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Research article

FLEXIBILITY IS NOT RELATED TO STRETCH-INDUCED DEFICITS IN FORCE OR POWER

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ABSTRACT
Previous studies have demonstrated that an acute bout of static stretching may cause significant performance impairments. However, there are no studies investigating the effect of prolonged stretch training on stretch-induced decrements. It was hypothesized that individuals exhibiting a greater range of motion (ROM) in the correlation study or those who attained a greater ROM with flexibility training would experience less stretch-induced deficits. A correlation study had 18 participants (25 ± 8.3 years, 1.68 ± 0.93 m, 73.5 ± 14.4 kg) stretch their quadriceps, hamstrings and plantar flexors three times each for 30 s with 30 s recovery. Subjects were tested pre- and post-stretch for ROM, knee extension maximum voluntary isometric contraction (MVIC) force and drop jump measures. A separate training study with 12 subjects (21.9 ± 2.1 years, 1.77 ± 0.11 m 79.8 ± 12.4 kg) involved a four-week, five-days per week, flexibility training programme that involved stretching of the quadriceps, hamstrings and plantar flexors. Pre- and post-training testing included ROM as well as knee extension and flexion MVIC, drop and countermovement jump measures conducted before and after an acute bout of stretching. An acute bout of stretching incurred significant impairments for knee extension (-6.1% to -8.2%; $p < 0.05$) and flexion (-6.6% to -10.7%; $p < 0.05$) MVIC, drop jump contact time (5.4% to 7.4%; $p < 0.01$) and countermovement jump height (-5.5% to -5.7%; $p < 0.01$). The correlation study showed no significant relationship between ROM and stretch-induced deficits. There was also no significant effect of flexibility training on the stretch-induced decrements. It is probable that because the stretches were held to the point of discomfort with all testing, the relative stress on the muscle was similar resulting in similar impairments irrespective of the ROM or tolerance to stretching of the muscle.

KEY WORDS: Flexibility, force, jumps, static stretching.

INTRODUCTION

There have been a number of articles in the recent literature reporting on decreases in isometric force (Behm et al., 2001; Fowles et al., 2000; Kokkonen et al., 1998; Power et al., 2004), one repetition maximum strength (Nelson and Kokkonen, 2001), jump height (Young and Behm, 2003) and muscle activation (Avela et al., 1999; Behm et al., 2001; Fowles et al., 2000; Guissard et al., 1988; 2001; Power et al., 2004) following an acute bout of static stretching. Acute bouts of static stretching to the point of discomfort have also been shown to impair balance, reaction and movement time (Behm et al., 2004). These stretch-induced impairments have been reported to occur as early as 1 min post-stretching

1. Pre-testing for Flexibility Training and Cross-sectional Correlation Study

Pre-stretch Testing
Knee Extension MVIC and Drop Jump measures (Correlation study)
Knee Extension and Flexion MVIC, Drop and Countermovement Jump measures (Training study)

Acute Bout of Stretching
Quadriceps, hamstrings and plantar flexors stretched 3 times each for 30 s with 30 s rest. (Both studies)

Post-stretch Testing
Knee Extension MVIC and Drop Jump measures (Correlation study)
Knee Extension and Flexion MVIC, Drop and Countermovement Jump measures (Training study)

4-Week Flexibility Training Programme
5 days per week for Quadriceps, Hamstrings and Plantar flexors

2. Post-stretch Training Tests for Flexibility Training Study

Pre-stretch Testing
Knee Extension and Flexion MVIC, Drop and Countermovement Jump measures

Acute Bout of Stretching
Quadriceps, hamstrings and plantar flexors stretched 3 times each for 30 s with 30 s rests.

Post-stretch Testing
Knee Extension and Flexion MVIC, Drop and Countermovement Jump measures

Figure 1. Experimental design.

(Behm et al., 2004) continuing for 120 min post-stretching (Power et al., 2004). Explanations for the stretch-induced deficits include increases in muscle compliance that could result in a longer rate of force development (Behm et al., 2001; Fowles et al., 2000). Others have suggested that afferent inhibition, due to the tensile stresses exerted, by placing the muscle under stretch to the point of discomfort for extended periods of time (i.e. 30-60 s), would contribute to the performance decrements (Behm et al., 2001; Fowles et al., 2000; Guissard et al., 1988; 2001). Both explanations suggest that the muscle has been placed under unfamiliar stress that may have led to changes in the muscle and subsequently impacting the excitability of the motor neuron pool.

A decrease in muscle stiffness has been reported following stretch training (Guissard and Duchateau, 2004). In contrast, Magnusson et al. (1996b) reported no significant differences in stiffness, energy or peak torque around the knee joint after three weeks of stretch training. These authors suggested that the increased range of motion (ROM) achieved with training could be a consequence of an increased stretch tolerance. It may be possible that the stretch-induced impairments reported in the literature are a training-specific phenomenon. A more flexible (greater ROM) musculotendinous unit (MTU) or a MTU that is more tolerant of stretch tension might accommodate the stresses associated with an acute bout of stretching more successfully than a stiff MTU. There have been no studies to our knowledge that have examined the relationship between the extent of ROM around a joint (flexibility) and the extent of stretch-induced impairments. Perhaps if an individual possessed a high level of flexibility or tolerance to stretch, then they may be able to better sustain the stress of an acute bout of stretching.

The objective of the study was twofold; to determine a) the relationship between an individual's joint ROM (flexibility) and acute stretching-induced changes and b) whether a four-week flexibility-training programme would reduce stretch-induced impairments.

METHODS

Experimental design

In order to test the hypotheses, two separate experiments were conducted. A cross-sectional correlation study tested 18 subjects for ROM associated with hip flexion, hip extension and plantar flexion-dorsiflexion. Subjects were tested before and following an acute bout of static stretching of the lower limbs for knee extension maximum voluntary isometric contraction (MVIC) force and drop jump performance. A correlation matrix was used to analyze the relationship between the extent of ROM at the various joints and the changes in isometric force and dynamic jump tests before and after the acute bout of stretching (Figure 1).

The second experiment was a longitudinal repeated measures design that had subjects tested for knee extension and flexion MVIC and drop jump performance as well as countermovement vertical jump performance before and following an acute bout of stretching. Twelve subjects participated in a five-day per week, four-week duration, flexibility training programme for the lower limbs. Following the training programme, subjects were again tested before and following an acute bout of stretching. Differences in knee extension and flexion MVIC, drop and countermovement jump performance before and following the acute bout of stretching were compared pre- and post-training to determine if training had diminished stretch-induced impairments (Figure 1).

Participants

A convenience group (9 men and 9 women) (mean ± SD: age; 25 ± 8.3 years, height; 1.68 ± 0.93 m, body mass; 73.5 ± 14.4 kg) participated in the correlation study. Similarly, a second group (12 men) (age; 21.9 ± 2.1 years, height; 1.77 ± 0.11 m, body mass; 79.8 ± 12.4 kg) who were not actively engaged in flexibility training volunteered to partake in the training study. All participants were from the University student population and completed a Physical Activity Readiness Questionnaire (PAR-Q) form (Canadian Society for Exercise Physiology, 2003b) indicating no significant health problems. Each subject was required to read and sign a consent form prior to participating in the study. The University Human Investigations Committee approved both studies.

Dependent variables

All correlation and training study participants warmed up on a cycle ergometer (Monark Ergomedic 828E) for five minutes at a minimum intensity of 70 Watts.

Correlation and training study active flexibility measures: All correlation study participants completed three trials of three active flexibility tests: sit and reach, plantar flexion-dorsiflexion and hip extension tests. Training study participants were tested using three trials of the sit and reach, hip extension and hip flexion tests. The plantar flexion-dorsiflexion test was replaced with the hip flexion test in the training study since the former test had a substantially smaller absolute range of motion making precision measurements more difficult. Since the sit and reach test involves both lower back and hamstring muscles, the hip flexion test which primarily targets the hamstrings was substituted in the training study. All participants were re-tested within 2-3 days of the pre-test to determine the reliability of the tests.

Using a sit and reach testing device (Acuflex I, Novel Products Inc., USA), participants sat on a mat with legs fully extended, and reached forward toward their feet. They held this position for two seconds while the distance was measured in cm (Canadian Society for Exercise Physiology, 2003a; Heyward, 2005). In the plantar flexion-dorsiflexion test, a goniometer was used to measure the ROM. One lever of the goniometer was land marked over the lateral midline of the fibula using the head of the fibula as a reference while the pivot was placed on the lateral aspect of the lateral malleolus. The other lever was positioned on the lateral aspect of the fifth metatarsal bone and its position was used to determine the degrees of movement (Heyward, 2005). Participants attempted to flex and extend their ankles through the greatest ROM possible. When performing the hip extension test, the subject lay prone on the floor and lifted their right leg toward the ceiling without assistance from the researcher. The researcher ensured that their hip (anterior superior iliac spine) maintained contact with the floor and their leg remained straight (knee extended) through out this test. The height of the patella was measured from the floor in cm (Canadian Society for Exercise Physiology, 2003a). With the hip flexion test, participants assumed a supine position and flexed their hip with extended knee as far as possible without assistance from the researcher. A goniometer was used to measure ROM. One lever of the goniometer was land marked on the lateral midline of the pelvis while the pivot was placed on the lateral aspect of the hip joint using the greater trochanter of the femur as a reference. The other lever was positioned on the lateral midline of the femur using the lateral epicondyle as the reference to determine the degrees of movement (Heyward, 2005).

Knee extension and flexion MVIC: Subjects in the correlation study performed three knee extension MVICs and three-drop jumps. In addition to the MVICs and drop jumps, training study participants also were tested with three countermovement vertical jumps and knee flexion MVIC. The series of MVICs and jumps were randomized. A minimum two-minute rest period was provided between each MVIC. For the knee extension MVIC, participants sat on a padded bench with hips and knees flexed at

90^o, their upper leg and hips restrained by two straps. The ankle was inserted into a padded strap at the level of the malleoli, attached by a high-tension wire to a Wheatstone bridge configuration strain gauge (Omega Engineering Inc. LCCA 250). Knee flexion MVIC involved the same set-up except the knee was flexed at 120^o. An angle of 120^o rather than 90^o (for knee extension) was used since it placed the hamstrings in a slightly lengthened position which provided greater hamstrings force output. Forces were recorded from the MVIC with the greatest force output. Forces were detected by the strain gauge, amplified (BioPac Systems Inc. DA 100 and analog to digital converter MP100WSW) and monitored on computer (Sona Phoenix PC). All data were collected on a computer at a sampling rate of 2000 Hz and stored. Data were recorded and analyzed with a commercially designed software programme (AcqKnowledge III, BioPac Systems Inc.).

Drop jumps: The three-drop jumps were interspersed by a minimum one-minute rest period. Drop jumps from a height of 30 cm were performed with the subjects emphasizing the shortest possible contact time and the greatest jump height (Young et al., 1995; 2001). With hands remaining on their hips, participants landed on a contact mat (Kinematic Measurement Systems, Skye SA Australia) imbedded with a timer switch, which was used by the acquisition software (Innervations, Muncie, Indiana) to calculate contact time and jump height. Within individuals, a particular jump may have had the shortest contact time while another jump may have achieved the greatest jump height. Since contact time can affect jump height, the mean of the two-drop jumps with the greatest height were used to analyze jump height and contact time.

Countermovement jumps: While standing on the contact mat participants were asked to perform three countermovement jumps. One-minute rest periods were allocated between each jump. Although, swinging of the arms was permitted and the speed and knee angle depth of the countermovement was self-selected, reliability measures were very high (ICC: 0.95). Since the duration of force application was not important in this test and thus the effect of one variable on the other (contact time affecting jump height) was not of primary importance, the greatest jump height of the three trials was used for analysis.

Independent variables

Correlation and training study intervention

Acute stretching protocol: The order of quadriceps, hamstrings and plantar flexors stretching were randomized. Based on previous research that has recommended 30 s or greater duration of stretching (Bandy et al., 1997; Bandy and Irion, 1994), stretches were held to the threshold of discomfort for a duration of 30 s with 30 s recovery periods between stretches. Each type of stretch was repeated three times. Stretching of both legs included a series of unilateral kneeling knee flexion (quadriceps), supine hip flexion with extended knee (hamstrings), extended leg (knee) dorsiflexion while standing (stretch of the plantar flexors with gastrocnemius emphasis), and flexed knee dorsiflexion while standing (stretch of the plantar flexors with soleus emphasis) (Alter, 1996). Stretching was passive for the quadriceps and hamstrings with the same investigator controlling the change in the ROM and resistance for all subjects. The researcher would extend the limb to the limits of the participant's ROM without incurring injury. In response to feedback from the participants during the individual stretches, the investigator would modify the tension on the muscle to maintain the same level of discomfort. Subjects provided their own resistance for the plantar flexors stretches with the instructions to continue to stretch the muscles to the point of discomfort.

Five minutes following the acute bout of stretching, MVIC and jump testing was conducted in the same manner described above. A 5-minute recovery period was utilized to simulate a sport situation where an individual would not commence their activity or competition immediately after completing their static stretching. Since the duration of the testing was approximately 20 minutes and the tests were randomized, the results would be applicable to any of the activities tested for a period of approximately 25 minutes following the stretching and aerobic warm-up.

Longitudinal study flexibility training programme: Following the pre-training stretching and testing, training subjects participated in a four-week flexibility-training programme. The programme consisted of four stretches repeated five days a week for four weeks. Stretches were the same as the acute bout of stretching, which included a kneeling knee flexion (quadriceps), supine hip flexion with extended knee (hamstrings), and extended and flexed knee dorsiflexion (plantar flexors) (Alter, 1996). Similar to the acute bout of stretching, each participant was assisted with their quadriceps and hamstring stretching by the investigator, who subjectively controlled the ROM and tension and observed the plantar flexor stretches to ensure that maximal stretch (to the point of discomfort) was being reached. The participant continually informed the investigator of any perceived changes in tension during the 30 s stretch. If stretch tension was not at the point of discomfort then the investigator or participant (for the plantar flexors stretches) increased the ROM until initial discomfort was attained again. At the end of four week flexibility training, subjects were required to perform the testing procedures previously described.

Statistical analysis:
Correlation data were analyzed using a Pearson product moment correlation matrix (SPSS statistical software; Version 11.5) to determine the relationship between the dependent (MVIC and drop jump tests) and independent (stretches) variables. A one way repeated measures analysis of variance (ANOVA) was performed to determine if significant differences existed between pre- and post-stretch data (GB Stat Dynamic Microsystems, Silver Spring Maryland USA) in the correlation study.

Whereas, the test measures involving the 12 subjects in the longitudinal training study exhibited a normal distribution (Critical value = 0.84 for $p < 0.05$; values ranged from countermovement jump = 0.86 to leg extension MVC = 0.91) a two way repeated measures ANOVA (2x2) could be used. Main effects or levels included 1) pre- and post-acute bouts of stretching and 2) pre- and post-stretch training. An alpha level of $p < 0.05$ was considered statistically significant. Effect sizes (ES) were also calculated and reported (Cohen, 1988). Reliability of the measures was assessed using an alpha (Cronbach) model intraclass correlation coefficient (ICC) with all subjects.

RESULTS

Correlation study
Flexibility: Although significant correlations existed between plantar flexion-dorsiflexion ROM, hip extension ROM and sit and reach flexibility (Table 1), no significant relationships were seen between initial ROM and stretch-induced performance changes overall or within genders.

Isometric force output: A -6.5% deficit ($p < 0.01$; ES = 0.16) was observed between pre- and post-stretch knee extension MVIC force output (615 ± 248 N *vs*. 575 ± 212 N respectively).

Drop jump: Contact time increased by 5.4% ($p < 0.01$; ES = 0.47) (pre-stretch: 220 ± 26 ms, post-stretch: 233 ± 20.0 ms) between pre- and post-stretch measures. There were no significant changes in drop jump height.

Table 1. Pearson product moment correlations for joint range of motion.

Sit and reach *vs*. ankle plantar flexion - dorsiflexion	.49 *
Sit and reach *vs*. hip extension	.73 *
Ankle plantar flexion - dorsiflexion *vs*. hip extension	.54 *

* $p < 0.05$

Longitudinal training study
Training-induced changes in ROM: There were increases in sit and reach (11.8%) ($p < 0.01$; ES = 0.59), hip extension (19.7%) ($p < 0.01$; ES = 1.87) and hip flexion (13.4%) ($p < 0.01$; ES = 1.47) measures following the four weeks of flexibility training (Table 2).

Table 2. Training-induced changes in joint range of motion. Data are means (±SD).

	Pre-training	**Post-training**
Sit and Reach (cm)	32.1 (6.4)	35.9 (5.4) *
Hip Flexion (°)	83.3 (7.6)	94.5 (6.9) *
Hip Extension (cm)	25.5 (4.8)	34.5 (5.6) *

* $p < 0.01$

Stretch-induced deficits: Prior to the flexibility training programme, the acute bout of stretching elicited significant impairments of -8.2% in knee extension MVIC force (Figure 2; $p < 0.05$; ES = 0.6), -6.6% in knee flexion MVIC force (Figure 3; $p < 0.05$; ES = 0.39), 7.4% (pre-stretch: 198 ± 27 ms, post-stretch: 184 ± 27 ms), in drop jump contact time ($p < 0.05$; ES = 0.54) and -5.7% (pre-stretch: 34.6 ± 6.6 cm, post-stretch: 32.6 ± 7.1cm) in countermovement jump height ($p < 0.01$; ES = 0.3). There were no significant ($p = 0.6$) changes in drop jump height (pre-stretch: 25 ± 8 cm, post-stretch: 27 ± 8 cm).

Following the flexibility training programme, the acute bout of stretching produced significant impairments of -6.1% for knee extension MVIC force (Figure 2; $p < 0.02$; ES = 0.63), -10.7% for knee flexion MVIC force (Figure 3; $p < 0.01$; ES = 0.57) and -5.5% (pre-stretch: 35.9 ± 7.1 cm, post-stretch: 33.9 ± 5.8 cm) for countermovement jump height ($p < 0.01$; ES = 0.34). There was a non-significant increase of 2.6% (pre-stretch: 198 ± 27

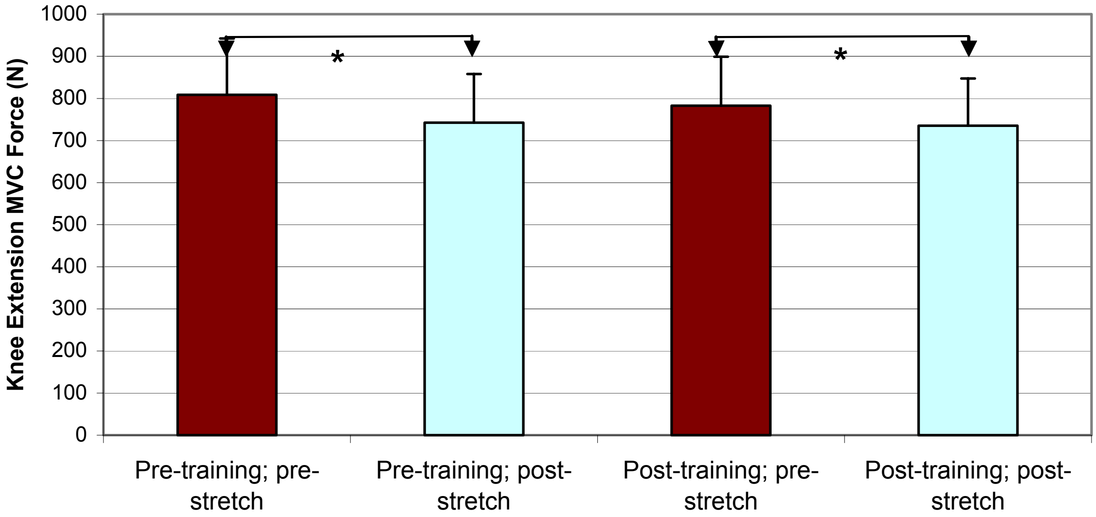

Figure 2. Changes in knee extension maximal voluntary isometric force (MVIC) before and following an acute bout of static stretching to the point of discomfort. Asterisks indicate significant differences in stretch-induced MVIC force prior to and after a four-week stretch training programme. Bars represent means of the group while vertical lines indicate standard deviation.

ms, post-stretch: 202 ± 31 ms) for drop jump contact time, with no appreciable change in drop jump height (pre-stretch: 25 ± 8 cm, post-stretch: 25 ± 7 cm).

Effect of Flexibility Training: A comparison of the pre- to post-stretch-induced changes before and following the flexibility-training programme revealed no significant effect for training.

Reliability

Reliability measures using ICC for MVIC force, drop jump contact time, drop jump height and countermovement height indicated correlations of 0.75, 0.90, 0.98 and 0.95 respectively. Flexibility reliability measures for the sit and reach test, hip flexion, hip extension and plantar flexion - dorsiflexion tests were 0.92, 0.96, 0.84 and 0.90 respectively

DISCUSSION

The most significant findings in this study were that an individual's initial level of joint ROM was not correlated with stretch-induced deficits and secondly, that four weeks of flexibility training did not diminish stretch-induced impairments. While there have been many studies demonstrating decreases in isometric force (Behm et al., 2001; Fowles et al., 2000; Kokkonen et al., 1998; Power et al., 2004), dynamic strength (Nelson and Kokkonen, 2001), and jump height (Young and Behm, 2003) following an acute bout of static stretching, there have been no studies reporting on the effect of greater joint ROM or flexibility training on stretch-induced impairments. Klinge et al. (1997) reported that the addition of flexibility exercises to a 13-week strength-training programme had no significant effect on the strength training responses. Wilson et al. (1992) found that the rebound bench press of powerlifters was enhanced following eight weeks of flexibility training due to an increased utilization of elastic strain energy during the lift. While Hunter and Marshall (2002) demonstrated increases in countermovement jumps with 10 weeks of flexibility training, Guissard and Duchateau (1988) showed no change in MVIC torque or rate of torque development following 30 sessions of static stretching. However, none of the aforementioned studies involved an acute bout of stretching immediately prior to the post-training measures.

It could be hypothesized that the repeated bouts of stretching associated with a flexibility-training programme would reduce impairments associated with a subsequent acute bout of static stretching. A more flexible musculotendinous unit (MTU) or a MTU that is more tolerant of stretch tension might accommodate the stresses associated with an acute bout of stretching more successfully than a stiff MTU. This was not the case in the present study. Since the stretching instructions were to stretch to the point of discomfort for both pre- and post-training, the intensity of stretching was relative to the stretch tolerance of the MTU. Whether an individual's ROM was greater prior to training (correlation study) or became greater with training, the more flexible MTU would have been elongated to a greater extent during the acute bout of stretching than a less flexible MTU. Thus, irrespective of the

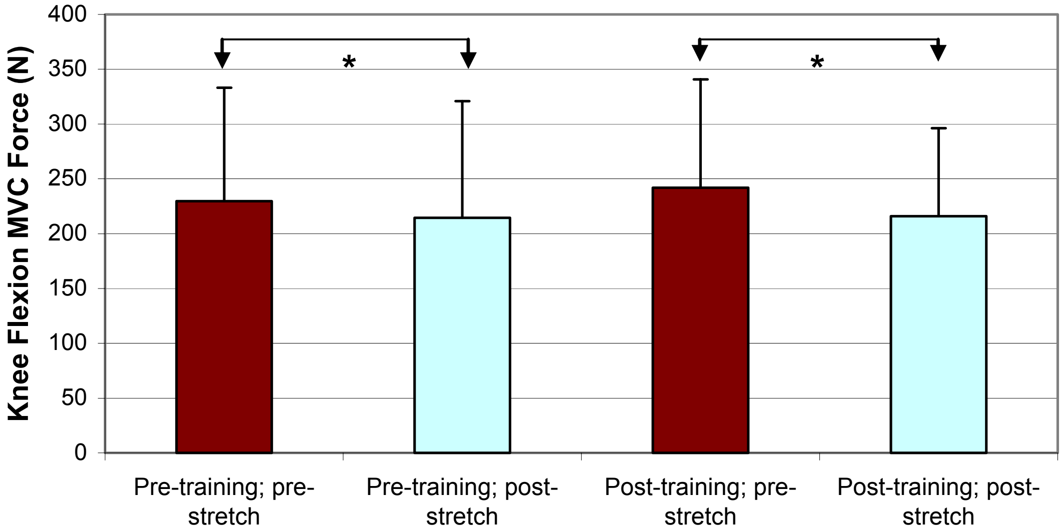

Figure 3: Changes in knee flexion maximal voluntary isometric force (MVIC) before and following an acute bout of static stretching to the point of discomfort. Asterisks indicate significant differences in stretch-induced MVIC force prior to and after a four-week stretch training programme. Bars represent means of the group while vertical lines indicate standard deviation.

absolute change in ROM, it seems that the relative stretch-induced stress placed on the MTU leads to similar impairments. Although it was not incorporated in the present study, it is conceivable that if the absolute change in ROM used in the pre-training stretch intervention was matched post-training, the relatively less stress (smaller ROM) placed on the more flexible MTU would have resulted in less impairment.

The decrements associated with the acute bouts of stretching both before and after the flexibility training programme reflect similar stretch-induced decreases in force (Behm et al., 2001; Fowles et al., 2000; Fowles and Sale, 1997), and power (Young and Behm, 2003) reported in other published studies. An acute bout of stretching has been reported to alter the length and stiffness of the affected limb MTU. Although the exact mechanisms responsible for increases in ROM following stretching are debatable, the increase has been attributed to decreased MTU stiffness (Wilson et al., 1991; 1992) as well as increased tolerance to stretch (Magnusson et al., 1996b). Studies have reported both decreases (Magnusson et al., 1996a; Toft et al., 1989) and no change (Magnusson et al., 2000) in MTU passive resistance or stiffness with an acute bout of stretching. Changes in MTU stiffness might be expected to impact the transmission of forces, the rate of force transmission and the rate at which changes in muscle length or tension are detected. A slacker parallel and series elastic component could increase the electromechanical delay by slowing the period between myofilament crossbridge kinetics and the exertion of tension by the MTU on the skeletal system. A lengthened muscle due to an acute bout of stretching could have a less than optimal cross-bridge overlap which, according to the length tension relationship (Rassier et al., 1999), could diminish muscle force output. The elongation of tendinous tissues can also have an effect on force output (Kawakami et al., 2002).

Another possibility is that stretch-induced stress could have a detrimental effect of on neuromuscular activation (Avela et al., 1999; Behm et al., 2001, Power et al., 2004). Avela et al. (1999) investigated the effects of passive stretching of the triceps surae muscle on reflex sensitivity. Following one hour of stretching there were significant decreases in MVC (23.2%), EMG (19.9%), stretch reflex peak-to-peak amplitude (84.8%), and the ratio of H-reflex to muscle compound action potential (M-wave) (43.8%). Although neural propagation seemed unaffected (M-wave), afferent excitation of the motoneuron pool (H-reflex) was impaired. Although, Guissard et al. (2001) reported decreases in H-reflex excitability during passive stretching, the decrement was limited to the duration of stretching. Avela et al. (1999) suggested that the decrease in the excitation of the motoneuron pool resulted from a reduction in excitatory drive from the Ia afferents onto the α-motoneurons, possibly due to decreased resting discharge of the muscle spindles via increased compliance of the MTU. Nonetheless, whether stretch-induced impairments arise from changes in muscle compliance solely or in concert with the afferent inhibition of the motoneuron, an increased ROM in the present study did not ameliorate the stretch-induced deficits.

There were significant increases in active ROM associated with the flexibility-training programme (sit and reach: 11.8%, $p < 0.01$; hip extension: 19.7%, $p < 0.01$ and hip flexion: 13.4%; $p < 0.01$). While the present study incorporated 20 sessions of stretching, others have reported statistically significant increases in ROM with only 12 stretches over a 4-week period (Davis et al., 2005). Since active stretches are limited by the strength of the opposing muscle groups, the increases in ROM may not be identical to passive flexibility measurements. However considering that activities of daily living almost never involve passive ROM, the active flexibility measures should better reflect daily realities.

Not all power measures demonstrated stretch-induced decrements. While the countermovement jump height was diminished by an acute bout of stretching, drop jump height was not significantly affected. Both types of jumps were included in the flexibility training study since the 30 cm drop jumps emphasized a short contact time (typically under 200 ms) whereas the countermovement jump typically had a greater duration (could not be directly measured in the present study) of the stretch-shortening cycle. It was felt that the short contact time drop jumps would mimic actions such as sprinting whereas the countermovement jump would be more typical of power movements such as shot put, basketball jumps, skating and other activities involving force exerted over a longer duration. Deficits with countermovement jumps demonstrated that static stretching held to the point of discomfort would adversely affect the aforementioned type activities. A lack of change in drop jump height could be attributed to the significant stretch-induced increase in drop jump contact time (pre-training: 5.4% and post-training: 7.4%). Increases in drop jump contact time post- acute stretching would allow for a greater impulse (force x time) to be exerted possibly permitting stretch-induced diminished forces (as exemplified by the decreased MVIC and countermovement jump) to be exerted over a longer duration.

The modest number of participants and the use of only men might hamper the implications and applications of the longitudinal study. Nonetheless, the participation of men only should not significantly affect the external validity of the findings, as the stretch-induced deficits in force with the cross-sectional study (men and women) were very similar to the training study (men) and other comparable studies (Behm et al., 2001; 2004; Fowles et al., 2000; Power et al., 2004). Furthermore, since the data was normally distributed and most effect sizes were moderate, an argument can be made for the assumption of external validity.

CONCLUSIONS

An acute bout of stretching to the point of discomfort resulted in impairments in MVIC force, countermovement jump height, and drop jump contact time. There were no significant correlations between the ROM around a joint and the extent of stretch-induced force and power deficits. Furthermore, four weeks of flexibility training did not influence the magnitude of stretch-induced impairments. Thus, if individuals hold stretches to the point of personal discomfort, the relative stress will be similar with flexible or inflexible muscles. Further studies should also examine the effectiveness of varying intensities of stretch on changes in ROM.

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KEY POINTS

- A correlation and training study were used to examine the effects of increased range of motion on stretch-induced changes in force and jump measures
- An acute bout of stretching incurred significant impairments for knee extension and flexion MVIC, drop jump contact time and countermovement jump height.
- Neither study showed any significant relationship between ROM and stretch-induced deficits.

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