

EFFECTS OF DYNAMIC AND STATIC STRETCHING ON VERTICAL JUMP PERFORMANCE AND ELECTROMYOGRAPHIC ACTIVITY

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ABSTRACT

Hough, PA, Ross, EZ, and Howatson, G. Effects of dynamic and static stretching on vertical jump performance and electromyographic activity. *J Strength Cond Res* 23(2): 507–512, 2009—The results of previous research have demonstrated that static stretching (SS) can reduce muscular performance and that dynamic stretching (DS) can enhance muscular performance. The purpose of this study was to assess the effects of SS and DS on vertical jump (VJ) performance and electromyographic (EMG) activity of the m. vastus medialis. Eleven healthy men (age 21 ± 2 years) took part in 3 conditions (no stretching [NS], SS, and DS), on separate occasions in a randomized, crossover design. During each condition, measurements of VJ height and EMG activity during the VJ were recorded. A repeated-measures analysis of variance and post hoc analysis indicated that VJ height was significantly less ($4.19 \pm 4.47\%$) after SS than NS ($p < 0.05$) and significantly greater ($9.44 \pm 4.25\%$) in DS than SS ($p < 0.05$). There was significantly greater EMG amplitude in the DS compared with the SS ($p < 0.05$). The results demonstrated that SS has a negative influence on VJ performance, whereas DS has a positive impact. Increased VJ performance after DS may be attributed to post-activation potentiation, whereas the reduction in VJ performance after SS may be attributable to neurological impairment and a possible alteration in the viscoelastic properties of the muscular tendon unit (MTU). This investigation provides some physiological basis for the inclusion of DS and exclusion of SS in preparation for activities requiring jumping performance.

KEY WORDS warm-up, neuromuscular, muscular tendon unit, postactivation potentiation

INTRODUCTION

It is a common practice to perform a warm-up before athletic activity because it has been shown to improve performance (7) and potentially reduce the risk of injury (7). It is widely accepted practice for warm-up routines to consist of moderate-intensity aerobic exercise and stretching exercises (2,3,28). Static stretching (SS) is a technique that is often incorporated into many warm-up routines (2,19,21) because it is known to increase range of movement (ROM) about the joint (11,24), which is beneficial to athletes who require higher levels of flexibility. It also has been suggested that SS before athletic activities can help prevent injuries (11,18). However, some recent studies have suggested that SS can have a negative effect on athletic performance by inducing short-term strength (9,14,22), power (5,8,9,38), and speed (12) deficits; consequently, a number of researchers have suggested that SS should be avoided during warm-up routines (8,9,22).

Another form of pre-event stretching that has become increasingly popular within sport is dynamic stretching (DS) (19). Recent studies have indicated that DS can improve power output during concentric resistance contractions (37), sprint running time (13), and vertical jump (VJ) performance (9,22,33). This suggests that the inclusion of DS in a warm-up may provide a viable alternative to SS (15).

The neuromuscular effects of SS have been documented previously (25,30,33,38). Power and colleagues (30) assessed the effects of SS on maximal voluntary force (MVC) production, muscle inactivation as measured by the interpolated twitch technique (ITT), and jumping performance. The results demonstrated significant overall decrements of 9.5 and 5.4% in the MVC of the quadriceps and ITT, respectively. Although a significant decrease in MVC occurred, this did not have a detrimental effect on jumping performance. In a recent study, Wallmann et al. (34) compared the effects of DS and a combination of DS and SS on VJ performance and electromyographic (EMG) activity of the gastrocnemius. The investigators reported no significant differences in VJ height or EMG activity. However, only 1 muscle group (gastrocnemius) was stretched, whereas a sports warm-up typically involves multiple stretches (2). Furthermore, this

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study used untrained individuals; therefore, the findings may not be wholly applicable to an athletic population. The purpose of the present study was to assess the effects of SS and DS on VJ height and EMG activity of the vastus medialis after stretching a number of muscle groups in the lower limb.

METHODS

Experimental Approach to the Problem

A concentric VJ was used instead of a traditional counter-movement jump. This was done to reduce the possibility of learning effects or familiarization and to ensure a consistent ROM during the concentric phase, which has been previously reported as difficult to maintain (30). Surface EMG was recorded from the m. vastus medialis during VJ, because previous research has indicated that EMG taken from nonbiarticular muscles produces greater reliability during a VJ (16). Participants attended the laboratory on 3 separate occasions separated by a minimum of 24 hours. On each visit, participants performed 1 of 3 conditions: no stretching (NS), SS, or DS in a randomized, crossover design.

Subjects

Before the start of the investigation, all procedures were approved by the university ethics committee. In addition, all volunteers completed written informed consent before taking part in the study. Eleven healthy men (age 21 ± 2 years; height 179.5 ± 5.5 cm; body mass 74.0 ± 6.4 kg; mean $\pm$ SD) who regularly competed in competitive university sports (football, hockey, athletics, squash, and cricket) were recruited for the study. All subjects were in training for their respective sports and were free from lower-limb injury at the time of testing. The subjects were asked to refrain from any strenuous physical activity for 24 hours before taking part in the tests. Furthermore, the subjects were asked to maintain a similar diet between trials and to abstain from caffeine for 12 hours before visiting the laboratory. A full explanation of the study design was given to all of the participants before the first session.

Procedures

Electromyography. Surface EMG was recorded from bipolar differential silver/silver chloride electrodes (Henley Medical, Stevenage, UK). The interelectrode distance was 20 mm. The skin surface was cleaned and abraded before electrode placement. The EMG signals were amplified (gain $\times 1000$) (1902, Cambridge Electronic Design, Cambridge, UK), band-pass filtered between 20 Hz and 2 kHz, digitized at a sampling rate of 4 kHz using an analog-to-digital converter (micro1401, Cambridge Electronic Design), and acquired and later analyzed in the time domain as root mean square (RMS) amplitude (mV) with a time constant of 25 milliseconds (Spike 2 v4.11, Cambridge Electronic Design). To ensure identical electrode placement in all test sessions, a sheet of clear acetate was placed over the electrodes, and the position was traced in relation to anatomic landmarks.

Treatments. After EMG electrode placement, participants completed a 5-minute submaximal warm-up on a cycle ergometer (Monark 824 Ergomedic, Varberg, Sweden), cycling between 70 and 75 rpm with a resistance of 1 kg to increase muscle temperature. After the cycling warm-up, each participant immediately performed 1 of the 3 conditions: NS, SS, or DS.

In the NS condition, each participant performed 3 maximal VJs (see VJ procedure) at 2 minutes (± 1 minute) after the cycling warm-up.

For the SS condition, immediately after the warm-up, each participant assumed a supine position on a ground mat, and the experimenter began the assisted SS as recommended by Yamaguchi and Ishii (36). The stretches were performed in the following order: plantar flexors, hip extensors, hamstrings, hip flexors, and quadriceps femoris. Each stretch was held in a position at which the participant verbally indicated that he had stretched the muscle to a point of mild discomfort, to stretch the muscle tendon system to a maximal point without causing the subject pain (10). Each stretch was performed once on each limb and was held for 30 seconds, in line with current recommendations on stretch frequency and duration (4,28). There was a 10- to 15-second rest period between each stretch so that the participant could change position. The total SS time was 7 ± 1 minutes. After SS, there was a 2-minute (± 1 minute) period before the participant performed the VJ procedure.

For the DS condition, immediately after the warm-up, each participant assumed a standing upright position and began to perform the DS exercises under the verbal guidance of the experimenter. The exercises were demonstrated to the participant, who received verbal feedback while performing each DS. The exercises were performed in the following order: plantar flexors, hip extensors, hamstrings, hip flexors, and quadriceps femoris (36). Each participant intentionally contracted the antagonist of the target muscle and performed the dynamic movement every 2 seconds under the verbal count of the experimenter. Each exercise was performed 5 times slowly and then 10 times as quickly as possible without bouncing (36). The procedure was performed on the right leg and then the left leg. The same 10- to 15-second rest period was taken between exercises as in the SS protocol. Total DS time was 7 ± 1 minutes. After DS, there was a 2-minute (± 1 minute) period before the participant performed the VJ procedure.

In the VJ procedure, a contact mat system (Power Timer 1.0, Newtest Ltd, Kiviharjuntie, Finland) was used to measure jump height (cm) and flight time (milliseconds). Each condition began with the participant performing 1 practice jump so that the investigator could verify that the participant was jumping with the appropriate technique, and to ensure the EMG data were being recorded correctly. Each participant stood in the middle of the contact mat with his hands on his hips and his feet shoulder width apart. Each

subject then moved into the jumping position by flexing his knees until he reached a position at which he felt most comfortable, in order to jump as high as possible. The participant remained in this position for 2 seconds to ensure that there was no eccentric movement before jumping that may have initiated a stretch-shortening cycle. After a 2-second period in the lowered position, the experimenter gave a verbal command to the participant to perform the VJ. The participant left the mat with the knee and ankle at full extension and landed in a similar position. A 20-second recovery period followed before the next VJ to allow time for recovery. The mean of the 3 jumps was used to calculate VJ height for each condition (26,34); a coefficient of variation of <3% for VJ performance has been established previously (26).

The EMG data were recorded from the exact point at which each participant began the concentric phase of the jump from the contact mat until the participant landed during each VJ. The contact mat system calculated the flight time (milliseconds) during each VJ, and the EMG data were analyzed by placing a cursor from the marked concentric phase for the duration of the VJ jump (calculated from flight time).

Statistical Analyses

The data were screened for normality. The RMS surface EMG and jump height results were analyzed using a repeated-measures analysis of variance. A Bonferroni post hoc test was applied to assess the difference between the baseline and post-NS, post-SS, and post-DS values. Values of $p \leq 0.05$ were considered statistically significant. Data are presented as mean $\pm$ SD and expressed both as percentages of change from baseline and as absolute values.

RESULTS

Vertical Jump Performance

There was a significant difference in jump performance between conditions ($F = 25.68$, $p < 0.001$, $\eta_p^2 = 0.85$), demonstrating that 85% of the overall variance in the jumping performance was attributed to the stretching conditions. Post hoc analysis revealed significant differences between the 3 conditions. There was a significant (4.2%) reduction in VJ height in the SS condition compared with the NS condition (CI = -0.033 to -2.33 , $p < 0.05$). There also was a significant (4.9%) reduction in VJ height in the NS compared with the DS (CI = 2.66 – 0.64 , $p < 0.05$). The largest decrease in VJ height

occurred between SS and DS, where VJ performance decreased by 9.44% (CI = 1.60 – 3.52 , $p < 0.001$) (Figure 1).

Vastus Medialis Electromyography

There was one significant difference in EMG data between conditions ($F = 6.15$, $p < 0.05$, $\eta_p^2 = 0.67$). The significant difference occurred between the SS and DS conditions (CI = -0.94 to -0.09 , $p < 0.05$). The EMG activity decreased by 38.1% between NS and DS; however, this was not statistically significant ($p > 0.05$), nor was the 14.4% increase in EMG activity between NS and DS ($p > 0.05$). However, there was a significant 85% ($p < 0.05$) increase in EMG activity between SS and DS (Figure 2).

DISCUSSION

The present study demonstrated that VJ performance was significantly reduced after SS compared with NS and DS. Furthermore, a significant improvement in VJ performance resulted after DS compared with SS. Results from the EMG analysis indicated that SS did not cause a significant reduction in EMG activity. However, there was a significant increase in EMG activity after DS compared with SS, indicating an increased neuromuscular response to the DS (Figure 2).

The significant decrease in VJ performance (-4.2%) supports the findings of a recent study in which a significant impairment in VJ performance was observed after SS across drop, squat, and countermovement jumps (6). Collectively, these data add to a growing body of evidence demonstrating decrements in VJ performance after SS (8,9,30,33). The present study found that VJ performance significantly improved after DS compared with NS ($4.9 \pm 5.00\%$) and, more notably, compared with SS ($9.4 \pm 4.25\%$). The finding that DS improved VJ performance coincides with previous research that has reported improvements in muscular performance in leg extension power (36), 50-m sprint time (12), and agility performance (23) after DS. In contrast,

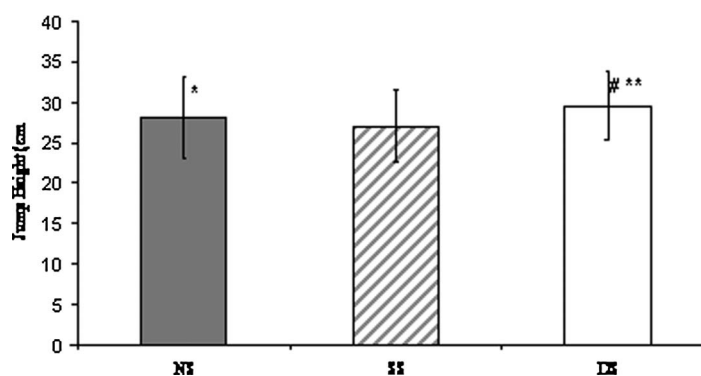


Figure 1. Mean $\pm$ SD changes in vertical jump performance (cm) after 3 stretching protocols ($n = 11$). *Significant difference between NS and SS ($p < 0.05$); #significant difference between NS and DS ($p < 0.05$); **significant difference between SS and DS ($p < 0.001$). NS = no stretching; SS = static stretching; DS = dynamic stretching.

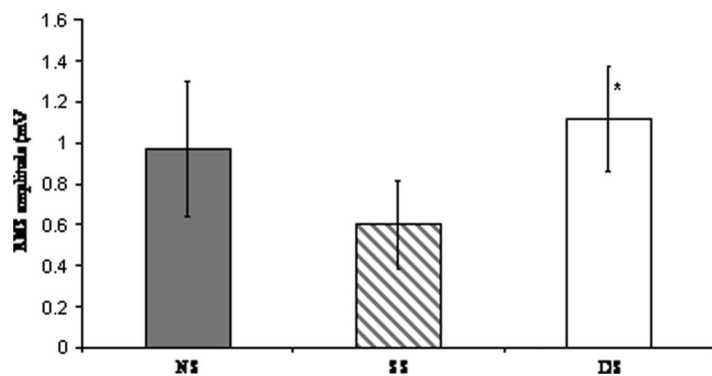


Figure 2. Mean $\pm$ SD changes in vastus medialis root mean square electromyographic data (mV) after 3 stretching protocols ($n = 8$). *Significant difference between SS and DS ($p < 0.05$). NS = no stretching; SS = static stretching; DS = dynamic stretching.

a recent study by Wallmann et al. (34) has reported no significant difference in VJ height after DS. However, the present study differed from this study in that DS was combined with SS, leading the authors to suggest that the SS may have negated any potential effects of the DS. Furthermore, only the gastrocnemius muscle was stretched, whereas a typical sports warm-up usually involves a number of stretching exercises (2,28).

Although there is a growing body of evidence advocating the use of DS, authors have often speculated as to the potential mechanisms for their observations. Some have attributed the increases in performance to increased neuromuscular activity, although this has not been demonstrated in VJ performance (7,36). In this investigation, EMG activity was significantly greater after DS compared with SS, indicating an increase in muscle activation post DS. This finding may provide a mechanistic basis for the increase in performance after DS.

There was a large, nonsignificant decrement (38.1%) in EMG activity after SS compared with NS. Although the decrement in EMG after SS was not significant, it is possible that the SS may have caused some neurological impairment resulting in decreased muscle activation. This suggestion is supported by previous research in which a significant reductions in EMG activity of the quadriceps (25) and triceps surae (9) have been reported after SS. Fowles et al. (14) discussed a number of factors that may cause such a decrease in muscle activation, including the Golgi tendon reflex, the mechanoreceptor (type III afferent), and the nociceptor pain feedback (type IV afferent) responses. However, not all of these proposed mechanisms may be applicable to the present study.

In the present study, nociceptor feedback responses are unlikely candidates to have caused neurological impairment, because the subjects did not stretch to the point of pain. However, activation of the Golgi tendon organs (GTOs) requires an intense stretch (3,21), and it is feasible that the

assisted SS may have been intense enough to activate the GTOs. Had the GTOs been activated, this would have resulted in reciprocal inhibition, causing decrements in the excitability of the motor neurons innervating the antagonist muscle, thereby causing autogenic inhibition (3). The increased relaxation in the muscle that was under tension would limit its force-generating capabilities.

It is also possible that the SS may have caused an increase in the viscoelastic properties of the muscular tendon unit (MTU) after stretching, which

has been hypothesized to alter the force-relaxation properties within a muscle (9,10,14), thereby reducing its force-generating capacity. In addition, decrements in VJ performance after SS may have been attributable to decreases in the rigidity of the MTU. Several authors have suggested that reductions in stiffness of the MTU after stretching may be responsible for reductions in muscular strength (22) and force (31). Wilson et al. (35) hypothesized that a stiffer MTU enhances force production by improving the length-tension and force-velocity relationships of the MTU. The present study used 5×30 -second SS on each leg in line with recommendations on stretch durations (4,28), and it seems feasible that MTU stiffness may have decreased in response to increases in the length of the muscle fascicles. Had the muscle fascicles increased in length, this would have placed the fascicles in a reduced optimal position of the length-tension curve, thereby reducing their ability to generate force and causing subsequent decrements in VJ performance.

The increase in EMG after DS suggests that neuromuscular mechanisms were also responsible for the subsequent increased VJ performance. A brief period of activity has been shown to induce acute changes that enhance neuromuscular function in terms of mechanical and electrical output (7). During the DS, the participants were asked to perform 5 slow maximal contractions and 5 rapid maximal contractions on each exercise. Previous research has demonstrated that after 20 maximal muscular contractions, neuromuscular propagation is increased (represented by a 24% increase in M-wave amplitude) (20). In the present study, the increased EMG activity may represent an increase in the number of active neurons per motor units recruited to facilitate motor unit activation through neuromuscular propagation after DS. In addition, the muscular activity involved in the DS exercises in the present study may have induced postactivation potentiation (PAP), which is known to be enhanced through performance of maximum voluntary contractions of the

target muscle (17). The mechanisms responsible for PAP include increased phosphorylation of myosin regulatory light chains (27) and increased Ca^{2+} release from the sarcoplasmic reticulum (1,29), causing increases in muscular force.

In the present study, a VJ was performed 2 minutes (± 1 minute) after the SS and DS; it is possible that this short period between the conditions and the VJ may have highlighted any changes in the mechanical and/or neurological properties of the muscles, thereby illustrating a greater change in VJ performance. If there had been a longer period between the treatments and conditions, any physiological changes may have been diminished. A recent study (32) found no significant differences in upper-body muscular performance after NS, SS, and DS. The authors propose that the 5-minute rest period between the exercises may have allowed any SS-induced changes to dissipate (32). This finding suggests that the time between stretching and performance may be an important issue when measuring physiological and performance responses after SS and DS, and it warrants further research.

PRACTICAL APPLICATIONS

In light of the present study's findings and those of previous research, it is apparent that SS with holds lasting more than 25 seconds should not be performed before performing activities requiring strength (9,14,22) and/or powerful muscular contractions (5,8,9,38). Instead, warm-ups should focus on some form of aerobic activity to induce favorable responses such as increases in core and muscular temperature, elevated heart rate, and increased baseline $\dot{V}\text{O}_2$ (7). Research suggests that, in conjunction with an aerobic warm-up, it is advantageous for athletes to incorporate DS into a warm-up routine to improve performance (12,13,23,36). The results of the present study are consistent with this notion, because it was found that VJ performance significantly improved after DS compared with SS and NS. In the present study, an increase in VJ performance coincided with an increase in neuromuscular activation of the vastus medialis. The finding that DS seems to enhance neuromuscular drive presents a physiological mechanism for improvements in athletic performance after DS.

Because the present study has demonstrated significant improvements in neuromuscular activation and VJ performance after DS, athletes involved in sports requiring powerful lower-extremity muscular contractions may find DS to be a more effective warm-up technique than SS and NS. However, it is unknown how long the favorable neuromuscular responses of DS may last, and therefore athletes and coaches should endeavor to perform DS exercises as close to competition as possible.

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