ACUTE EFFECTS OF PROLONGED STATIC STRETCHING ON JUMPING PERFORMANCE AND RANGE OF MOTION IN YOUNG FEMALE GYMNASTS

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Original article

Abstract
This study examined changes in countermovement jump (CMJ) height and hip and knee joint range of motion (ROM), after an acute bout of prolonged static stretching. Nineteen, female "Gymnastics for All" gymnasts (age: 9.8±0.5 years, training experience: 2.5±1.5 years, height: 135.0±7.3cm, body mass: 33.4±6.9 kg) performed 90s of quadriceps stretching. A single-leg stretching and jumping design was used, with the contra-lateral limb serving as control. One-leg CMJ performance for the stretched and the control leg and two-legs CMJ were measured after warm-up, and 2 min post-stretching. ROM of the stretched leg was measured before and after stretching. One-leg CMJ height remained unchanged for both the stretched (pre: 7.4±1.7, post: 6.9±1.8 cm) and the control leg (pre: 7.0±1.7, post: 6.7±2.1 cm), as shown by the lack of main effects for time (pre vs. post: p= 0.278), leg (stretched vs. non-stretched leg: p= 0.207), and interaction (p= 0.444). Two-legs CMJ also remained unchanged (pre: 16.9±3.1, post: 16.3±3.4 cm, p=0.186). Hip joint ROM increased after stretching (pre: 16.3±3.7, post: 18.2±4.2^o, p=0.002), while knee joint ROM remained unchanged (pre: 26.6±2.7, post: 25.9±3.0^o, p= 0.218). Prolonged static stretching increases ROM, but has no negative effect on CMJ performance in very young, flexibility-trained female gymnasts.

Key words: *youth sports, flexibility, muscle power, warm-up, gymnastics.*

INTRODUCTION

The aim of a warm-up prior to training and competition is to optimize subsequent performance and prevent injuries (Chaouachi et al., 2010; Haff, 2006). Warm-up is typically composed of a submaximal aerobic activity, stretching of major muscle groups, and sport-specific exercises (Taylor, Sheppard, Lee, & Plummer, 2009). Stretching, following submaximal aerobic activity, has been shown to further increase range of motion (Magnusson & Renström, 2006) and to enhance performance (Young & Behm, 2002) while recent research has shown that pre-activity stretching may also be beneficial for injury prevention (Behm, Blazevich, Kay, & Mc Hugh, 2015).

A large number of previous studies in adults, demonstrated that prolonged static stretching (total duration > 45 s) may acutely reduce the ability of the stretched muscles to generate power output (Behm & Chaouachi, 2011; Kay & Blazevich, 2012). This stretch-induced power loss has been attributed to neuromuscular inhibition (Magnusson, 1998), and increased muscle-tendon compliance (Kay, Husbands-Beasley, & Blazevich, 2015; Morse, Degens, Seynnes, Maganaris, & Jones, 2008). Nevertheless, the negative effect of static stretching on muscle power is transient and largely depends on the stretching protocol characteristics (e.g. duration and intensity of each stretch, stretch position and muscle group) (Apostolopoulos, Metsios, Flouris, Koutedakis, & Wyon, 2015; Bogdanis, Donti, Tsolakis, Smilios, & Bishop, 2017; Lima et al., 2016). Some authors reported that the negative effect of static stretching is restored in a short-time following stretching. For example, Mizuno, Matsumoto and Umemura (2013) examined maximal voluntary contractions immediately, 5, 10, 15 and 30 min following 5 min of static stretching in adult, female participants. The authors reported decreased maximal voluntary contraction torque immediately after, and 5 min post-stretching however, this decrement recovered 10 min post-stretch.

Flexibility, is a performance determinant in sports requiring the ability to move in a ‘fluid’ and unconstrained manner through a large range of motion (ROM), like gymnastics and dance (Sands, 2002). Childhood is a key time to develop flexibility, with the age range between 6 to 11 years proposed as a sensitive period for morphological changes (Malina, Bouchard, & Bar-Or, 2004). However, data on stretching interventions in youth sports are limited (Donti et al., 2017; Kinser et al., 2008; Sands et al., 2016). Some studies that examined the acute effect of static stretching on jumping performance in adolescent athletes reported muscle power reduction following stretching (Faigenbaum, Bellucci, Bernieri, Bakker, & Hoorens, 2005; Di Cagcno et al., 2010; McNeal & Sands, 2003; Sands, McNeal, & Stone, 2009). A previous study that examined the acute effect of static stretching on muscle power, in child-gymnasts (Siatras, Papadopoulos, Mameletzi, Gerodimos, & Kellis, 2003) reported that 2 x 30 s of lower limb static stretching, decreased mean running speed for a handspring vault in young male gymnasts (9.8 ± 0.8 years).

For young gymnasts, the ability to generate muscle power is essential for executing acrobatic flight elements on all the apparatuses (Arkaev & Sutsilin, 2004). Increased joint ROM is equally important for technical execution (Karpenko et al., 2003) and prolonged static stretching bouts (60-90 s or more) are typically used before training or competition to enhance joint ROM (Karpenko et al., 2003; Matsuo et al., 2013). However, prolonged stretching may temporarily decrease muscle power and thus, the conflicting effects of prolonged stretching during warm-up for practice or competition, (i.e. increase in ROM and reduction in power), need to be further examined in young gymnasts. Thus, the purpose of the present study was to examine changes in one and two-legs countermovement jump (CMJ) performance and hip and knee joint range of motion (ROM), 2 min after an acute 90 s bout of static stretching, in 9-11 years old female gymnasts.

METHODS

Nineteen “Gymnastics for All”, female gymnasts, (age: 9.8±0.5 years, training experience: 2.5±1.5 years, height: 135.0±7.3 cm, body mass: 33.4±6.9 kg), were assessed for eligibility. The eligibility criteria were: training experience (1-3 y) and no history of lower limb injuries for the past six months. Gymnasts trained three times a week for 90-min each time. Gymnastics training involved general and special physical conditioning, as well as technical preparation on the apparatuses. The physical conditioning part was aimed to improve strength and power, flexibility and muscular endurance. This part contained, exercises using body weight, strength oriented gymnastic skills and combinations of skills. During this time, the gymnasts also competed in order to qualify for the gold, silver or bronze team, according to the International Gymnastics Federation Gymnastics for All Rules and Regulations (2009). Before participating in the study, the subjects and their parents were fully informed about the testing procedures to be used, the purpose and risks of this study, confidentiality, anonymity, and the right to terminate participation at will. In addition, written parental consent was obtained for each participant. The procedures of the study were approved by the local Institutional Ethics Committee and complied with the ethical standards for research involving human participants set by the Declaration of Helsinki.

The current study required the participants to complete two testing sessions at their training facilities, performed two days apart. Twenty-four hours prior to performing the main testing sessions, the gymnasts were asked to avoid any strenuous activity. The first testing session included anthropometric measures and familiarization with the testing procedures. At the end of the familiarization session, two efforts of the CMJs and hip joint ROM were recorded to calculate intra-class correlation coefficients. At the start of the second session, and following 5 min jogging at a moderate intensity (50-60% of age-predicted maximal heart rate), gymnasts underwent a series of tests in the following order: one-leg CMJ height, two-leg CMJ height, baseline hip and knee joint ROM measurement, 90 s of continuous static stretching, post-stretching hip and knee joint ROM measurement, and, 2 min after stretching, one-leg CMJ height and two leg CMJ height (Figure 1). During the 2-min recovery time following stretching, the gymnasts remained standing, and inactive. The assignment of the "stretched" and "control" leg was random and counterbalanced.

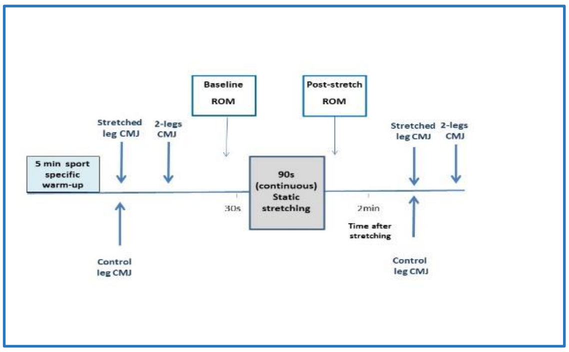

Figure 1. Schematic representation of the study protocol.

Anthropometry was assessed in the familiarization session. Standing height was measured to the nearest 0.1 cm with the use of a stadiometer and body mass was measured to the nearest 0.1 kg with a calibrated digital scale (Seca 208 and Seca 710, Hamburg, Germany).

The gymnasts performed 90 s of continuous static stretching of the quadriceps of one leg. This total stretch duration was chosen on the basis of its effectiveness on ROM enhancement (Magnusson, Simonsen, Aagaard, Sørensen & Kjaer, 1996) and its widespread use in the training practice of gymnastics (Arkaev & Sutsilin, 2004).

The main testing session included 90 s of continuous static stretching of one leg (stretched leg) while the other leg served as control and received no stretching treatment (control leg). The assignment of the gymnasts' legs to "stretched" and "control" was done in a random and counterbalanced manner so that half of the subjects performed the stretching protocol on their left leg and the rest on their right leg.

The prone quadriceps stretch (hip extension combined with knee flexion while lying on a prone position on a mat), with force applied by an investigator to the point of discomfort, was the movement used to stretch the hip flexors and knee extensor muscles of the one leg. Gymnasts were familiar with this stretching manoeuver, as they performed it regularly in their training sessions (Figure 2).

During testing, participants laid face down on the floor and flexed their knee. At the point of maximum knee flexion, an experienced investigator pushed their heel towards their hips, and their thigh upwards while keeping the gymnasts' hips firmly down on the floor to avoid pelvic tilt (Figure 2). The stretch intensity was determined based on the feedback from the subjects to ensure that stretch achieved the point of discomfort (rating 90 to 100, indicated by the gymnast on a visual analogue scale of 0-100). Based on the same procedure used in prior investigations (Behm & Kibele, 2007) the gymnasts were informed that 0 represented "no stretch discomfort at all" and 100 represented "maximal stretch discomfort". Stretching of the one leg took 90 s and 2 min after, the athletes performed one- and two-legs CMJ (in total ~ 4 min between jumps).

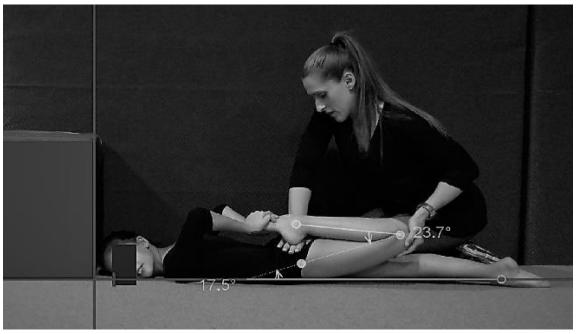

Figure 2. Prone quadriceps stretch manoeuvre.

Range of motion was measured using reflective motion analysis markers placed on the following anatomical marks: hip (trochanterion), knee (femur-tibia joint line) and ankle (lateral malleolus). The position of the markers was recorded using a digital camera (Casio Exilim Pro EX-F1) placed perpendicular to the plane of motion of the leg, and hip and knee angles were calculated using free software (Tracker 4.91 © 2016 Douglas Brown). Hip joint ROM was defined as the angle between horizontal and the line joining the hip and knee markers. Knee joint ROM was defined as the angle between the line joining the hip and knee markers and the line joining the knee and ankle markers (Figure 2).

In all the testing sessions CMJ height was assessed using an electronic contact mat (Boscosystem® Chronojump) for the stretched and the control leg and the two-leg jump immediately (10-15 s) after warm-up, and 2 min post stretching (Fig. 1). Two efforts were given for each jump after warm-up, and the best value was recorded for further analysis. Two minutes post-stretching, only one attempt was permitted for each jump. The order of the jumps was balanced so that half of the athletes performed the one-leg CMJ with the stretched and the other half with the control leg first. The subjects were instructed to perform a maximum effort and 'jump as high as possible' with their hands on their hips and while keeping the free leg hanging parallel to the jumping leg and flexed on the knee throughout the jump. For the one- and two-legs countermovement jump, subjects performed a countermovement until their knees were bent at approximately 90°, and then immediately jumped up. Body configuration was required to be the same during take-off and landing. Three criteria were adopted for a valid jump: a) correct body posture during flight, b) jumping straight up with no side to side or forward movement, and c) soft landing, including toe to heel rocking and progressive bent of the knees.

Statistical analyses were carried out using SPSS (IBM SPSS Statistics Version 22.0). The normality of data distribution was checked with the Shapiro Wilk's test. The acute effect of the stretching protocol on one leg CMJ height was examined by 2-way ANOVA with repeated measures on both factors (leg x pre-post) and a Tukey HSD test. Paired *t*-test examined pre- and post-stretching changes in hip joint ROM and two-legs CMJ height. Effect sizes (ES) for the ANOVA were determined by partial eta squared (η^2) (small: 0.01 to 0.059, moderate: 0.06 to 0.137, large >0.138). For pairwise comparisons, ES was determined by Cohen's d (trivial: 0–0.19, small: 0.20–0.49, medium: 0.50–0.79 and large: 0.80 and greater) (Cohen, 1992). The intra-class correlation coefficient (ICC) was used as a measure of test-retest reliability (Hopkins, Marshall, Batterman, & Hanin, 2009), for the variables examined in this study, and was determined by using a 2-way mixed model. Additionally, the standard error of measurement (SEM) was calculated as the square root of the mean square error term from the ANOVA and was expressed both as an absolute value and as a percentage of the participants' mean scores (coefficient of variation) (Weir, 2005).

Statistical significance was accepted at $p<0.05$.

RESULTS

Test-retest reliability for the one-leg CMJ and knee joint ROM was high (ICC=0.79, p<0.01; SEM=2.3 cm; CV=0.23%, and ICC=0.84, p<0.01; SEM=2.5° CV=0.9%, respectively). For the two-leg CMJ and hip joint test-retest reliability was excellent (ICC=0.93, p<0.01; SEM=2.3 cm; CV=0.19%, and ICC=0.94, p<0.01; SEM=2.3°; CV=0.21%, respectively).

Table 1

One-leg and two-legs counter movement jump (CMJ) height in the stretched and control leg and hip and knee joint range of motion (ROM) pre- and post- 90 s of static stretching (n=19).

	Pre-stretching	Post-stretching	Cohen's *d*	p
One-leg CMJ (cm) Stretched leg	7.4±1.7	6.9±1.8	0.29	0.207
Control leg	7.0 ±1.7	6.7±2.1	0.16	0.278
Two-legs CMJ (cm)	16.9±3.1	16.3±3.4	0.19	0.186
Hip ROM (°) Stretched leg	16.3±3.7	18.2±4.2	0.49	0.002
Knee ROM (°) Stretched leg	26.6±2.7	25.9±3.0	0.25	0.218

One-leg CMJ height remained unchanged post stretch for both the stretched and the control leg as shown by the lack of main effects (p= 0.207, η^2=0.087 and p= 0.278, η^2=0.065 for pre-post stretch and leg, respectively) and interaction (p= 0.444, η^2=0.033) (Table 1). Two-leg CMJ also remained unchanged post stretch (p= 0.186). Hip joint ROM increased significantly post-stretching by 13%, while knee joint ROM remained unchanged (p= 0.218) (Table 1).

DISCUSSION

The aim of this study was to examine changes in one- and two-legs CMJ height and hip joint ROM, 2 min after an acute bout of 90 s of continuous static stretching in young female gymnasts. The main finding of this study was that jump height remained unchanged 2 min post-stretch for both the stretched and the control leg, as well as for the two-legs CMJ, while ROM significantly increased post stretching. The effect sizes for pre- and post-stretch changes in one-leg CMJ for the stretched and the control leg and the two-legs jumps were small (*d*=0.29, *d*=0.16, and *d*=0.19, respectively) indicating that in these flexibility-trained young athletes there is no negative effect of static stretching on jumping performance, despite the prolonged stretching duration.

A substantial body of research has demonstrated that prolonged static stretching (total duration > 45-60 s) may temporarily reduce maximal muscular performance in a dose dependent manner, (Behm, Blazevich, Kay, & Mc Hugh, 2015; Behm & Chaouachi, 2011; Kay & Blazevich, 2012; Trajano, Nosaka & Blazevich, 2017). In adult populations, stretch-induced force and power loss may be attributed to acute reductions in muscle and tendon stiffness (Morse et al., 2008) possibly due to the thixotropic behavior of the muscles (Axelson, 2005) and to neural changes causing an improved stretch tolerance (Magnusson, 1998, Weppler & Magnusson, 2010). However, evidence is limited on stretch-induced power loss in children and only a small number of studies examined muscle performance changes following static stretching in adolescents (Faigenbaum, Bellucci, Bernieri, Bakker, & Hoorens, 2005; Di Cagcno et al., 2010; Mc Neal & Sands, 2003). For example, Mc Neal and Sands (2003) reported significantly reduced flight time but not contact time during drop jump, following a total stretching time of ≈ 180 s in adolescent gymnasts (13.3 ±2.6 years), while Di Cagno et al. (2010) found reductions in gymnastics leaps flight time by 7%, following ≈ 10 min of static stretching (4 different lower body exercises x 3 times x 30 s), in 38 adolescent rhythmic gymnasts (14.1 ± 3.2 years).

Interestingly, all these studies, examined gymnasts' jumping performance immediately post-stretching, and to date there was no evidence about the magnitude and the duration of muscle power decrements following an acute bout of prolonged static stretching. The results of the present study, found no power deficit in the stretched leg, 2 min post-stretching, suggesting that a possible negative effect of static stretching is abolished shortly after the cessation of the stretching manoeuver. This suggestion is supported by the findings of Mizuno et al. (2013) who found decreased maximal voluntary contraction torque immediately after, and 5 min post-stretching, which was however, recovered 10 min post-stretch. In other studies where performance tests were conducted more than 10 min following stretching, performance decrements were small, unless extreme stretching duration protocols had been used (Behm, Blazevich, Kay, & Mc Hugh, 2015). For example, Power et al. (2004) found 9.5% and 5.4% decrements in quadriceps maximal voluntary and evoked force following 270 s of static stretching. In that study, force remained significantly decreased for 120 min (10.4%), while range of motion was increased (6%) (Power et al., 2004). The results of the present study showed an almost two-fold higher improvement in ROM (13%, *d*=0.49), while leg muscle power was not significantly changed (Table 1). This improvement in ROM with no negative effect on power output may be important for young gymnasts who train and compete after performing prolonged static stretching routines. In contrast, knee joint ROM remained unchanged post-stretching (p=0.218) probably because of the nature of the stretching movement: gymnasts' heel was touching their hips, before the upwards movement of the thigh.

The lack of stretch-induced jumping decrements in the present study may also be explained by the fact that these young gymnasts regularly applied stretching protocols of this duration during training. Previous studies in trained athletes, failed to detect impairments in muscle performance after static stretching (Chaouachi et al., 2010; Egan et al., 2006), or even reported enhancement of muscle work at longer muscle lengths and/or, if the duration of the stretching bouts was brief (≤30 s) (Bogdanis et al., 2017; Godges, Macrae, Longdon, & Tinberg, 1989). Therefore, it is proposed that flexibility trained athletes might be less susceptible to stretch-induced deficits than their unaccustomed counterparts (Chaouachi et al., 2010; Donti, Tsolakis, & Bogdanis, 2014; Egan, Cramer, Massey, & Marek, 2006). In addition, preadolescent children may be less susceptible to stretch-induced muscle power loss than adults or adolescents due to their decreased neuromuscular activation (Dotan, Mitchell, Klentrou, Gabriel, & Falk, 2012) and to the increased pliability of the musculotendinous tissue during childhood (Rumpf, Cronin, Oliver, & Hughes, 2013). For example, Rumpf, Cronin, Oliver, and Hughes, (2013) found that prepubertal athletes have more pliable musculotendinous tissue than older athletes and this may reduce the negative effects of stretching, while positively affecting the energy storage in slow stretch shortening cycle movements, such as a one-leg CMJ (Komi, 1999). Similarly, Kubo, Kanehisha, Kawakami and Fukunaga (2001), reported that the tendons of younger boys (10.8 ± 0.9 years) were more compliant than those of older boys (14.8 ± 0.3 years) and adults (24.7 ± 1.6 years).

A few previous studies have shown contralateral effects of stretching on the unstretched limb (Chaouachi, Padulo, Kasmi, Othmen, Chatra. Behm, 2017; Cramer et al., 2005). For example, Chaouachi et al (2017) reported similar increases in hip flexion in the stretched and the non-stretched limb (*d*=0.91 and *d*=0.69, respectively) following eight repetitions of 30 s of static stretching. In another study, Cramer et al., (2005) reported decreases in muscle activation from pre to post-stretch in both the stretched and the unstretched leg extensors, suggesting that the stretch-induced muscle power deficit could be related to a central nervous system inhibitory mechanism. However, in the present study, hip and knee joint ROM were not measured in the control leg as it was thought that any stretching maneuver and ROM measurement may affect subsequent jump height. Nevertheless, jumping height in the control leg was not changed from pre- to post intervention (p=0.278).

In the present study, a single stretching exercise of an important muscle group for jumping (i.e. knee extensors) was performed in order to examine changes in one-leg CMJ performance. The use of the other leg as a control allowed for the calculation of the net effect of static stretching on jumping performance. As the knee extensors contribute significantly (≈25-30%) to the total power output during jumping (Van Soest et al., 1985; Wong et al., 2016), any influence of stretching these muscles on vertical jump performance would be evident. In contrast with several studies that use a series of stretching exercises (e.g. quadriceps, hamstrings, calf muscles etc) with one or more sets for each leg separately, it was decided to use only one stretching exercise and perform single leg performance testing. This allows to assess the immediate effect of stretching a muscle group on muscle power in a movement that it has a significant contribution. In the case of stretching multiple muscle groups (e.g. quadriceps, hamstrings, calf muscles) in both legs with one or more sets for each, there is a long period between stretching of one muscle group (e.g. the quadriceps, if they are stretched first) and performance testing, while the order of stretching also influences the outcome. Thus, the effects of stretching one muscle on performance may diminish due to the time lapse between stretching and performance testing. Although the protocol used in the present study has the limitation of not stretching the hip and ankle extensors, which are major power generators during single leg jumping (Van Soest et al., 1985; Wong et al., 2016), it allows for a controlled timing of stretching and testing an important muscle group.

CONCLUSIONS

The results of this study demonstrated that an acute bout of continuous static stretching of 90 s increased hip joint ROM, but had no statistically significant effect on jumping height 2 min post stretch. Probably the long-term flexibility training and the increased musculotendinous pliability of young gymnasts may have contributed to prevent the transient decrease in strength and power typically seen after prolonged static stretching. Further research should examine the combination of static with dynamic stretching and/or potentiating exercises in preadolescent athletes in the context of a real-life training and competition setting.

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