Jumping Exercise Restores Stretching-Induced Power Loss in Healthy Adults

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ABSTRACT The purpose of this study was to examine the acute effects of jumping exercise (JE) immediately after different stretching protocols on flexibility and power in healthy adults. This study was conducted with a balanced crossover design. Thirteen healthy males (25.4±3.46 years old) voluntarily participated in this study. All participants randomly completed four trials, including three different stretching protocols; 1) static stretching (SS), 2) dynamic stretching (DS), 3) proprioceptive neuromuscular facilitation stretching (PNFS), and 4) a non-stretching control (NS) followed by the JE with seven-day intervals between tests. JE was composed of three sets of five tuck jumps. Flexibility was determined by the ability to perform a straight leg raise (SLR) and power by vertical jump performance (VJP). Both SLR and VJP were measured at four time points; 1) baseline, 2) post-jogging, 3) post-stretching, and 4) post-JE; 4 × 4 repeated measures analysis of variances were applied. There were significant interaction effects on SLR (F=8.935, p<.001) and VJP (F=3.965, p=.009). The SLR score increased in all stretching protocols except the NS protocol post-stretching and post-JE. After stretching, the VJP score decreased in the NS (-2.6%), SS (-3.6%), and PNFS (-4.4%) protocols but maintained a positive score for the DS (1.8%) protocol. However, the VJP score recovered to the previous value in the SS (3.2%) and PNFS (6.5%) protocols after the jumping exercise. The present study suggests that jumping exercise immediately after SS and PNFS protocols could be an efficient program for restoring stretching-induced power loss in healthy adults.

KEY WORDS flexibility, jumping exercise, power, stretching

Introduction

The importance of warm-up prior to main exercise and sports events has been widely recognized for preventing injuries and optimizing exercise performance (Woods, Bishop, & Jones, 2007). The warm-up programme generally consists of light aerobic activity, stretching, and sport-specific movements for 15-20 minutes (Woods et al., 2007). Light aerobic activities, such as jogging and cycling, have been known to increase body temperature and blood circulation, which leads to improved exercise performance, such as flexibility, strength, and power (Bishop, 2003; Young & Behm, 2002).

Stretching exercises are commonly applied following light intensity aerobic activities to increase flexibility and decrease injuries (Hartig & Henderson, 1999). Various stretching protocols, such as static stretching (SS), dynamic stretching (DS), and proprioceptive neuromuscular facilitation stretching (PNFS), have been introduced as pre-exercise stretching protocols. SS is a common stretching technique that serves as a warm-up programme, and this technique has been known to improve range of motion and decrease muscle soreness (Andersen, 2005). The DS has become a preferred choice in the athletic community in recent years, because this technique has been shown to improve performances in power (Franco, Signorelli, Trajano, Costa, & de Oliveira, 2012), sprints (Fletcher & Jones, 2004), and strength (Sekir, Arabaci, Akova, & Kadagan, 2010) despite musculotendinous unit (MTU) stiffness being decreased (Herda et al., 2013). The PNFS is widely...
applied in a clinical environment to enhance both active and passive ranges of motion with the ultimate goal being to optimize muscular performance (Bradley, Olsen, & Portas, 2007). The PNFS protocol is not commonly recommended immediately prior to explosive athletic movement because it could diminish jump performance and muscle strength (Bradley et al., 2007; Marek, Cramer, Fincher, & Massey, 2005). However, this protocol provides great benefits for those who participate in exercises that require great flexibility, such as gymnastics. Many studies on stretching and exercise performance have been conducted, but the outcomes are still controversial depending on the duration and type of stretching protocols (Bradley et al., 2007; Fletchér & Jones, 2004; Franco et al., 2012; Marek et al., 2005; Sekir et al., 2010), the performer’s baseline status (Behm & Chauouachi, 2011; Donti, Tsolakis, & Bogdanis, 2014), and gender differences (Donti et al., 2014).

As a final component of warm-up programmes, potentiating exercise is applied with specific forms related to upcoming sports events or activities. The potentiating exercise focuses on the intensity of activities that include various explosive movements such as sprinting, jumping, and throwing (Till & Cooke, 2009; Tillin & Bishop, 2009). It has been known to facilitate a high degree of central nervous stimulation; thus, the recruitment of fast twitch motor units is enhanced (Hamada, Sale, MacDougall, & Tarnopolsky, 2000; Hodgson, Docherty, & Robbins, 2005). In particular, plyometric type jumping exercise (JE) is often used as a form of potentiating exercise. However, it is not well understood how plyometric jumping exercise influences flexibility and power performance when combined with different stretching protocols. A previous study reported that three sets of five jumping exercises after static stretching restored counter-movement jump (CMJ) in international fencing athletes (Tsolakis, Bogdanis, 2012). However, Donti et al. (2014) reported that one set of five tuck jumps did not improve power performance in elite gymnasts. Another study also reported that jumping exercise immediately after DS did not improve vertical jump performance (Turki et al., 2011).

As mentioned previously, the performance outcomes, including strength and power, following different stretching are well understood in the previous studies (Behm & Chaouachi, 2011; Bishop, 2003), but it is unclear the how the jumping exercise affects performance when combined with different types of stretching (i.e., SS, DS, and PNFS) even though warm-up programmes commonly include stretching and explosive movements. In this study, we have specifically selected a jumping exercise (tuck jump) as a potentiating exercise because strength and power in lower limbs play an important role in most sports events. In addition, the tuck jump does not require specific techniques, which enable it to be applied for general populations, such as healthy adults. Thus far, most studies regarding stretching and performance predominantly have used athletes as subjects (Donti et al., 2014; Tsolakis & Bogdanis, 2012; Turki et al., 2011). However, it is important to know that athletes are a unique group in comparison to the general population, because their body (i.e., physiological, functional) and mind (psychological) respond differently to exercise or warm-up (Dehkordi, 2001; Koch et al., 2003). We believe the importance of warm-up programmes should be emphasised in healthy adults as well as athletes as the number of participants who exercise has increased among healthy adults. This study would provide practical information to healthy adults, which enable the application of a warm-up programme before exercise or a sport event. Therefore, the purpose of this study was to examine the acute effects of jumping exercise immediately after different stretching protocols on flexibility and power in healthy adults. We hypothesize that jumping exercise immediately after different stretching protocols will enhance flexibility and power performance in healthy adults.

Methods

Participants

Participants were recruited through advertisements at the university. Seventeen healthy collegiate males voluntarily participated in this study. No subjects engaged in any stretching-related exercise (i.e. yoga, Pilates), and had no skeletomuscular injuries in the previous two to three years. During the study period, four subjects dropped out due to personal reasons. Therefore, thirteen healthy males (25.4±3.46 years, 171.7±6.97 cm, 77.0±12.28 kg) completed the study. The study procedures, including the potential risk factors, were explained to the participants. Written informed consent was obtained from the participants prior to testing. This study was approved by the Institutional Review Board of Texas A&M University-San Antonio.

FIGURE 1 Study procedure

Note. * SLR; straight leg raise, VJP; vertical jump performance
* Stretching protocols: three different stretching protocols (SS, DS, PNFS) and NS control were applied in a 7-day interval
* Potentiating exercise: three sets of five tuck jumps

SLR

VJP

Jogging

0’

5’

8’

13’

16’

18’

21’

Stretching

Jumping exercise

SLR

VJP

SLR

VJP

SLR

VJP

SLR

VJP

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* Potentiating exercise: three sets of five tuck jumps
**Study design**

This study was conducted in a balanced crossover design (Figure 1). Height and weight were measured via the use of a wall-mounted stadiometer (Stadi-O-Meter®, Rockton, USA) and a digital scale (SECA, Hamburg, Germany), respectively. Prior to stretching, participants performed five minutes of jogging on a treadmill (6.4 km/hour). Three different stretching protocols (SS, DS, and PNFS) combined with JE were randomly applied with a seven-day interval between tests. Non-stretching combined with JE served as the control group. Straight leg raise (SLR) and VJP were measured at four time points: baseline, post-jogging, post-stretching, and post-JE with three minutes of recovery time between the measurements.

**Stretching protocols**

Three stretching (SS, DS, and PNFS) protocols were specially targeted towards lower limb muscles (calf, hamstrings, quadriceps, and gluteus maximus). Each stretching protocol was applied to a single muscle group of 30 seconds with mild discomfort for a total of five minutes. For NS control, participants sat in a chair for five minutes. The stretching protocols were modified based on previous studies (Doniti et al., 2014; Franco et al., 2012). The components of stretching techniques are described in Table 1.

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**Jumping exercise programme**

After each stretching protocol was completed, participants performed three sets of five tuck jumps with 30-second intervals between sets (Doniti et al., 2014).

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Exercise performance testing
SLR and VJP tests were selected for the measurements of flexibility and power performance. The SLR was measured with a goniometer (Baseline stainless steel goniometers, USA). Participants lay in a supine position on a medical bed with their backs flat to prevent possible pelvic rotation. Then participants raised their dominant leg as far as possible while maintaining the knee fully extended with ankle joint in a dorsiflexion position. One lever of the goniometer was 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 opposite leg was firmly held down to prevent flexion at the hip joint. Participants performed two-trials, and the highest score was recorded. The intra-class correlation coefficient (ICC) for SLR was 0.98. The VJP test was measured as a marker of power performance. Participants first raised their right arm on the measuring bar with a fully extended elbow, which marked an initial point. Then, they were instructed to jump with their maximal effort as high as possible. The jump height was calculated from maximal jump height minus initial point. Each participant performed two trials, and the highest score was recorded. The ICC for VJP was 0.93.

Statistical analysis
SPSS (version 24.00, SPSS Inc., Chicago, Illinois) was used for statistical analysis. All data were presented as mean and standard deviations. The percentage change of scores was also calculated for all measures. 4 × 4 repeated measures analysis of variances (ANOVA) were applied to analyse the changes of SLR and VJP between (a) different stretching protocols and (b) time sequences. If any significant interactions or main effects were detected, repeated measure ANOVAs with a Bonferroni post hoc test was applied. One-way ANOVAs were applied to analyse the percentage changes of SLR and VJP between the different protocols at the post-jogging, the post-stretching, and the post-JE. Partial eta squared ($\eta_p^2$) was used to classify the effect size. The reliability estimated for the best score in SLR and VJP was determined by calculating the intra-class correlation coefficient (ICC) (Wood, & Zhu, 2006). The level of statistical significance was set at p<.05.

Results
Flexibility
There was a significant interaction effect (protocol × time) on the straight leg raise (F=8.935, p<.001, $\eta_p^2=4.27$). There were also significant effects for time (F=61.789, p<.001, $\eta_p^2=.837$) and trial (F=17.739, p<.001, $\eta_p^2=.596$). The Bonferroni post hoc test showed that the SLR score significantly increased in all trials after jogging. Although the SLR score increased after SS, DS, and PNFS, this score did not change after NS. Jumping exercise immediately after all stretching protocols did not provide additional benefit in flexibility. Overall, jumping exercise immediately after three stretching protocols increased SLR from baseline. Figure 2 describes the changes in flexibility.

![Figure 2: The changes of flexibility](image-url)
Power
A significant interaction effect (protocol × time) on VJP was observed (F=3.965, p=.009, \( \eta^2 = .248 \)). There was also a significant time effect (F=20.403, p<.001, \( \eta^2 = .630 \)). The Bonferroni post hoc test revealed that the VJP score significantly increased in all trials after jogging. However, the VJP score decreased after the NS, SS, and PNFS protocols, although it did not change after DS. After the jumping exercise, the VJP score was only restored post-jogging in the SS and PNFS protocols, whereas it did not change in the NS and DS protocols. Overall, the jumping exercise immediately after DS and PNFS significantly improved the VJP from baseline. Figure 3 represents the changes of VJP.

Discussion
This study was aimed at investigating the acute effects of jumping exercise immediately after different stretching protocols on flexibility and power in healthy adults. The main findings are as follows: 1) jumping exercise immediately after the DS and PNFS protocols improves flexibility and power from the baseline; 2) jumping exercise restores the static and PNF stretching-induced power loss in healthy adults.

In the current study, the percentage increase in SLR from jogging was greater in SS (9.4%), DS (4.9%) and PNFS (11.9%) trials than NS (-0.1%) trial at post-stretching. Even though there were no statistical differences in SLR among the three stretching protocols, the PNFS protocol showed the greatest improvement in SLR. PNFS is known as the most effective method for increasing range of motion in joints and flexibility (Konrad, Gad, & Tilp, 2015). This contract-relax stretching method may have an impact on autogenic inhibition, especially the Golgi tendon organ. Increasing tension during the contraction phase may increase antagonist muscle activity while the function of the Golgi tendon organ decreases during the relaxation phase; therefore, the joint range of motion increased (Konrad et al., 2015). The DS protocol showed the lowest improvement in SLR among three stretching protocols. A previous study reported that DS is not as effective in increasing flexibility compared to SS and PNFS (Behm & Chaouachi, 2011).

In the present study, VJP significantly decreased in the NS (-2.6%), SS (-3.6%), PNFS (-4.4%) trials but did not change in the DS (1.8%) trial post-stretching. Non-dynamic stretching, such as static and PNF stretching, has been known to reduce power performance (Behm & Chaouachi, 2011). Wallmann, Mercer, & McWhorter
(2005) demonstrated that three sets of 30 seconds static stretching decreased jump performance (-5.6%). Another study also reported that four reps of 30 seconds SS and PNFS (5 sec contract and 25 sec relaxation phase) for five minutes, decreased vertical jump performance (SS: 4%, PNFS: 5.1%). The mechanism underlying these results demonstrated that prolonged static stretching might inhibit the neural drive and asynchronies of muscle activity (Power, Behm, Cahill, Carroll, & Young, 2004). The stretch-induced impairment of the length-tension relationship may be another factor that limits further motor unit recruitments (Costa et al., 2012). However, the VJP score was maintained after the DS trial in the present study. We assume that DS may have a different role in power performance compared with other stretching protocols. DS involves many active movements, which induce physiological changes such as increased heart rate, body temperature, and altering other metabolic factors (Fletcher, 2010). Even though a previous study speculated that MTU stiffness is decreased after DS (Herda et al., 2013), which is similarly shown in other stretching protocols (Ryan et al., 2014), the physiological benefits may outweigh the stretching-induced power loss. This study confirmed that five minutes of static and PNFS stretching alone reduce VJP while DS did not affect the improved VJP induced by jogging.

A plyometric-type jumping exercise after stretching is commonly applied as a potentiating exercise to promote muscle activity. In the present study, jumping exercise restored the VJP in the SS (3.2%) and PNFS (6.5%) protocols whereas this score did not significantly change in the NS and DS protocols. A previous study reported that the combination warm-up (run+stretch+jumps) programme showed the highest score in jumping performance compared to running alone or a run+stretch warm-up programme (Young & Behm, 2003). Another study reported that 45 seconds of static stretching decreased CMJ (5.5%), but 3 sets × 5 tuck jumps immediately after stretching restored the power performance in international fencing athletes (Tsikalakis & Bogdanis, 2012). Donitl et al. (2014) conducted different volumes of jumping exercise. The study reported that 3 sets × 5 tuck jumps after 30 sec static stretching enhanced CMJ, but one set of five times tuck jump did not improve CMJ in elite gymnasts.

There are various possible reasons that additional jumping exercise after stretching provides benefit to power performance. The first theory is that various explosive-movements may increase central nerve stimulation, which involves the Hoffmann Reflex (H-reflex), resulting in greater fast twitch motor unit recruitments (Hodgson et al., 2005). The second theory involves phosphorylation, which produces more ATP, resulting in greater muscle activation at the structure level of skeletal muscle (Rixon, Lamont, & Bemben, 2007). It has also been proposed that explosive movements recruit more fast twitch muscle fibres that lead to improved power performance after JE (Hamada et al., 2000). However, the additional jumping exercises after DS do not provide positive benefits over VJP. Behm, Button, Barbour, Butt, & Young (2004) pointed out the importance of balance between post-activation potentiation exercise and fatigue. A previous study supported our result that dynamic stretching alone improved muscular performance, but an additional 3 × 3 times of tuck jumps did not provide the benefits on VJP (Turki et al., 2011). The current study suggests that jumping exercise (5 times × 3 set) after DS may not provide additional benefit over VJP, while undertaking this programme immediately after SS and PNFS may restore the stretching-induced power loss.

The present study suggests that jumping exercise immediately after SS and PNFS protocols could be an efficient programme for restoring stretching-induced power loss in healthy adults. However, jumping exercise after DS did not provide additional benefit to power performance.

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