Acute and long-term effects of two different static stretching training protocols on range of motion and vertical jump in preadolescent athletes

AUTHORS: Olyvia Donti[1], Konstantina Papia[1], Argyris Toubekis[1], Anastasia Donti[1], William A. Sands[2], Gregory C. Bogdanis[1]

[1] School of Physical Education & Sport Science, National & Kapodistrian University of Athens, Greece
[2] Ski & Snowboard Association, USA

Corresponding author:
Gregory C. Bogdanis
41 Ethnikis Antistasis Street
Dafne, Athens, Greece
Tel.: +30 201 7276115
Email: gbogdanis@phed.uoa.gr

ABSTRACT: This study examined the acute and long-term effects of two static stretching protocols of equal duration, performed either as a single stretch or multiple shorter duration repetitions on hip hyperextension range of motion (ROM) and single leg countermovement jump height (CMJ). Thirty female gymnasts were randomly assigned to stretching (SG) or control groups (CG). The SG performed two different protocols of static stretching, three times per week for 9 weeks. One leg performed repeated stretching (3×30 s with 30 s rest) while the other leg performed a single stretch (90 s). The CG continued regular training. ROM and CMJ were measured pre- and 2 min post-stretching on weeks 0, 3, 6, 9, and 3 weeks into detraining. CMJ height increased over time irrespective of group (main effect time, $p = 0.001$), with no statistical difference between groups (main effect group, $p = 0.272$). Three-way ANOVA showed that, CMJ height after stretching was not affected by either stretching protocol at any time point ($p = 0.503$ to 0.996). Both stretching protocols equally increased ROM on weeks 6 ($10.9 \pm 13.4\%$, $p < 0.001$, $d = 0.42$), and 9 ($21.5 \pm 13.4\%$, $p < 0.001$, $d = 0.78$), and this increase was maintained during detraining ($17.0 \pm 15.0\%$, $p < 0.001$, $d = 0.68$). No increase in ROM was observed in the CG ($p > 0.874$). Static stretching of long duration applied either as single or multiple bouts of equal duration, results in similar acute and long-term improvements in ROM. Furthermore, both stretching protocols do not acutely affect subsequent CMJ performance, and this effect is not influenced by the large increase in ROM and CMJ overtime.

INTRODUCTION

Static stretching is commonly applied in sports as an important component of both warm-up and chronic flexibility training, aiming to increase joint range of motion (ROM) [1, 2]. Previous studies have shown that, besides an increase in ROM, prolonged static stretching (> 60–90 s per muscle group) may temporarily decrease force and power production [3, 4]. However, the acute effects of static stretching on performance depend not only on total stretch duration [5, 6], but also on whether stretching is performed as a single prolonged bout or as multiple repetitions [7, 8, 9]. The results comparing continuous (single) and intermittent (repeated) bouts of static stretching on force and power output are inconclusive [7, 9]. For example, there was a 2-fold greater decrease in force (23.8 vs. 14.3%) immediately after intermittent compared with continuous stretching of 5 min total duration [7]. In contrast, an 8.1% improvement in power was evident 4 min after intermittent stretching of prolonged duration (90 s), performed in 3 bouts of 30 s each [9].

Prolonged static stretching bouts (60–90 s or more) are often used in sports requiring movements with large joint ROM as well as high muscle power (e.g. gymnastics, martial arts). In these sports, enhanced joint ROM is important not only to execute complex technical skills [10], but also to increase the distance over which muscle force is applied [11] or absorbed. Flexibility is also considered an essential fitness component for youth athletes in these sports [12, 13] with the period of middle childhood (6–11 years) proposed as a "window of opportunity" for flexibility development [14]. However, longitudinal data on stretching interventions in developing athletes are sparse, although in some sports young athletes are submitted to long-term, systematic flexibility training schedules [10]. Interestingly, previous cross-sectional studies suggested that flexibility-trained individuals may be less susceptible to stretch-induced strength and power decrements [15, 16].

Loading characteristics of the stretching protocol influence acute joint ROM increases [3, 4], and past research reported that the total

stretch duration is more important for joint ROM enhancement irrespective of whether stretching was performed as a single longer bout or in shorter repetitions [17]. However, there is limited evidence regarding the effects of acute stretching or long-term flexibility training with prolonged single or repeated stretches on ROM in young athletes [13, 18]. Moreover, it is unknown whether the negative acute effects of static stretching on vertical jumping performance (CMJ) in preadolescent and adolescent athletes [19, 20] can be modified by long-term flexibility training.

In the present study, it was hypothesized that long-term flexibility training would increase joint range of motion and reduce the negative effects of acute stretching on CMJ performance. It was deemed important to examine this in younger athletes, who may experience large improvements in ROM through regular and intense stretching training [13]. Therefore, the purpose of this study was to examine the acute and long-term effects of prolonged (90 s) static stretching training of equal total duration, performed as a single stretch or multiple shorter duration repetitions, on hip ROM and CMJ in preadolescent female gymnasts.

MATERIALS AND METHODS

Research Design

A mixed-model design, involving two groups (stretching and control), performing repeated measures over time, was used to examine the acute and long-term effects of two protocols of static stretching training on CMJ and ROM. Child female gymnasts, who trained three times per week for 90 min each time, were divided into two groups (stretching and control). The stretching group performed static stretching of the knee extensors of both legs, three times per week for 9 weeks, at the start of each training session. One leg performed three bouts of stretching (3×30 s) with 30 s rest in between, while the other leg performed a single stretch of equal total duration (90 s). Thus, the total time of the stretching intervention, including rest periods, was 4 min. During the 4 min stretching intervention, subjects of the control group performed choreography movements. After the 9 weeks of intervention a 3-week period of detraining took place. During detraining, the stretching group ceased to perform the 4 min stretching training and followed the regular gymnastics training program, which was common with the control group.

The dependent variables (CMJ and ROM) were measured as follows: (a) pre- and 2 min post-stretching (CMJ) and (b) pre- and immediately post-stretching (ROM) (see Figure 1). These measurements were performed at week 0 (pre-intervention), and were repeated on weeks 3, 6, 9, and after 3 weeks of detraining.

The acute effect of the two stretching protocols on the dependent variables (ROM and CMJ), was defined as the difference between the pre-stretching and post-stretching values measured at each timepoint. The long-term effect of the two static stretching protocols on the dependent variables (ROM and CMJ), was examined using the pre-stretching values at week 0, 3, 6, 9 and 3 weeks into detraining (week 12).
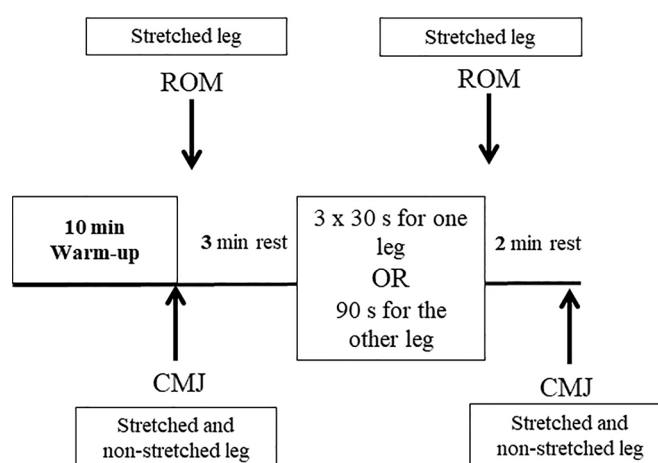

FIG. 1. Schematic representation of the study protocol

Participants

Thirty-three female 'Gymnastics for All', gymnasts, aged 8–10 years, were recruited for the study. All gymnasts were from the same gymnastics club and trained with the same coach in three groups of 10–12 athletes each. Two groups of gymnasts were randomly allocated to the stretching group (SG) while the third group acted as control (CG). Of these, two gymnasts from the stretching group and one gymnast from the control group did not perform all tests and visits and were excluded from the study. The characteristics and maturity offset [21] of the participants are shown in Table 1. Participants were injury-free six months prior to the study start and no gymnast was injured during the study.

Before participating in the study, the subjects and their parents were fully informed about the training methods to be used, the purpose and risks of this study, confidentiality, anonymity, and provided

TABLE 1. Age, training experience, maturity offset and anthropometric characteristics (mean ± SD) of the subjects in the stretching group (SG) and the control group (CG)

	SG (n = 19)	CG (n = 11)	p
Age (y)	9.8 ± 0.5	9.5 ± 0.8	0.118
Training experience (y)	2.5 ± 1.8	2.1 ± 1.2	0.533
Height (cm)	134.6 ± 7.3	133.5 ± 7.0	0.696
Body mass (Kg)	33.4 ± 7.0	33.4 ± 8.0	0.985
BMI (kg/m^2)	18.3 ± 2.1	18.5 ± 2.3	0.779
Leg length (cm)	69.5 ± 2.5	67.8 ± 3.8	0.147
Maturity offset (y)	-3.9 ± 0.4	-4.2 ± 0.6	0.157

written consent. All procedures were in accordance with the ethical standards of the Helsinki Declaration and Institutional Ethics Committee approved the study (registration number: 1040, 14-2-2018).

Familiarization Sessions and Preliminary Measurements
The study was performed during the gymnastics pre-season (October to January). Four familiarization sessions preceded testing and training. In these sessions, the gymnasts performed multiple ROM and CMJ trials, to improve reliability of the testing procedures. Data from the last two familiarization sessions were used for reliability calculations. Anthropometry was also performed in the first familiarization session. Standing height was measured to the nearest 0.1 cm and body mass was measured to the nearest 0.1 kg (Seca 208 and Seca 710, Hamburg, Germany). Leg length was obtained by subtracting sitting height from standing height.

Static stretching training
Static stretching training was performed three times per week on non-consecutive days, at the start of each gymnastics training session, over a 9-week period (total: 27 sessions). Following a 10 min standardized sport-specific warm-up, the athletes of the SG performed prone quadriceps stretch, using repeated bouts of stretching on one leg (3 x 30 s with 30 s of rest in between) and a single prolonged stretch on the other leg (90 s). The two stretching training protocols were randomly assigned and balanced between the right and left leg.

For the whole duration of stretching, hips were held firmly down on the ground and the knee was elevated on a mat. Then the athlete pulled the leg until full hip hyper-extension was achieved, under the supervision of a coach (Figure 2). Stretch intensity was indicated by the gymnasts using the 0–10 Wong-Baker FACES Pain Scale for children [22] to ensure that stretch achieved a pain of discomfort level of 8 in the scale of 0–10.

Testing procedures
Two testing sessions per week, on non-consecutive days (Monday, Wednesday), were performed at weeks 0, 3, 6, 9 and 3 weeks into detraining (week 12). On one testing session, the leg that was trained using a single, prolonged stretch (90 s) was examined, and the dependent variables (ROM and CMJ) were measured on both legs (stretched and non-stretched). On the other testing session, the leg that was trained using repeated bouts of stretching (3 x 30 s) was examined and the dependent variables (ROM and CMJ) were measured on both legs. The order of testing was randomized and balanced.

Countermovement jump height
Following 10 min standardized sport-specific warm-up, single leg CMJs were performed for the stretched and the non-stretched leg before and 2 min after the static stretching intervention. Jump height was determined from flight-time, using an Optojump system (Microgate, SLR, Italy). The subjects were instructed to perform a countermovement until the knee bent to approximately 90 degrees, and then immediately jump up as high as possible with their hands akimbo, throughout the jump. Gymnasts were instructed to keep an extended body position at takeoff and landing, (i.e. torso, hips and

FIG. 2. Static stretching training exercise

feet on the same vertical line). Test-retest reliability for the single leg CMJ was high: [Intra-class Correlation Coefficient (ICC) = 0.932, $p < 0.001$; Meaningful Detectable Change at 90% Confidence Interval (MDC_{90}) = 0.9 cm, SEM = 0.4 cm or 5.6%.

Range of motion measurements

ROM was measured after CMJ performance (pre-stretching measurement) and at the end of each static stretching protocol (post-stretching measurement) using the prone quadriceps stretch. Reflective motion analysis markers were placed on the 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, Shibuya, Tokyo, Japan) placed perpendicular to the plane of motion of the leg, and hip and knee angle was calculated using free software (Tracker 4.91© 2016 Douglas Brown). Hip ROM was defined as the angle between horizontal and the line joining the hip and knee markers. During testing, participants laid face down on the floor and flexed their knee towards their back. At the point of maximum knee flexion, an experienced investigator pulled their thigh upwards while keeping the gymnasts' hips firmly down on the floor to avoid pelvic tilt (Figure 3).

All measurements were performed at a standard temperature (22–23℃), at the same time of the day (from 17:00 to 20:00) and by the same evaluators. Test retest reliability was high: [Intra-class Correlation Coefficient (ICC) = 0.974, $p < 0.001$; Meaningful Detectable Change at 90% Confidence Interval (MDC_{90}) = 1.3°. SEM = 0.5 cm or 3.0%.

Statistical analysis

Statistical analyses were carried out using SPSS (IBM SPSS Statistics Version 22.0). The normality of data distribution was checked with the Shapiro-Wilks test. Between-groups differences, in anthropometric characteristics and baseline CMJ and ROM, were analyzed using unpaired t-test.

The acute effect of the two stretching protocols on CMJ performance was examined separately in each group using 3-way repeated measures ANOVA (5 time points x 2 stretching protocols x 2 legs [stretched and non-stretched]). Furthermore, the acute effect of the two stretching protocols on CMJ performance was compared between groups using a mixed model 3-way ANOVA (5 time points x 2 stretching protocols x 2 groups). To examine the long-term changes in baseline CMJ during the intervention, a mixed model 3-way analysis of variance (ANOVA) (5 time points x 2 stretching protocols x 2 groups) was used.

The acute effect of the two stretching protocols on ROM, was examined separately in each group using 3-way repeated measures ANOVA (5 time points x 2 stretching protocols x 2 measurements [pre- and post-stretching]). The long-term effect of the two stretching protocols on hip hyperextension ROM baseline values in the two groups was examined by a 3-way mixed model ANOVA (5 time points x 2 stretching protocols x 2 groups).

When a significant main effect or interaction was observed ($p < 0.05$) a Tukey's post–hoc test was applied. 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

FIG. 3. Position of the participants during range of motion assessment

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) [23]. Test-retest reliability was assessed by calculating the intra-class correlation coefficient (ICC) using a two-way mixed effects model ANOVA (single rater measurement, absolute agreement). Additionally, the standard error of measurement (SEM) and the meaningful detectable change at 90% confidence interval (MDC_{90}) were calculated.

RESULTS

CMJ height

There were no statistical differences in pre-intervention (week 0) baseline CMJ values between the SG and the CG (7.0 ± 1.7 cm vs. 6.4 ± 1.6 cm, p = 0.188). The 3-way ANOVA showed that baseline CMJ height increased over time irrespective of group (main effect for time, p = 0.001, $\eta^2 = 0.410$), with no statistical difference between groups (main effect group, p = 0.272), stretching protocols (main effect stretch, p = 0.648) or any interactions between time, group and protocol (p = 0.367 to 0.968) (Table 2). Post-hoc test for the time main effect showed that the average increase overtime for both groups combined was significant after 6 weeks (10.2 ± 12.1%, p < 0.001, d = 0.40 compared with week 0) and peaked after 9 weeks (15.7 ± 15.3%, p < 0.001, d = 0.62 compared with week 0). CMJ performance was maintained 3 weeks into detraining (17.1 ± 15.1%, p < 0.001, d = 0.68 compared with week 0).

There were no statistically significant acute effects of stretching on CMJ height for both the SG and the CG at all time points, as shown by the separate 3-way repeated measures ANOVA for each group. More specifically, for the SG, there was no main effect for time (p = 0.972), stretch (p = 0.858) or leg (p = 0.734) and no time x leg (p = 0.971) time x stretch (p = 0.996), or time x stretch x leg interaction (p = 0.988). Similarly, for the CG, the 3-way ANOVA showed that there was no statistically significant main effect for time

(p = 0.970), stretch (p = 0.503) or leg (p = 0.972). In addition, there was no time x leg (p = 0.999) time x stretch (p = 0.998) and time x stretch x leg interaction (p = 0.983) statistically significant effects. The results of each time point for both groups and both legs (stretched and control) are shown in Figure 4. Also, there was no difference between groups in the acute effects of stretching, as shown by the mixed model ANOVA (all main effects and interactions, p = 0.447 to 0.999).

ROM

There were no statistical differences in ROM baseline values between the SG and the CG (repeated bouts leg: 16.0 ± 4.2° vs. 15.5 ± 4.6°, p = 0.760, respectively, and single stretch leg: 15.9 ± 4.7° vs. 14.5 ± 3.3°, p = 0.385, respectively).

The 3-way ANOVA for baseline ROM values showed a significant time x group interaction (p = 0.001, $\eta^2 = 0.258$), with the post-hoc tests showing that in the SG, ROM was increased on the 6th week by 10.9 ± 13.4% (p < 0.001, d = 0.42) compared to week 0, and further by 21.5 ± 13.4% (p < 0.001, d = 0.78) on the 9th week compared to week 0, irrespective of stretching protocol. This improvement was maintained until the end of detraining (improvement: 17.0 ± 15.0%, p = 0.001 d = 0.68 compared to week 0). There was no change of ROM overtime for the control group, as shown by the post-hoc test (p > 0.874) (Figure 5).

The 3-way repeated measures ANOVA examining the acute increases in hip ROM in the SG, showed a pre-post stretching x time interaction (p = 0.009, $\eta^2 = 0.170$), a main effect for time (p = 0.001, $\eta^2 = 0.538$), a main effect for pre-post stretching (p = 0.001, $\eta^2 = 0.910$), with no main effect for stretching protocol (p = 0.674), stretching protocol x time interaction (p = 0.936) or 3-way interaction (p = 0.397). The post-hoc test showed that there were statistically significant increases of ROM post-stretching, compared with the pre-stretching values at all time points (Figure 5).

TABLE 2. Single leg countermovement jump performance (CMJ) for each leg in the stretching and control groups (mean ± SD).

CMJ for STRETCHING GROUP (cm)									
Intermittently stretched leg						Continuously stretched leg			
Week 0	Week 3	Week 6	Week 9	Week 12		Week 0	Week 3	Week 6	Week 9	Week 12
6.96	7.23	7.84†§	7.89†§	7.87†§		6.99	7.14	7.75†§	7.95†§	8.11†§
1.74	1.73	1.72	1.48	1.57		1.67	1.59	1.70	1.65	1.68
CMJ for CONTROL GROUP (cm)									
Leg 1						Leg 2			
Week 0	Week 3	Week 6	Week 9	Week 12		Week 0	Week 3	Week 6	Week 9	Week 12
6.51	6.54	7.00†§	7.43†§	7.47†§		6.30	6.38	6.55†§	7.41†§	7.61†§
1.30	1.63	1.78	1.86	1.96		1.63	1.91	1.75	2.00	1.88

Note: Week 12 shows results after 3 weeks of detraining. There was only a main effect of time (p < 0.001). Post-hoc comparisons refer to the grand mean of all groups and legs. †: p < 0.001 from Week 0; §: p < 0.001 from Week 3.
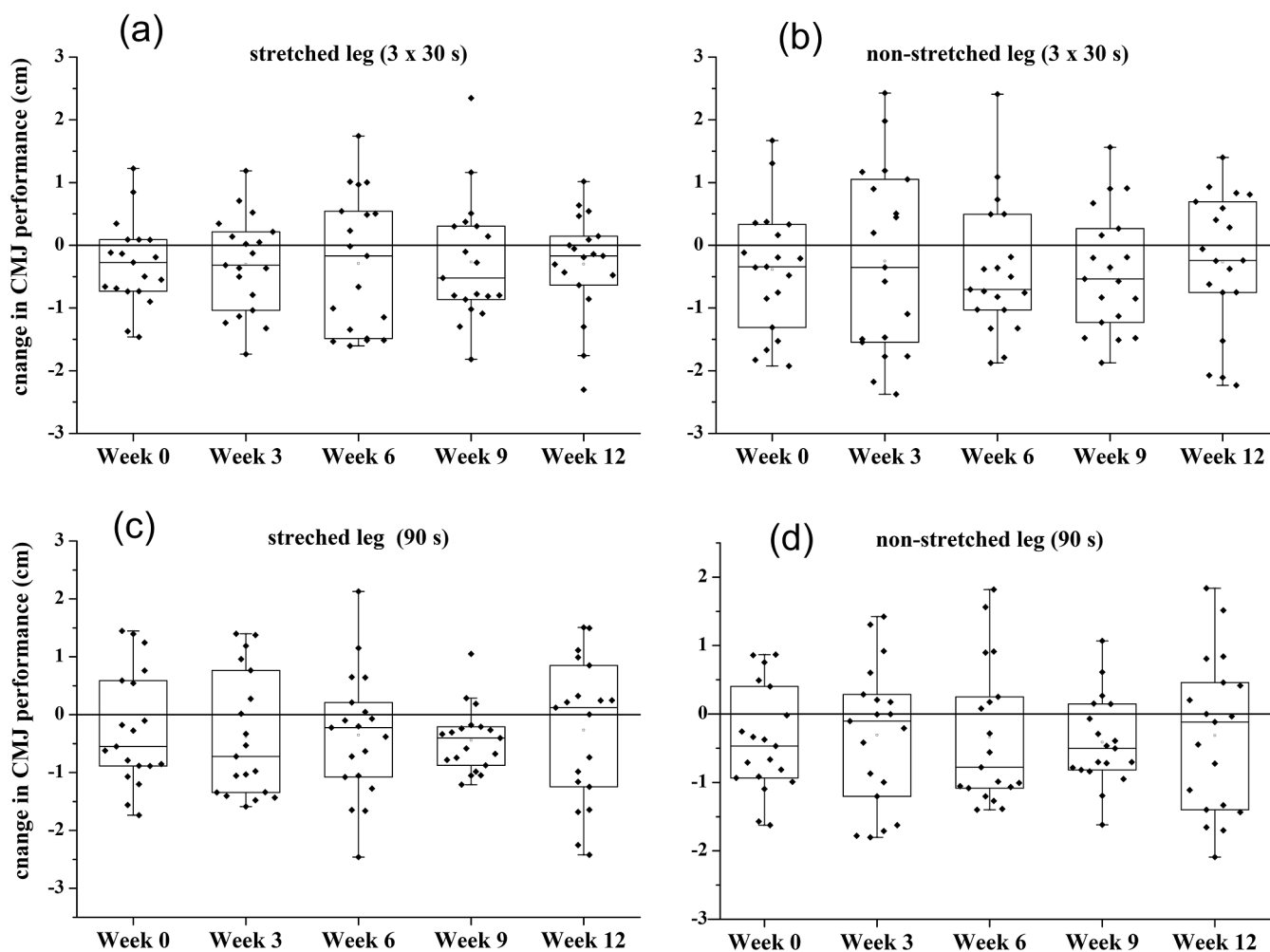
FIG. 4. Box-plots showing the change in CMJ performance (post-stretching minus pre-stretching values) for the stretching group over the course of training (Week 0 to Week 9) and detraining (Week 12), for the repeated bouts (3 x 30 s, panel a and b) and the single stretching protocol (90 s, panel c and d). Measurements of the control leg were taken without any stretching intervention. Individual values are represented as dots.
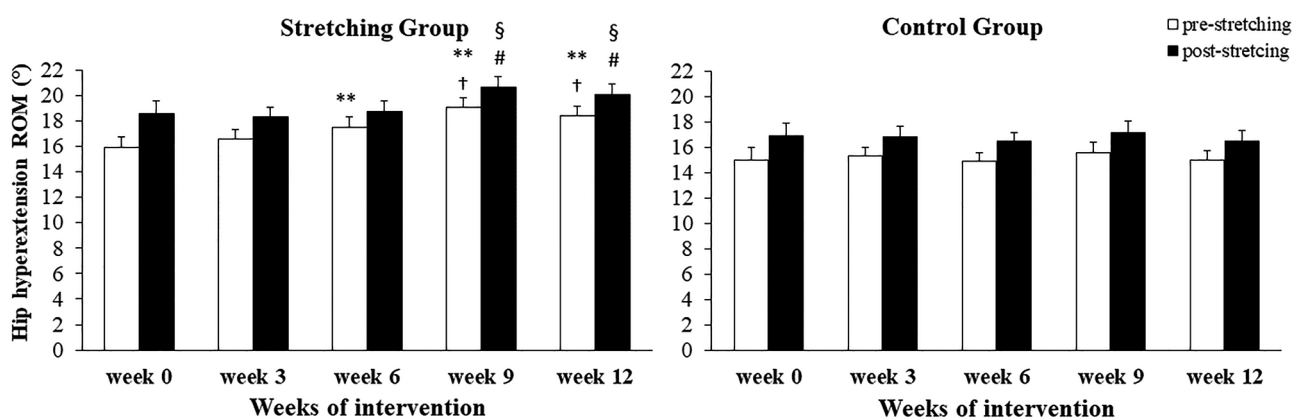
FIG. 5. Pre- and post-stretching values of hip hyperextension range of motion (ROM) for the stretching group (left panel) and the control group (right panel) throughout the 9 weeks of training and after 3 weeks of detraining (week 12). Results are presented as average for single and repeated bouts of stretching training legs. **: $p < 0.001$ from the corresponding pre-stretching value at week 0; §: $p < 0.001$ from the corresponding post-stretching value at week 0; †: $p < 0.001$ from the corresponding pre-stretching value at week 6; #: $p < 0.001$ from the corresponding post-stretching value at week 6.

Furthermore, post-stretching ROM was increased only after 9-weeks of stretching training and this change was maintained after 3 weeks detraining (Figure 5). The 3-way repeated measures ANOVA examining the acute increases in hip ROM in the CG, revealed only a pre-post main effect (p = 0.001, η^2 = 0.968), but no other main effects or interactions (p > 0.05) (Figure 5).

DISCUSSION

The main finding of this study was that CMJ performance was not acutely affected by either a long duration continuous stretch (90 s) or repeated stretches (30 s with 30 s rest) of equal total duration at any time-point of a 9 week training followed by 3 weeks of detraining. This lack of an acute effect of long duration stretching on CMJ height, persisted throughout training and detraining, despite a relatively large increase of ROM and CMJ performance overtime. Notably, the improvements of ROM and CMJ were maintained into detraining.

Although a substantial body of research demonstrated that prolonged static stretching generally induces moderate (~5%) performance impairments in adults [3], evidence is sparse in developing athletes [10,13,24] and there is little information, regarding the effects of stretching variables on subsequent performance. The limited number of previous studies in youth athletes have reported a decrease in CMJ measured immediately after static stretching [19, 20]. However, the results of the present study indicated that there was no decrease in single-leg CMJ, in the stretched compared to the non-stretched limb, 2 min post-stretching, irrespective of stretching protocol. Previous research suggested that acute stretch-induced force impairments following stretching are attributed to neural inhibition (i.e a reduction in motor command from the central nervous system to the muscle during voluntary contraction [25] and to reductions in muscle-tendon stiffness [26]. Several studies have shown that neural mechanisms are primarily responsible for the acute stretch-induced force decrements [25, 27]. For example, H-reflex excitability immediately decreases in a proportion to the stretch level [27]. Nevertheless, when stretching is followed by a passive muscle shortening movement some of the neuromuscular parameters responsible for the H-reflex depression are reset [27]. Therefore, the non-significant effect of stretching on jumping performance observed in the present study may be due to a quick reversal of the possible negative neural effects when CMJ is measured 2 min after stretching.

It is also plausible that muscle power may be less affected by prolonged static stretching in preadolescent children compared with adults, due to the increased pliability of the musculotendinous tissue during childhood [28] and to their decreased neuromuscular activation [29]. For example, tendon structures in prepubertal boys are more pliable than those in older boys and young men [30], and this may reduce the negative effect of stretching on muscle-tendon unit stiffness. Moreover, children are less capable than adults in voluntarily activating their motor units and have more Type I fibers compared to adults [29, 31]. Thus, the above evidence suggests that children may be less susceptible to stretch-induced muscle power loss than adults.

Previous studies have shown contralateral effects of stretching on the non-stretched limb [32, 33]. For example, acute decreases in muscle activation from pre- to post-stretch have been reported in both the stretched and the unstretched leg extensors, suggesting a crossover stretching effect [33]. In the present study, CMJ height was not different from baseline for both the stretched and the non-stretched leg, 2 min post-stretching. Therefore, an acute contralateral effect of stretching on jumping height in child athletes was not observed.

A limitation of the study is that stretching was applied only to the knee extensors. Clearly, other muscle groups, such as the hip and ankle extensors, contribute to CMJ performance during single leg jumping [34]. However, knee extensors are important contributors to peak and mean power output during single leg jumping (≈24–27%) [34] and thus, a decrease in their power due to stretching would be evident in CMJ performance.

It should also be noted that the participants of this study were trained youth gymnasts. The lack of stretch-induced jumping decrements in the present study may also be explained by the fact that these young gymnasts regularly applied prolonged stretching during training.

The results of this study indicated that stretching protocols increased ROM significantly and similarly after the 6th week of intervention, and this improvement was maintained 3 weeks into detraining. Previous research in adults also demonstrated significant improvements in ROM following 3 - 6 weeks of static stretching training with a greater increase occurring in the first 3 or 4 weeks of the training [17]. In contrast, the two stretching protocols in the present study resulted in significant increases in pre-stretching ROM after 6 weeks and in the post-stretching ROM after 9 weeks of training (Figure 5). This would suggest that to obtain measurable changes in ROM in trained individuals, at least 6–9 weeks of stretching training may be necessary. In accordance with the present findings, a previous study in adult male gymnasts using an acute intermittent or a continuous static stretching protocol of equal total duration (3 x 30 vs. 90 sec, respectively) reported that both stretching protocols induced similar increases in hip extension [9]. Taken together, the findings of the present study and previous research would suggest that both repeated-bouts and prolonged single stretching of equal duration confer similar improvements in ROM, at least for the time frame, muscle group, and the population examined. The lack of improvement in ROM in the CG, would imply that dynamic flexibility movements executed during gymnastics skills may not be an adequate stimulus to enhance joint ROM in preadolescent female gymnasts, but only to maintain it.

CONCLUSIONS

Prolonged static stretching, applied as single or repeated bouts of equal total duration, results in similar acute and long-term improvements in ROM, that are maintained after 3 weeks of detraining. Furthermore, both stretching protocols did not acutely affect subsequent CMJ performance, and this was not influenced by the large increase in ROM and CMJ overtime. The results of this study may

provide useful information for coaches who may incorporate either repeated bouts or single prolonged static stretching protocols of relatively long total duration (90 s) as part of a warm-up or flexibility training in young gymnasts' training, without expecting any measurable decrease in muscle power.

REFERENCES

1. Freitas SR, Mil-Homens P. Effect of 8-week high-intensity stretching training on biceps femoris architecture. J Strength Cond Res. 2015;29:1737–1740.

2. Magnusson P, Renström P. The European College of Sports Sciences Position statement: The role of stretching exercises in sports. Eur J Sport Sci. 2006;6:87–91.

3. Behm DG, Blazevich AJ, Kay AD, Mc Hugh M. Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review. Appl Physiol Nutr Metab. 2015; 41: 1–11.

4. Kay AD, Blazevich AJ. Effect of acute static stretching on maximal muscle performance. Med Sci Sports Exerc. 2012;44: 154–164.

5. Lima CD, Brown LE, Wong MA, et al. Acute Effects of Static vs. Ballistic Stretching on Strength and Muscular Fatigue Between Ballet Dancers and Resistance Trained Women. J Strength Cond Res. 2016;30:3220–3227.

6. Matsuo S, Suzuki S, Iwata M, et al. Acute effects of different stretching durations on passive torque, mobility, and isometric muscle force. J. Strength Cond Res. 2013;27:3367–3376.

7. Trajano GS, Nosaka K, Seitz LB, Blazevich AJ. Intermittent stretch reduces force and central drive more than continuous stretch. Med Sci Sports Exerc. 2014;46: 902–910.

8. Blazevich AJ, Gill ND, Kvorning T, et al. No effect of muscle stretching within a full, dynamic warm-up on athletic performance. Med Sci Sports Exerc. 2018;50:1258–1266.

9. Bogdanis GC, Donti O, Tsolakis C, Smilios I, Bishop DJ. Intermittent but not continuous static stretching improves subsequent vertical jump performance in flexibility-trained athletes. J Strength Cond Res. 2017;33:203–210.

10. Sands WA, McNeal JR, Penitente G, et al. Stretching the spines of gymnasts: a review. Sports Med. 2016; 46:315–327.

11. Falsone, S. Optimising Flexibility. In: Joyce UD, Lewindon D, editors. High-Performance Training for Sports. P.O. Box, 5076, Champaign, IL, Human Kinetics, 2014. p. 61–70.

12. Lloyd RS, Oliver JL. The youth physical development model: A novel approach to long-term athletic development. Strength Cond J. 2012;34:61–72.

13. Donti O, Papia K, Toubekis A, et al. Flexibility training in preadolescent female athletes: Acute and long-term effects of intermittent and continuous static stretching. J Sports Sci. 2018; 36:1453–1460.

14. Malina RM, Bouchard C, Bar-Or O. Growth, Maturation, and Physical Activity. Champain, IL: Human Kinetics; 2004.

15. Chaouachi A, Castagna C, Chtara M, et al. Effect of warm-ups involving static or dynamic stretching on agility, sprinting, and jumping performance in trained individuals. J Strength Cond Res. 2010; 24:2001–2011.

16. Donti O, Tsolakis C, Bogdanis GC. Effects of baseline levels of flexibility and vertical jump ability on performance following different volumes of static stretching and potentiating exercises in elite gymnasts. J Sports Sci Med. 2014;13:105–113.

17. Cipriani D, Abel B, Pirrwitz DA. Comparison of two stretching protocols on hip range of motion: implications for total daily stretch duration. J Strength Cond Res. 2003;17:274–278.

18. Donti O, Gaspari V, Papia K, Panidi I, Donti A, Bogdanis GC. (2020). Acute Effects of Intermittent and Continuous Static Stretching on Hip Flexion Angle in Athletes with Varying Flexibility Training Background. Sports. 2020;8:28.

19. McNeal JR, Sands WA. Acute static stretching reduces lower extremity power in trained children. Pediat Exerc Sci. 2003;15:139–145.

20. Siatras T, Papadopoulos G, Mameletzi D, Gerodimos V, Kellis S. Static and dynamic acute stretching effect on gymnasts' speed in vaulting. Pediatr Exerc Sci. 2003;15:383–391.

21. Mirwald RL, Baxter-Jones AD, Bailey DA, Beunen GP. An assessment of maturity from anthropometric measurements. Med Sci Sports Exerc. 2002;34:689–694.

22. Wong DL, Hockenberry-Eaton M, Wilson D, Winkelstein ML, Schwartz, P. Wong's Essentials of Pediatric Nursing. 6th ed. St Louis: Mosby; 2001.

23. Cohen J. A power primer. Psychol Bull. 1992;112: 155–159.

24. Merino-Marban R, Fuentes V, Torres M, Mayorga-Vega D. Acute effect of a static- and dynamic-based stretching warm-up on standing long jump performance in primary schoolchildren. Biol Sport. 2020:333–339. doi:10.5114/biolsport.2021.99703

25. Trajano GS, Nosaka K, Blazevich AJ. Neurophysiological mechanisms underpinning stretch-induced force loss. Sports Med. 2017;47:1531–1541.

26. Morse CI, Degens H, Seynnes OR, Maganaris CN, Jones, DA. The acute effect of stretching on the passive stiffness of the human gastrocnemius muscle tendon unit. J Psychiol. 2008; 586: 97–106.

27. Budini F, Tilp M. Changes in H-reflex amplitude to muscle stretch and lengthening in humans. Rev Neuroscience. 2016;27:511–522.

28. Rumpf MC, Cronin JB, Oliver JL, Hughes MG. Vertical and leg stiffness and stretch-shortening cycle changes across maturation during maximal sprint running. Hum Mov Sci. 2013; 32:668–676.

29. Dotan R, Mitchell C, Cohen R, et al. Child—adult differences in muscle activation—a review. Pediatr Exerc Sci. 2012;24 2–21.

30. Kubo K, Kanehisa H, Kawakami Y, Fukanaga T. Growth changes in the elastic properties of human tendon structures. Int J Sports Med. 2001; 22:138–143.

31. Jansson, E. Age-related fibre type changes in human skeletal muscle. In: Maughan RJ, Shirreffs SM, editors. Biochemistry of Exercise IX. Champain, IL: Human Kinetics; 1996. p. 297–307.

32. Chaouachi A, Padulo J, Kasmi S, et al. Unilateral static and dynamic hamstrings stretching increases contralateral hip flexion range of motion. Clin Physiol Funct Imaging. 2017;37:23–29.

33. Cramer JT, Housh TJ, Weir JP, et al. The acute effects of static stretching on peak torque, mean power output, electromyography, and mechanomyography. Eur J Appl Physiol. 2005;93:530–539.

34. Van Soest AJ, Roebroeck ME, Bobbert MF, Huijing PA. van Ingen Schenau GJ. A comparison of one-legged and two-legged countermovement jumps. Med Sci Sports Exerc. 1985; 17:635–639.