. According to Richardson (2011), partial eta squared is classified as small (0.01 to 0.059), moderate (0.06 to 0.137) and large (≥0.138). Test–retest reliability for all the dependent variables measured in this investigation was determined in separate experiments by calculating the intraclass correlation coefficient (ICC) using a 2-way mixed model (Shrout and Fleis, 1979). Statistical significance was accepted at $p < 0.05$.

Results

ROM

The 3-way ANOVA (condition x time x group) did not demonstrate a 3-way interaction effect ($p = 0.59$, $\eta^2 = 0.03$). In addition, no significant interaction effects were found for condition x group ($p = 0.60$, $\eta^2 = 0.03$) and time x group ($p = 0.14$, $\eta^2 = 0.05$), indicating that the three groups of athletes responded in a similar fashion to the two warm-up protocols. The only significant interaction found was condition x time ($p = 0.031$, $\eta^2 = 0.09$). The post-hoc test for the condition x time interaction showed that in the short warm-up protocol, ROM increased after warm-up and remained unchanged thereafter, despite the stretching intervention (Figure 2). In the long warm-up protocol ROM increased after warm-up (by 2.9±0.4%, Figure 2) and further after the stretching intervention (5.9%±0.7% greater ROM compared with rest) and then dropped 12 min after the 3x5 tuck jumps, without reaching baseline levels (Figure 2). ROM was greater in the long warm-up protocol, compared with the short warm-up protocol after the stretching intervention (POST STRETCH time point, Figure 2)

The two-way ANOVA comparing the baseline values showed large differences ROM between the three groups of gymnasts at baseline ($p = 0.001$, $\eta^2 = 0.99$), as shown in Table 2.

CMJ

The 3-way ANOVA (condition x time x group) did not show a 3-way interaction effect ($p = 0.30$, $\eta^2 = 0.06$). In addition, no significant interaction effects were found for condition x group ($p = 0.49$ $\eta^2 = 0.04$) and time x group ($p = 0.78$, $\eta^2 = 0.04$), indicating that the three groups of athletes responded in a similar way to the two warm-up protocols. The only significant interaction found was condition x time ($p = 0.016$, $\eta^2 = 0.09$). The post-hoc test for the condition x time interaction showed that in the short stretching protocol, CMJ remained unchanged compared to the baseline throughout the testing period (Figure 3). However, in the long stretching protocol CMJ increased by 4.6 ± 0.9%, 4 min after the tuck jumps and then

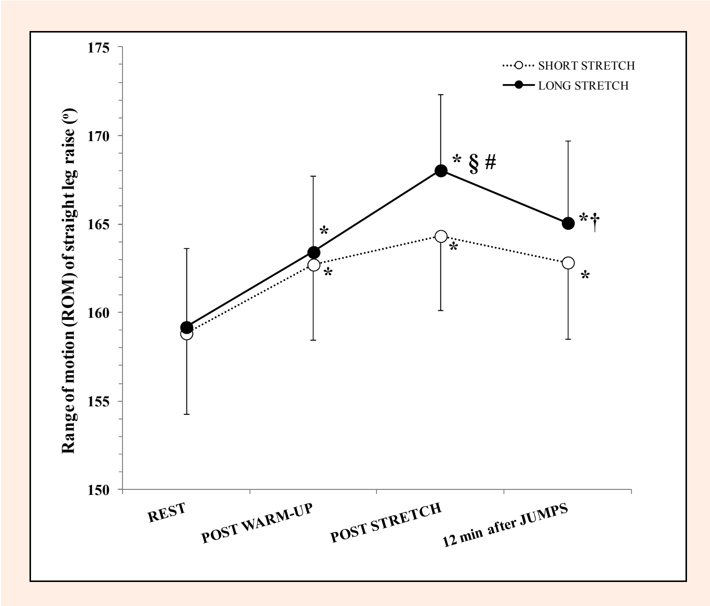

Figure 2. Straight leg raise range of motion (ROM) during the long and the short stretching conditions. * = $p < 0.01$ from rest; § = $p < 0.01$ from post Warm-Up; † = $p < 0.01$ from post-stretch; # = $p < 0.05$ between short and long stretch condition at that time point

returned to the baseline value at the 8th min after the jumps (Figure 3 and 4). CMJ performance 4 min after the tuckjumps was higher in the long, compared with the short warm-up protocol (Figure 3 and 4).

The two-way ANOVA comparing the baseline values showed large differences ROM between the three groups of gymnasts at baseline ($p = 0.001$, $\eta^2 = 0.99$). As can be seen in Table 2, male artistic gymnasts had the highest CMJ performance and the lowest flexibility, while in contrast rhythmic gymnasts had the greatest ROM and the lowest CMJ performance.

Discussion

This study examined the effects of baseline flexibility and vertical jump a bility on straight leg raise range of motion (ROM) and counter movement jump performance (CMJ) following different volumes of stretching and potentiating exercises in elite gymnasts. In particular, the effects of two different stretching durations (15 s and 30 s) were studied in combination with two different volumes of conditioning tuck jumps, aiming to induce PAP and thus enhance CMJ performance at the end of warm-up. One main finding of the study was that the initial level of lower limb flexibility and vertical jump ability did not alter the responses of elite gymnasts to the two warm-up conditions. The second main finding was that CMJ performance in the long warm-up condition increased considerably by 4.6%, despite a relatively large increase in flexibility by 5.9%.

In the present study the group with the greater flexibility had the lowest CMJ performance relative to their

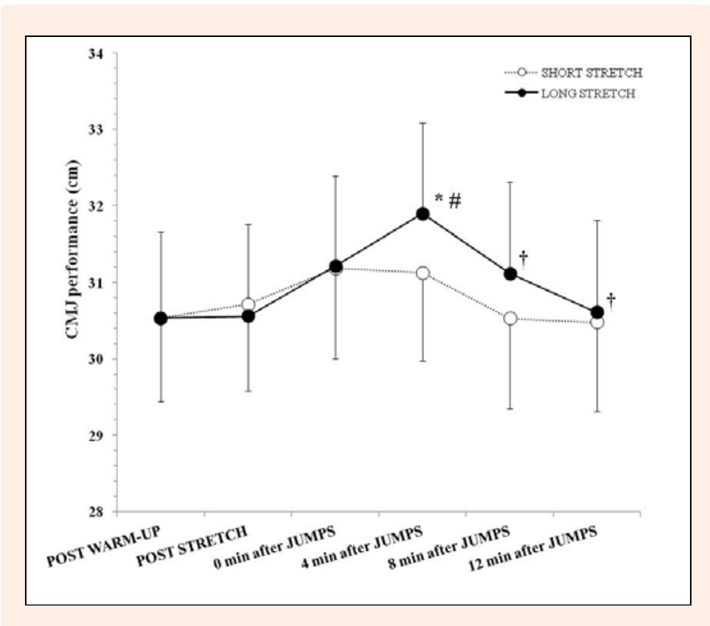

Figure 3. Countermovement jump (CMJ) performance during the long and the short stretching conditions. * = $p < 0.01$ from Warm-Up; † = $p < 0.01$ from 4 min. after tuck jumps; # = $p < 0.05$ between short and long stretch condition at that point (4 min after the tuck jumps).

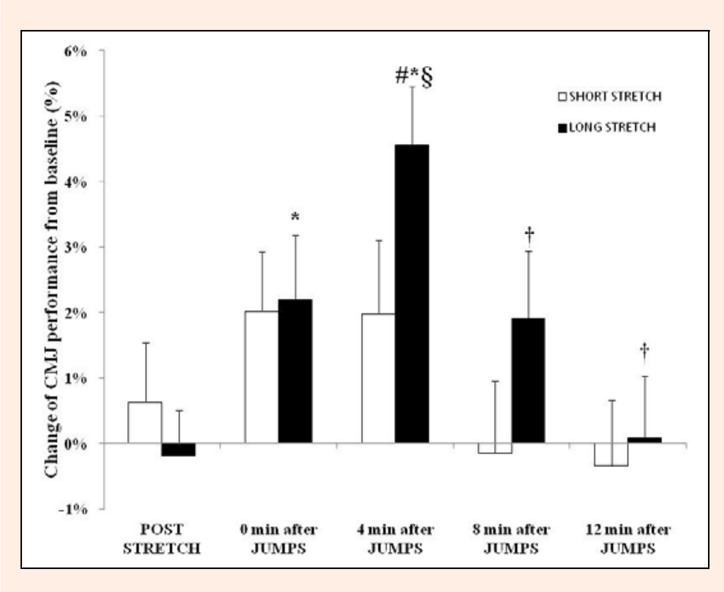

Figure 4. Percent change of countermovement jump (CMJ) performance from the post warm-up value during the long and the short stretching conditions. * = $p < 0.01$ from Post-stretch; § = $p < 0.01$ from 0 min. after tuck jumps; † = $p < 0.01$ from 4 min. after tuck jumps; # = $p < 0.05$ between short and long stretch condition at that point (4 min after the tuck jumps).

body mass (rhythmic gymnasts), while the more powerful artistic gymnasts had lower flexibility. However, the results showed that having high CMJ performance and lower flexibility or the inverse, does not affect the responses to stretching and potentiating exercises on ROM and CMJ in elite gymnasts. The fact that the responses to stretching and potentiating exercises were similar in the groups of male (artistic gymnasts) and female athletes (artistic and rhythmic gymnasts) shows that there is no gender effect. One previous study has examined the effects of flexibility (initial ROM) on the stretch-induced deficits in force or power (Behm et al. 2006). That paper included a correlation study that showed no significant relationship between ROM and stretch-induced decrements in knee extension isometric force and drop jump performance. It also included a flexibility training study (four weeks, 5 days per week) that also showed no effects of flexibility training on stretch-induced decrements of muscle performance. The authors concluded that this was probably because stretches were held to the point of discomfort and thus the relative stress on the muscle was similar in individuals with different flexibility. They argued that this resulted in similar impairments of muscle performance irrespective of the ROM or tolerance to stretching of the muscle. In the present study, although flexibility varied largely among the three groups of athletes, there was no impairment of CMJ performance in any group for both the short (15 s) and long (30 s) stretching duration. This may be due to the fact that elite level gymnasts were accustomed to stretching of long duration (>2min) and thus static stretching durations of 15 and 30 s were probably too short to have any effect on CMJ performance.

The results of the present study indicated that the long stretching duration (30 s) increased flexibility without impairing jumping performance immediately after stretching (see Figure 2 and 3, “post-stretch” time point). It is possible that in this group of athletes, the long-term flexibility training may result in specific adaptations such as maintenance of stiffness and thus muscle performance, following a stretching-induced increase in muscle length (Magnusson et al., 1996). In addition, neural adaptations, such as a decrease in Hoffmann reflex (H-reflex) and tendon reflex (T-reflex), have been reported after flexibility training, and this may also contribute to the responses to stretching in elite gymnasts (Guissard and Duchateau, 2004). This may also be related with “stretch tolerance”, as proposed by Magnusson and Renström (2006). In contrast with previous studies that showed a decrease in muscle power output following static stretching-induced increases in flexibility (Behm and Chaouachi, 2011; Young and Behm, 2002), the results of the present study indicated that increases in flexibility due to 30 s of static stretching can co-exist with increases in CMJ performance following a PAP intervention (3 x 5 tuck jumps). A detrimental effect of static stretching lasting 30-45 s on subsequent jump performance has been previously reported for well-trained athletes (Behm et al., 2006; Tsolakis and Bogdanis, 2012; Winchester et al., 2008). However, performance impairments following longer durations of static stretching occur when individuals are unaccustomed to this type of stretching (Behm and Chaouachi, 2011). One recent study (Chaouachi et al. 2010), showed that static stretching to the point of discomfort did not affect sprint and jumping performance in elite athletes and attributed it to their high training status. Thus, it may be argued that the elite level gymnasts did not show an impairment of CMJ performance after stretching, because their training involves a large volume of stretching exercises of similar characteristics. Alternatively, due to the fact that flexibility in all groups of gymnasts is well above the average flexibility observed in athletes of other sports, the increase in muscle length caused by stretching may not significantly affect the length-tension relationship within the functional limits (Rassier et al., 1999).

Static stretching of short duration (15 s) resulted in no statistically significant improvement in the straight leg raise ROM of rhythmic and artistic male and female gymnasts. This is in contrast with findings from previous studies that showed considerable increase in flexibility even after short durations (≤15 s) of stretch (Kay and Blazevich, 2012; Tsolakis and Bogdanis, 2012). However, artistic and rhythmic elite gymnasts start systematic training in flexibility on a daily basis from a very young age (6-7 years old), as optimal period to increase flexibility is considered to be the age of 7-10 years old (Arkaev and Sutsilin, 2004). Until the age of 15-16 years, they are ready to perform at elite level, hence their flexibility has already reached the high standards required to cope with the demands of elite level competition and training (Arkaev and Sutsilin, 2004). Given the high level of flexibility and their long training experience, it seems that 15 s of static stretching is not adequate to temporarily increase ROM in elite gymnasts.

No post activation potentiation of jump performance was observed in rhythmic and artistic female and male gymnasts, following one set of 5 tuck jumps in the short warm-up condition. Till and Cooke (2009) reported a failure of one set of 5 double-legged tucked jumps to enhance the excitability of the fast twitch motor units and to cause a PAP effect. Similarly, maximal strength of back squat exercise was unaffected when 3 double-legged tuck jumps were performed 30 s before testing (Masamoto et al., 2003). In a more recent study (Turki et al., 2011), demonstrated that 3 sets of 3 tuck jumps were not adequate to increase CMJ performance that was measured 0, 4, 8, 12, 16 and 20 min following the jumps. These results, in conjunction with those of the present study, support the notion that one set of 3-5 tuck jumps is not adequate to induce PAP. On the other hand, performing more sets and/or repetitions of a conditioning activity such as the tuck jumps, may induce fatigue, that may reduce or even cancel the effect of PAP (Tillin and Bishop, 2009). A previous study using 3 sets of 5 tuck jumps has shown no effect of this potentiating exercise on CMJ over a 12 min recovery time in elite fencers (Tsolakis et al., 2011). In contrast, the results of the present study showed a relatively high (4.6%) increase in CMJ performance after the same volume of conditioning exercises. This may be due to the different fitness level of the athletes of the two different sports, highlighting the importance of the balance between fatigue and PAP following a conditioning activity.

Conclusion

In conclusion, the results of the present study indicated that the initial levels of flexibility and vertical jump ability do not alter the responses of elite gymnasts to warm-up protocols differing in stretching and potentiating exercise volumes. A warm-up protocol incorporating 15 s of static stretching exercises and 5 tuck jumps had no effect on straight leg raise range of motion (ROM) and countermovement jump performance (CMJ). In contrast, a warm-up protocol with 30 s of static stretching exercises and 3 sets of 5 tuck jumps resulted in considerable increases in both ROM and CMJ. The fact that increased ROM due to static stretching co-existed with increased CMJ, as a result of the tuck jumps, shows that this type of warm-up is beneficial for those elite athletes.

Practical applications

The results of the present study showed that the baseline levels of flexibility and vertical jump ability do not affect the acute responses to stretching and muscle conditioning activities, aiming to increase ROM and CMJ in elite gymnasts. Gymnasts with widely different flexibility and CMJ performance levels respond similarly to static stretching and PAP interventions during warm-up.

Thirty seconds of static stretching to the point of discomfort may be incorporated in the warm-up of elite gymnasts, without impairing subsequent explosive performance. CMJ performance can increase considerably, if three sets of 5 tuck jumps are also performed after stretching. The results of the present study may be specific to these highly-trained elite level gymnasts and may not necessarily be directly applicable in all individuals, although similar practices are widely used in many sports.

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Key points

- The initial levels of flexibility and vertical jump ability have no effect on straight leg raise range of motion (ROM) and counter-movement jump performance (CMJ) of elite gymnasts following warm-up protocols differing in stretching and potentiating exercise volumes
- Stretching of the main leg muscle groups for only 15 s has no effect on ROM of elite gymnasts
- In these highly-trained athletes, one set of 5 tuck jumps during warm-up is not adequate to increase CMJ performance, while 3 sets of 5 tuck jumps result in a relatively large increase in CMJ performance (by 4.6% above baseline), despite a 5.9% increase in flexibility due to the 30 s stretching exercises

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