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The Effect of Static, Ballistic, and Proprioceptive Neuromuscular Facilitation Stretching on Vertical Jump Performance

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Abstract. Bradley, P.S., P.D. Olsen, and M.D. Portas. The effect of static, ballistic, and proprioceptive neuromuscular facilitation stretching on vertical jump performance. *J. Strength Cond. Res. 21(1):223–226. 2007.*—The purpose of this study was to compare the acute effects of different modes of stretching on vertical jump performance. Eighteen male university students (age, 24.3 ± 3.2 years; height, 181.5 ± 11.4 cm; body mass, 78.1 ± 6.4 kg; mean ± *SD*) completed 4 different conditions in a randomized order, on different days, interspersed by a minimum of 72 hours of rest. Each session consisted of a standard 5-minute cycle warm-up, accompanied by one of the subsequent conditions: (a) control, (b) 10-minute static stretching, (c) 10-minute ballistic stretching, or (d) 10-minute proprioceptive neuromuscular facilitation (PNF) stretching. The subjects performed 3 trials of static and countermovement jumps prior to stretching and poststretching at 5, 15, 30, 45, and 60 minutes. Vertical jump height decreased after static and PNF stretching (4.0% and 5.1%, $p < 0.05$) and there was a smaller decrease after ballistic stretching (2.7%, $p > 0.05$). However, jumping performance had fully recovered 15 minutes after all stretching conditions. In conclusion, vertical jump performance is diminished for 15 minutes if performed after static or PNF stretching, whereas ballistic stretching has little effect on jumping performance. Consequently, PNF or static stretching should not be performed immediately prior to an explosive athletic movement.

Key Words. explosive performance, stretch shortening cycle, warm-up

Introduction

Competitive and recreational athletes typically use preparatory exercises such as warm-up and stretching to prepare the body for vigorous physical activity (4, 7). Several minutes of light physical activity followed by stretching exercises are generally recommended for all sports and levels of competition (8, 35). Stretching is believed to enhance performance, reduce injury, and be an effective means of developing flexibility and alleviating muscular soreness (2, 18, 29, 31, 33, 40). However, recent research has indicated that stretching prior to athletic or sporting movements may have a detrimental effect on performance (9, 27, 38).

Static stretching prior to exercise has been found to have a negative effect on maximal muscular performance (9–11, 16, 21, 22, 24, 26, 41). These findings have prompted some researchers to challenge the practice of stretching prior to sports that require maximal strength or power, such as gymnastics (24), sprinting (15), and jumping events (9, 41). However, these suggestions seem premature, as few studies have investigated the acute effects of ballistic and proprioceptive neuromuscular facilitation (PNF) stretching on maximal muscular performance, and there are no published studies comparing the combined effects of static, ballistic, and PNF stretching on athletic performance. Moreover, the limited research on the effect of ballistic or PNF stretching has produced conflicting findings. Unick et al. (38) found no significant reduction in countermovement or drop jump performance following ballistic stretching in trained women. In contrast, Nelson and Kokkonen (28) found that maximal strength during knee flexion and extension decreased substantially after ballistic stretching. Church et al. (9) found that PNF stretching decreased countermovement jump height, whereas Young and Elliott (41) found minimal reduction in static jump height and explosive force production following PNF stretching. Therefore, further research is needed to determine the effect of different modes of stretching on the performance of athletic movements.

Fowles et al. (16) observed a 28% decrease in isometric plantarflexor torque immediately after 30 minutes of static stretching; torque remained depressed by 9% at 60 minutes. However, a limitation of this research was that the volume of stretching did not represent what an athlete would typically perform (16), nor did it represent the complexity of movements performed in competition. Therefore, it is not known whether this deficit would occur in athletic movements such as the vertical jump after a smaller volume of stretching. This information would be useful to coaches and athletes, as recommendations regarding the optimal time to perform stretching prior to athletic movements could be made. Therefore, the purpose of this study was twofold: first, to compare the acute effects of static, ballistic, and PNF stretching on vertical jump performance, and second, to determine the time course of potential stretch-induced deficits in jumping performance over a 60-minute period.

Methods

Experimental Approach to the Problem

The present study was designed to investigate the effects of 3 conditions of stretching on vertical jump performance relative to a control. All subjects performed the conditions in a randomized order on different days, interspersed by a minimum of 72 hours of rest. Subjects performed for 10 minutes under one of the following conditions: (a) no stretching, (b) static stretching, (c) ballistic stretching, or (d) PNF stretching (Figure 1). Subjects performed 3 static and 3 countermovement vertical jumps before, immediately after, and throughout a 60-minute period after each condition. Jump height (cm) was measured and the average of the 3 trials was calculated.

Subjects

Eighteen male university students (age, 24.3 ± 3.2 years; height, 181.5 ± 11.4 cm; body mass, 78.1 ± 6.4 kg; mean ± *SD*) volunteered to participate in the study. All subjects were free from injury and able to perform maximal ver-

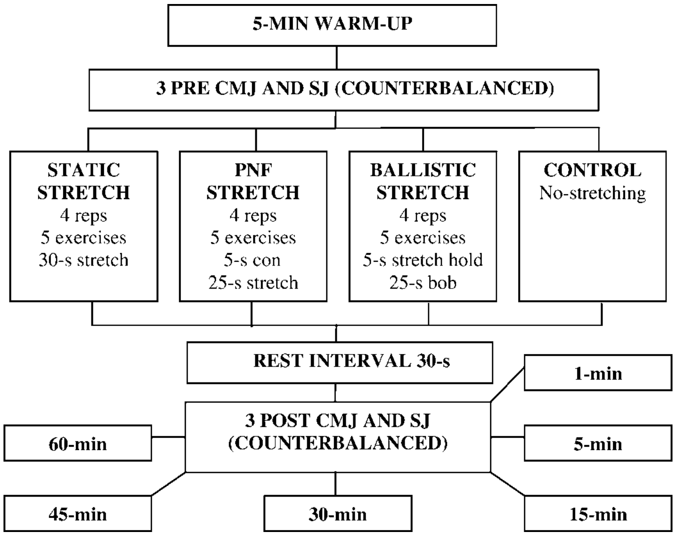

FIGURE 1. Experimental design. CMJ = countermovement jump; SJ = static jump; PNF = proprioceptive neuromuscular facilitation; con = contraction.

tical jumps and stretching techniques without pain. Subjects were instructed to refrain from vigorous physical activity for 48 hours before testing sessions. Written informed consent was obtained from all subjects and the study was approved by the university's ethics committee.

Procedures

Subjects reported to the laboratory on 5 separate occasions. The first session familiarized subjects with test procedures and equipment. During the orientation, subjects performed 5 trials of the static and countermovement jumps to reduce the likelihood of a learning effect during the study (19). In the remaining sessions, the subjects sat for 10 minutes, cycled for 5 minutes (Monark 818E, Varberg, Sweden) at 120 W (32), and then performed the vertical jumps before, immediately after, and at 5, 15, 30, 45, and 60 minutes poststretching. The order of the type of vertical jump was randomized (41). Data collection occurred during sessions 2–5, and tests were performed at the same time of day to minimize the effect of circadian variation on performance (12, 13).

In each condition, the quadriceps, hamstrings, and plantarflexor muscle groups were stretched, as these are prime movers in the vertical jump (5, 17, 34); the exception was the control group, in which no stretching was performed. Stretches included the supine gastrocnemius stretch, butterfly stretch, supine hamstring stretch, prone quadriceps stretch, and kneeling quadriceps stretch (1). To ensure consistency in the exercises, an experienced practitioner passively stretched the muscles to assist the subject in reaching his maximal range of motion. The stretches were repeated 4 times in both legs in an alternating manner so that the lower limbs were stretched for a total of 10 minutes.

During the static stretching condition, the researcher passively stretched the muscle(s) to a point of mild discomfort for 30 seconds. Thirty seconds was selected because this duration is typically used by athletes (29) and has been found to increase the compliance of the musculotendinous unit (1, 2). The ballistic condition was similar to the static stretching protocol, except that at the end range of motion, the researcher passively stretched the muscle(s) by moving forward and backward at a rate of approximately 1 bob every second for 30 seconds (28).

The PNF condition involved stretching the lower extremity using the contract-relax technique (1). During the contract-relax method, the agonist muscle was passively stretched to its end point (1) and the subject performed a 5-second maximal voluntary isometric contraction of the antagonist muscle group. The researcher then passively stretched the subject's agonist muscles for 30 seconds. The PNF protocol used was modified from the stretching regimen conducted in the study of Young and Elliott (41). In all stretching conditions, each stretch was interspersed with a 30-second recovery period. During the control condition, subjects performed the standard cycle warm-up and then rested for 10 minutes so that the time between pre- and posttesting periods was consistent in all conditions. Subjects were randomly assigned to the control and stretching conditions. To enable comparisons between the interventions, the duration and number of stretches were similar in all conditions.

Subjects performed 6 vertical jumps (3 static and 3 countermovement jumps). The first set comprised 3 static jumps that involved no active prestretch of the leg muscles. This was initiated from a static squatting position that was maintained for 3 seconds before launching the body vertically. The second set included 3 countermovement jumps, which used a preliminary movement by rapidly flexing the knees before launching the body vertically. The vertical ground reaction force (N) generated during each jump was collected using a Kistler force platform operating at a sampling frequency of 1,000 Hz and analyzed with Bioware software (Kistler Instrument 9281CA, Winterthur, Switzerland). Jump height was calculated from the vertical velocity at take-off (11). All trials had a 60-second recovery period between each jump (20, 30). Subjects were instructed to perform every trial with maximum effort and to place their hands on their hips (17, 34). Vertical ground reaction force during a vertical jump has been found to vary with the angle of the knee joint (5, 6, 37). Consequently, to ensure consistency in jumping technique, a knee angle of 90° was used throughout testing. To obtain a 90° angle, subjects flexed their knees so that the gluteal fold touched a string line. The height of the string line that produced a knee angle of 90° was determined in the orientation session using a goniometer (Dasco Pro, Rockford, IL). Pilot work using the string line found high reliability for jump height from a knee angle of 90° for static and countermovement jumps (R = 0.87–0.96 and 0.86–0.98, n = 12).

Statistical Analyses

Descriptive statistics were calculated for the dependent variable (jump height) and confirmed assumptions of normality. The statistical model used to analyze the data was a 3-way (jump type × condition × time) repeated-measures analysis of variance using SPSS for Windows (version 11.5; SPSS, Inc., Chicago, IL). The assumption of sphericity was tested by the Mauchly Test of Sphericity, and statistical significance was set at $p \leq 0.05$. Post-hoc tests were performed with paired-sample t-tests. The Bonferroni-Dunn procedure was used to reduce Type I error risk by adjusting the alpha level depending on the number of pairwise comparisons (36).

RESULTS

Jump Height

Significant main effects were found for jump type and condition and condition × time interaction. Paired-sam-

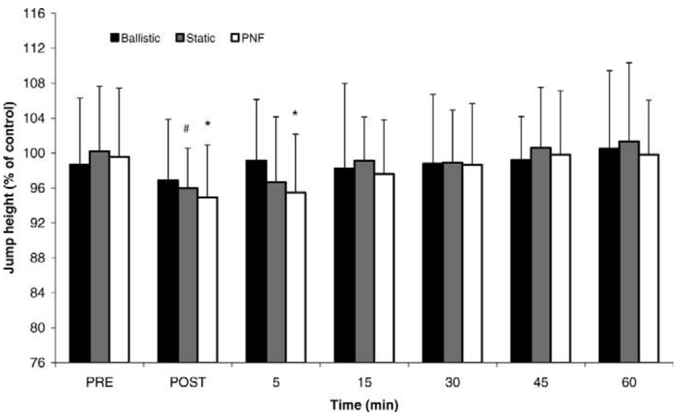

FIGURE 2. Differences (%) in jump height in the experimental conditions relative to the control pre- and post- static, ballistic, and proprioceptive neuromuscular facilitation (PNF) stretching. Static condition significantly below control value: # $p < 0.05$. PNF condition significantly below control value: * $p < 0.05$. Values are mean ± *SD*.

ple *t*-tests showed that static jump height was significantly lower than countermovement height (approximately 5.3%, $p < 0.01$) throughout the study. When data were collapsed across jump type there was a significant reduction in poststretch jump height in the static (4.0%, $p < 0.05$) and PNF (5.1%, $p < 0.01$) conditions (Figure 2). There was also a decrease in jump height after ballistic stretching (2.7%, $p > 0.05$). No significant difference ($p > 0.05$) was observed between static and PNF stretching conditions throughout the 60-minute time course. In static and PNF stretching conditions, jump heights were similar to prestretching measurements after 15 minutes.

DISCUSSION

Vertical jump performance decreased by approximately 5% after static and PNF stretching. Magnusson et al. (23) found that static and PNF stretching decreased stiffness in the musculotendinous unit, which could impair force production in muscles as a result of changes in the force velocity and length-tension relationship (16, 24, 27, 41). Consequently, it is possible that PNF and static stretching in the present study decreased musculotendinous stiffness in a similar manner to decrease jump height. The decrease in jump height after static stretching was similar to that observed in previous studies (3, 9–11, 15, 24, 26, 27, 38, 41); however, the same decrease after PNF stretching conflicts with the results of other research (9, 41). Church et al. (9) found PNF stretching produced a larger decrease in countermovement jump height than did static stretching. In contrast, Young and Elliott (41) found a significant decrease in jump performance following static stretching but minimal difference after PNF stretching. The reasons for the contradictory findings are unknown but could be due to Church et al. (9) using two 10-second isometric contractions for each exercise, whereas Young and Elliott (41) used one 5-second contraction followed by a 15-second passive stretch. Ballistic stretching had a minimal effect on vertical jump performance compared to the control condition. Unick et al. (38) also found little change in jump performance in trained women following a ballistic stretching protocol. Unick et al. (38) attributed the lack of change in performance after ballistic or static stretching to factors such as walking prior to activity, short duration of stretching (15 seconds), and the use of highly trained female athletes. This study differed from that of Unick et al. (38), as minimal activity occurred before the vertical jumps, subjects were moderately trained, and a longer stretch duration (30 seconds) was used. Our findings provide further evidence that ballistic stretching does not impair jumping performance and that these effects could be independent of sex or training status, whereas Nelson and Kokkonen (28) found that maximal strength decreased by 8% after ballistic stretching. A possible reason for the decrease in the Nelson and Kokkonen (28) study is the total volume of stretching. In the present study and in that of Unick et al. (38), muscle groups were stretched for less than 10 minutes, whereas Nelson and Kokkonen stretched the quadriceps and hamstrings for 20 minutes. More research is needed to determine the effect of different volumes of PNF and ballistic stretching on the performance of athletic movements.

Vertical jump performance had returned to control values 15 minutes after stretching in all conditions. However, Fowles et al. (16) found peak isometric torque was still reduced by 9% 60 minutes after stretching. The contrasting findings could be due to the volume of stretching and changes in the neuromuscular and mechanical properties of the muscles. The volume of stretching used in the present study (i.e., 10 minutes) was similar to that performed in an athletic setting (1, 29), whereas subjects in the study of Fowles and colleagues stretched for 30 minutes. Fowles et al. (16) indicated that initial decreases in peak torque after static stretching were due to changes in the neuromuscular and mechanical properties of a muscle, whereas decreases after 15 minutes were caused by impaired mechanical function from deformation in the supporting structures of the muscle (16). Consequently, restoration of jump performance after 15 minutes was probably due to recovery of voluntary muscle activation and increased stiffness in the musculotendinous unit, as the duration of stretching in this study probably did not cause long-term changes in the contractile properties of the muscle (16). Another possible explanation is that Fowles et al. (16) used a single-joint maximal voluntary contraction as a performance measure, while the present study used the vertical jump, which involves multiple joint movements and a high degree of coordination in the lower limbs (17, 34). It is not possible to determine whether differences in the study of Fowles et al. (16) and this research are due to different stretching protocols or performance measures. The results from this study indicate that coaches and athletes should have at least a 15-minute interim before the performance of an explosive athletic movement after static and PNF stretching.

The present study did not examine the mechanisms responsible for changes in jump performance after stretching. Nevertheless, static and PNF stretching probably impaired performance through mechanical and neurological mechanisms such as reduced musculotendinous unit (MTU) stiffness (16, 26–28, 38), altered reflex sensitivity, and decreased muscle activation (3, 11, 16). With regard to mechanical mechanisms, Wilson et al. (39) found that maximal force during the concentric phase of a bench press was positively correlated to MTU stiffness. However, static and PNF stretching have been found to decrease stiffness or increase compliance in the MTU (14, 23). Therefore it is possible that the PNF and static stretching used in this research decreased jump performance as a result of the correlation between force production and MTU stiffness. Neurological mechanisms that change reflex sensitivity and motor unit activation have been proposed or found to decrease after stretching (3, 11, 16, 25). For example, static stretching produces a myotatic reflex, while contract-relax PNF stretching causes autogenic and reciprocal inhibition, which in turn decreases neural activity in the stretched muscle (1). Etnyre and Abraham (14) also found that PNF stretching produced greater decreases in motor neuron activity compared to static stretching. Consequently, in this study, the larger decline in jump performance after PNF stretching compared to static stretching could be due to an additive effect of autogenic and reciprocal inhibition on neural excitability. Future research could examine the underlying mechanisms that cause changes in performance after ballistic and PNF stretching.

Practical Applications

The results of the present study indicate that static and PNF stretching produced a reduction in vertical jump performance, whereas jumping performance was relatively unaffected after ballistic stretching. Consequently, PNF or static stretching immediately prior to an explosive athletic movement is not recommended. However, if static or PNF stretching is necessary before an event, coaches and athletes should ensure that stretching occurs at least 15 minutes before performance. Alternatively, ballistic stretching could be used, as it is less likely to decrease performance and permits specificity in training and warm-up, as the exercises have similar movement dynamics to actions performed in sport. This type of stretching may also be particularly useful for athletes during breaks in competition (e.g., halftime in a soccer game) and for reserves or substitutes who are warming up.

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