Acute Effects of Static Stretching, Proprioceptive Neuromuscular Facilitation Stretching, and Maximum Voluntary Contractions on Explosive Force Production and Jumping Performance

Warren Young and Simon Elliott

Key words: warm-up, muscular power, stretch-shortening cycle

Warm-up prior to physical activity is a well accepted practice believed to reduce the risk of injury and enhance performance (McArdle, Katch, & Katch, 1991; Safran, Seaber, & Garrett, 1989). Various stretching techniques are commonly included in a warm-up to reduce muscle stiffness and increase the range of motion (ROM) at joints. Stanley and McNair (1996) compared the effects of running, static stretching, and combined running and stretching on muscle stiffness and ROM. While the combination of running and stretching were most effective for increasing ankle ROM, stretching added nothing to running to decrease musculotendinous (MTEN) stiffness. Although stretching is generally effective for inducing acute and chronic changes in ROM (Alter, 1996; Wienmann & Hahn 1997; Wiktorsson-Moller, Oberg, Ekstrand, & Gillquist, 1983), its effects on MTEN stiffness and the optimum stiffness for physical performance are not so clear (Wilson, 1991).

Eight weeks of static stretching training of the pectoral muscle group has been shown to result in a 7.2% decrease in MTEN stiffness, as measured by an oscillation technique (Wilson, Elliott, & Wood, 1992). This was accompanied by a significant increase in bench press performance when this exercise was performed using a stretch-shortening cycle (SSC) but not when executed with pure concentric muscle actions. The authors suggested that the increased MTEN compliance was favorable for storage and release of elastic energy during the SSC performance. Wilson, Wood, and Elliott (1991) reported a significant negative correlation between MTEN stiffness and the augmentation derived from prior stretch in the SSC bench press. However, a positive correlation has been reported for MTEN stiffness and isometric and concentric muscle actions in a bench press-type activity (Wilson et al., 1994). Tests of the lower body musculature have also shown MTEN stiffness to correlate negatively with SSC performance (Walsh & Wilson, 1997; Walsh, Wilson, & Murphy, 1996) and positively with isometric and concentric muscle performance (Walsh et al., 1996). Collectively, these findings indicate that a lower MTEN stiffness is advantageous for SSC muscle performance but disadvantageous for isometric and concentric performance. Consequently, it could be speculated that any warm-up protocol, such as stretching, that induces an acute reduction in MTEN stiffness would enhance SSC performance but negatively affect isometric and concentric performance. While compliance rather than stiffness seems to be important for SSC performance, Wilson (1991) acknowledged that during a relatively short SSC activity, such as the ground contact phase in sprinting, a relatively stiff MTEN unit might be needed to ensure minimal delay between muscle stretching and shortening.

Static stretching has been shown to significantly reduce leg strength (Davies, Finlay, Hilly, & Purdam, 1992; Kokkonen, Nelson, & Cornwell, 1998), as well as jump height and peak force in static and countermovement
jumps (Nelson et al., 1996). Fowles and Sale (1997) showed that 30 min of passive stretching induced a significant reduction in strength and motor unit activation 5 min poststretch, and a 9% reduction in strength was still significant at 60 min. These findings suggest that a neural inhibition was induced by the stretching and are consistent with the notion of an inverse myotatic reflex, whereby a sustained stretch is thought to stimulate golgi tendon organ discharge (Alter, 1996; Thigpen, Moritani, Thiebaud, & Hargis, 1985). The above research indicates that stretching has the potential to influence MTEN stiffness as well as neural mechanisms that might either positively or negatively affect neuromuscular performance, depending on the nature of the activity.

Another strategy used by athletes in a pre-event warm-up is the performance of high-intensity contractions to increase motor unit excitability and enhance force production (Gullich & Schmid, 1996). The performance of maximum voluntary contractions (MVC) or heavy load resistance exercises has been shown to augment neural output in humans (Gullich & Schmid, 1996; Trimble & Harp, 1998; Vandervoort, Quinlan, & McComas, 1983) and is interpreted as a postactivation potentiation (Hirst, Redman, & Wong, 1981; Lev-Tov, Pinter, & Burke, 1983; Luscher, Ruenzel, & Hemmen, 1983). Significant gains in vertical jumping performance have been reported following static (Gullich & Schmid, 1996) and dynamic muscle actions (Young, Jenner, & Griffiths, 1998). The research of Gullich and Schmid (1996) was notable, because the acute enhancement of jumping performance was associated with neural potentiation for 4–11 min post-MVC, as measured by increased H-reflex amplitude.

In summary, the acute effects of stretching and high-intensity contractions on muscle performance can be significant, although the parameters associated which these effects have not been fully explored. Therefore, the purpose of the present research was to compare the acute effects of two stretching protocols and isometric MVC on explosive force production and jumping performance.

**General Study Design**

All participants completed four different warm-up conditions, performed on different days 2–4 days apart, in a counterbalanced order. Each session involved a 5-min jog warm-up, followed by one of the following conditions: static stretching, proprioceptive neuromuscular facilitation (PNF) stretching, MVC, or a control condition. A 4-min rest period was administered, which consisted of slow walking to minimize any reduction in body temperature. The participants then performed two vertical jumping tests as measures of lower body explosive force production and jumping performance (see Figure 1).

**Warm-up Treatments**

A 5-min jog warm-up preceded each treatment, because this act is typically performed prior to stretching or more vigorous warm-up activities. The participants were instructed to "jog at a comfortable speed," which was observed to be a relatively consistent pace. This low-intensity running was intended to produce an increase in core body temperature, although this was not measured. The treatments were performed on three muscle groups: the triceps surae, gluteals, and the quadriceps in that order, because they are involved in jumping activities. The quadriceps were treated last because of their relative importance in vertical jumping (Jovic, Ristanovic, & Corcos, 1989). The left leg muscle groups were always treated before the corresponding right leg muscle group. Accordingly, the treatment by muscle group was: left triceps surae, right triceps surae, left gluteal, right gluteal, left quadriceps, right quadriceps.

To minimize any effect of joint angle position, an attempt was made to administer the treatment in a standardized position for each condition. The triceps surae treatments were performed while participants were seated against a padded wall with their legs outstretched to adopt a 180° knee angle (see Figure 2).

The gluteals treatments were administered with the participant lying supine on a mat, with the ankle of the leg being treated crossed over the opposite, outstretched leg. The participant was asked to take the ankle as far up the opposing leg as possible toward the hip to emphasize gluteal involvement. The procedures then involved a force applied by the researcher to the flexed knee in the direction of the opposite shoulder.

The position for quadriceps treatment required the participant to rest the target knee on the ground, with the body in an upright position facing a wall and the arms outstretched. The participant was instructed to maintain a flat back and resist anterior tilting of the pelvis so that the rectus femoris muscle would be stretched. The tester then applied a force to the ankle of the leg to be treated to facilitate the stretch or provide resistance. If necessary, the knee was brought back further from the wall to ensure the treatment was adequate and the stretch was felt at the mid-to-end-range of motion of the knee (see Figure 3).

**Method**

**Participants**

Fourteen male participants (Mage = 22 years, SD = 3; M height = 183 cm, SD = 6; and M body mass = 82.1 kg, SD = 6.4) participated in this study. The participants provided informed consent after the study was approved by the Human Research Ethics Committee of the University of Ballarat. Participants were required to have a minimum of one season's experience in a sport requiring jumping to encourage consistent jumping performances. The sports they represented included track and field, various football codes, and field hockey.
**Static Stretching**

For the static stretching treatment, the tester passively stretched the participant until "the point of onset of pain," as indicated by the participant. The stretch was held for 15 s, as adopted by Kokkonen et al. (1998), before a rest interval of 20 s. This was repeated 3 times per muscle group before progressing to the opposite leg.

**PNF Stretching**

The PNF stretches took the form of the "contract-relax" type, involving a maximal isometric contraction against resistance from the tester for 5 s. This was followed by relaxation by the participant, while the tester passively stretched the joint to the "onset of pain" where the participant held the stretch for 15 s. The participant then rested for 20 s before the procedure was repeated, for a total of 3 repetitions. These treatment times for the stretch duration and contraction time were selected such that this PNF condition (5-s contraction, 15-s stretch) was equivalent to the MVC treatment (5-s contraction) plus the static stretch (15 s). This was done to allow comparison between the treatments. These time periods were also similar to the 6-s contraction and 10-s stretch used by Magnusson (1998). In an attempt to control the intensity of the stretching, all stretches were taken to the point of "onset of pain," as subjectively reported by each participant.

**MVC**

The MVC involved a maximal isometric contraction of the target muscle group for a period of 5 s, as used by Gullich and Schmidtbleicher (1996). The tester and a large immovable wooden block for the calves provided resistance for the gluteals and quadricep treatments. The participant pushed as hard as possible against the resistance, then rested for 30 s, before repeating the procedure again for a total of 3 repetitions.

**Control Condition**

For the control condition, the participants were given the standard 4-min rest interval after completing the 5-min jog; then they performed the two jump tests.

**Vertical Jumping Tests**

Two jumping tests were administered to assess different types of leg muscle function.

*Squat Jump.* This test involved jumping with a 10-kg bar on the shoulders, which the participant performed in a modified Smith machine. A force platform (Z4852/C) operating at 1000 Hz (Kistler, Winterthur, Switzerland) measured the force generated by the participant during the take-off phase of the jump. The peak force and the maximum rate of force developed (RFD) over 5-ms
samples during the ascending portion of the curve were recorded as explosive force production variables (Young, Wilson, & Byrne, 1999). The participant held a static squat position at a 100° knee angle, measured by a manual goniometer for a 2-s period, and then jumped for maximum height as fast as possible while extending the legs. In the bottom position, the bar rested on metal stops and was standardized for all treatment conditions. Because the bar could only rise, the jump involved pure concentric actions of the leg muscles.

*Drop Jump.* The participants performed a drop jump (DJ) from a 30-cm high box. The participants were instructed to keep their hands on the hips and step off the box with one leg straight to ensure that the fall commenced from a 30-cm height. They were instructed to jump for maximum height and minimum ground contact time to maximize the height divided by contact time. These instructions have been shown to produce relatively short ground contact times (< 200 ms) and significantly change the nature of the jumping task compared to jumping for height only (Young, Pryor, & Wilson, 1995; Young et al., 1999). The acute effects of stretching and MVC have not been previously assessed with this method of performing the DJ. The jump height and contact times were assessed by a contact mat system (Swift Performance Equipment, Lismore, New South Wales, Australia) as previously described (Young et al., 1999). Three trials that were relatively consistent were administered for each test. The average of these trials was retained as a representative result.

**Data Analysis**

A repeated-measures multiple analysis of variance was performed to determine if significant differences in explosive force production and jumping performance existed between the warm-up protocols and the control condition. Within-participants contrasts were performed to identify the conditions that differed at a .05 level of significance.

**Results**

Means and standard deviations for all conditions are shown in Table 1 and indicate that the only significant difference between conditions was for the DJ test (p = .026). Within-participants contrasts revealed that the static condition produced a significantly lower (p < .05) height/time score than all other conditions, but there were no other differences among the other conditions (see Table 1).

**Discussion**

The major finding of this study was a significant reduction in DJ performance from static stretching during the warm-up (p = .026) compared to the other conditions. However, there were no significant differences for any of the concentric jump variables. Previous research indicated that MTEN compliance is positively related to SSC performance for the upper body musculature (Wilson et al., 1991) and the lower body muscles during jumping (Walshe & Wilson 1997; Walshe et al., 1996). This would suggest that stretching could induce an enhancement of SSC performance. However, no change in SSC perfor-
performance as measured by the difference between countermovement jump height and concentric squat jump height was reported by Nelson, Cornell, and Heise (1996) following static stretching.

In all the above research, SSC performance was assessed with relatively slow movements, such as a bench press or a DJ performed for height. In the present study, the DJ test typically involved ground contact times shorter than 250 ms, which would be expected to involve relatively high eccentric loads (Young et al., 1999). Therefore, a relatively high level of MTEN stiffness might be desirable for the DJ used in the present study for two reasons. First, in a DJ requiring high eccentric loads, a high level of pre-activation of muscles before ground contact (and an associated high level of stiffness) is required to achieve a good rebound performance (Gollhofer & Kyrolainen, 1991; Komi, 1992). Second, a high level of MTEN stiffness would ensure fast transmission of muscular force to the bones, producing good explosive force production. A reduction in eccentric strength as a result of static stretching (Davies et al., 1992) is also consistent with the reduced DJ performance in the present study.

Because concentric muscle performance is positively correlated to MTEN stiffness (Walshe et al. 1996; Wilson, Murphy, & Pryor, 1994), a decrement in squat jump performance might have been expected following the static stretching. All three variables were reduced (2.0–6.1%) compared to the control condition, but the reductions did not reach statistical significance. It is possible that the magnitude of the reductions was "diluted" by a positive effect of the jogging component of the warm-up. The jogging was included, because it is typically used by athletes in the early stages of a warm-up. It could be speculated that in the absence of the 5 min of jogging, the DJ and concentric performances might have been reduced to a greater extent.

The significant reduction in DJ performance and the tendency for decreased explosive force production in the concentric test might be explained in part by an inhibitory neural mechanism, such as an inverse myotatic reflex (Alter 1996; Thigpen et al. 1985). Fowles and Sale (1997) reported a significant decrease in MUA following static stretching, which persisted for 1 hr.

The PNF stretching treatment had no significant effect on concentric performance or stretch-shortening cycle performance in the present study. There has been no previous research on the acute effect of PNF stretching on subsequent strength or power performance. Magnusson (1998) found that a contract-relax PNF stretch did not affect the material properties or reflex contractile activity in muscle differently from a static stretch. It is, therefore, conceivable that PNF stretching acutely decreases MTEN stiffness in a way similar to static stretching. Therefore, it could be postulated that PNF stretching might induce detrimental effects to explosive force production. The present study found that PNF stretching reduced mean DJ performance by 3.2% and mean concentric RFD by 3.3%, compared to the controls; however, these changes were not statistically significant.

The differing effects for static stretching and PNF stretching techniques on the DJ performance suggest somewhat different mechanisms. While PNF techniques might decrease MTEN stiffness, a neurological facilitation might be present from the preceding contraction of the target muscle used in the contract-relax protocol. Moore and Hutton (1980) suggested that a lingering discharge (facilitation) resulted from the contraction phase of the PNF stretch, as opposed to the traditional view that the muscle experiences a relaxation following contraction. If this occurred, the facilitation could counter the effects of a reduced stiffness and might explain the lack of significant effects from the PNF treatment in the present study.

The use of MVC in the warm-up did not significantly influence concentric performance or SSC performance. This is in opposition to the findings of Gullich and Schmidtbleicher (1996), who reported significant gains in MUA and jumping performance in athletes following isometric MVC. Some possible reasons for this discrepancy are offered. First, while the tests involved multiple joint motion using jumping, the present study used single joint

<table>
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<tr>
<th>Table 1. Mean and standard deviation results for both jumping tests for all warm-up conditions</th>
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<td>Static</td>
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<td>Concentric jump Jumplheight (cm)</td>
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<td>Peak force (bw)</td>
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<td>RFD (N/s)</td>
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<td>Drop jump Height/time (cm/s)</td>
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*Static significantly lower (p < .05) than the other three conditions.

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MVC for the warm-up treatment, whereas Gullich and Schmidtbliicher (1996) used a unilateral leg-press position. In the present study, the use of single joint MVC was adopted to approximate the joint positions used in the static and PNF stretches. This procedure attempted to control for the effect of joint angle and muscle length on the effectiveness of the treatments. However, it is likely that the motor unit recruitment pattern differed for single- and multiple-joint actions. Therefore, it is possible that the single-joint MVC employed might not have induced a potentiation due to different MUA patterns. Second, the participants in the present study were not well-trained athletes. It has been shown that the potentiation from high-intensity contractions is greater for individuals who are relatively experienced in strength training (Gullich & Schmidtbliicher 1996; Young et al., 1998). Third, despite encouragement from the investigators, not all participants appeared to give maximum efforts during the MVC or jumping tests.

Conclusions and Practical Implication

The results of this study indicated that static stretching produced a significant decrement in DJ performance and a nonsignificant decrease in concentric explosive muscle performance. The negative acute effect of static stretching was thought to be related to increases in MTEN compliance and an inhibitory neural mechanism, although the mechanisms were not specifically investigated. Stretching with PNF and MVC of the leg extensor muscles had no significant effect on concentric or SSC muscle performance.

These findings suggest that for activities involving relatively short SSC muscle function (e.g., the contact phase of sprinting or jumping from an approach run) static stretching might have a detrimental effect on performance. If the other proposed warm-up benefits of static stretching (e.g., injury prevention) can be achieved by alternative modes, such as PNF or dynamic stretching, these methods might be preferable. Static stretching might remain effective for inducing chronic rather than acute effects in joint range of motion (flexibility) and for warm-up for other activities. Further research is required generally to elucidate optimum warm-up strategies and should take into account different forms of muscle function.

References


**Authors’ Note**

Please address all correspondence concerning this article to Warren Young, School of Human Movement and Sport Sciences, University of Ballarat, P.O. Box 663, Ballarat, Victoria, Australia, 3353.

E-mail: wyoung@ballarat.edu.au