Effect of Acute Static Stretching on Force, Balance, Reaction Time, and Movement Time

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ABSTRACT

BEHM, D. G., A. BAMBURY, F. CAHILL, and K. POWER. Effect of Acute Static Stretching on Force, Balance, Reaction Time, and Movement Time. *Med. Sci. Sports Exerc.*, Vol. 36, No. 8, pp. 1397–1402, 2004. **Purpose:** The purpose of the study was to investigate the effect of an acute bout of lower limb static stretching on balance, proprioception, reaction, and movement time. **Methods:** Sixteen subjects were tested before and after both a static stretching of the quadriceps, hamstrings, and plantar flexors or a similar duration control condition. The stretching protocol involved a 5-min cycle warm-up followed by three stretches to the point of discomfort of 45 s each with 15-s rest periods for each muscle group. Measurements included maximal voluntary isometric contraction (MVC) force of the leg extensors, static balance using a computerized wobble board, reaction and movement time of the dominant lower limb, and the ability to match 30% and 50% MVC forces with and without visual feedback. **Results:** There were no significant differences in the decrease in MVC between the stretch and control conditions or in the ability to match submaximal forces. However, there was a significant ($P < 0.009$) decrease in balance scores with the stretch (↓ 9.2%) compared with the control (↑ 17.3%) condition. Similarly, decreases in reaction (5.8%) and movement (5.7%) time with the control condition differed significantly ($P < 0.01$) from the stretch-induced increases of 4.0% and 1.9%, respectively. **Conclusion:** In conclusion, it appears that an acute bout of stretching impaired the warm-up effect achieved under control conditions with balance and reaction/movement time. **Key Words:** STABILITY, ISOMETRIC FORCE, PROPRIOCEPTION, FLEXIBILITY

Stretching is commonly utilized to increase the range of motion (ROM) around the joint (12,19) and theorized to improve athletic performance (28). With the exception of an increased ROM, recent studies have not found substantial evidence to support the use of stretching for improved performance. A number of studies report that acute and prolonged stretching may actually reduce human performance through decreases in force (4,14,15) and power (11,40).

The stretch-induced decreases in force and power have been attributed to impairments in neural output (2,4,13) as well as changes to the musculo-tendinous unit (MTU) (13,34). Fowles et al. (13) demonstrated an increase in fascicle length of the soleus and lateral gastrocnemius of a single subject with 30 min of stretching. Studies have reported both decreases (24,35) and no change (23) in MTU passive resistance or stiffness with stretching. MTU stiffness incorporates the muscle, tendon, and other associated connective tissue and can determine the effectiveness and rapidity by which internal forces generated by the muscle are transmitted to the skeletal system (38). Among the functions of the intrafusal (includes stretch receptors) muscle fibers, Golgi tendon organs and other proprioceptors is to aid in the maintenance of balance (26) and detection of the position of the body in space (proprioception) (8,10). Acute changes in MTU length, stiffness, force output, and muscle activation could alter the ability to detect (afferent proprioception) and respond (efferent muscle activation) to changes in the immediate environment. Stretch-induced impairments might affect overall balance and stability or limb proprioception. Furthermore, a more compliant MTU (greater muscle and connective tissue slack) in conjunction with a disturbed activation of the muscle could alter reaction (RT) and movement (MT) times. There have been no studies reporting on the effects of an acute bout of stretching on balance, proprioception or reaction/movement time.

Balance involves the interaction of automatic postural and voluntary motor commands of both the trunk and limb musculature (6,30). Automatic postural responses are modulated by both trunk and leg inputs (5), with the central nervous system (CNS) performing anticipatory postural adjustments when expecting self-inflicted postural perturbations (1). Because under conditions of high instability the CNS may suppress anticipatory postural adjustments, voluntary responses of trunk and limb muscles to postural challenges would play a prominent role. Stretch-induced changes to either the afferent limb muscle responses (proprioception) or the mechanical output would be expected to affect the ability to adapt effectively to stability challenges.

At the elite sport level, where milliseconds can mean the difference between winning and losing, even small changes in RT, MT, and balance can have a dramatic impact. For example, differences between the personal best times of the

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top sprinters in the world can differ by approximately 1% (i.e., Greene: 9.79 s, Bailey 9.84 s, Christie: 9.87 s, Cason 9.92 s). Thus, even minor changes in RT, MT, and balance could have important implications for athletic endeavors. The possibility of stretch-induced impairments to balance, RT, and MT not only affects sport applications but the loss of dynamic balance is also a risk factor for osteoporotic fractures (27). The contributions of RT and MT to dynamic balance could have implications not only for athletes and fitness enthusiasts but also for rehabilitation professionals who prescribe stretching.

The objective of the present study was to examine alterations in static balance, proprioception, RT and MT, and force. It was hypothesized based on previous studies that demonstrated decreases in force and activation as well as changes in MTU stiffness that all the dependent variables would be adversely affected by an acute bout of static stretching.

METHODOLOGY

Approach to the problem and experimental design. Because a number of the previous studies investigating stretch-induced force and power decrements used prolonged stretching routines (15–30 min) of single muscle groups (4,13) that were not representative of typical stretching routines, the present study used a moderate volume of stretching with three lower-limb muscle groups. Subjects were tested before and after both an acute bout of static stretching of the quadriceps, hamstrings, and plantar flexors or a similar duration control condition. The stretching protocol involved a 5-min cycle warm-up followed by three stretches to the point of discomfort of 45 s each with 15-s rest periods for each muscle group (independent variable). Measurements were conducted over a 20-min period that included maximal voluntary isometric contraction (MVC) force of the leg extensors, static balance using a computerized wobble board, reaction and movement time of the dominant lower limb, and the ability to match 30% and 50% MVC forces with and without visual feedback (dependent variables).

Subjects. Sixteen healthy male university students (age = 24.1 ± 7.4 yr, weight = 71.5 ± 15.4 kg, height = 172.3 ± 6.5 cm) volunteered for the experiment. All participants were verbally informed of the protocol, and read and signed a consent form. Each participant also read and signed a Physical Activity Participation Questionnaire (PAR-Q: Canadian Society for Exercise Physiology) to ensure that their health status was adequate for participation in the study. The study was sanctioned by the Memorial University of Newfoundland Human Investigations Committee.

Intervention. Before stretching of both legs, subjects performed a warm-up procedure consisting of a 5-min cycle on a cycle ergometer (Monark Ergomedic 828E) at 70 rpm with 1-kp resistance. The order of quadriceps, hamstrings, and plantar flexors stretching was randomized. Stretches were held to the threshold of discomfort for a duration of 45 s with 15-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), hip flexion with extended leg while supine (hamstrings), extended leg 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). Stretching was passive for the quadriceps and hamstrings with the same researcher controlling the change in the range of motion and resistance for all subjects. The researcher would extend the limb to the limits of the participant's range of motion without incurring injury. Subjects provided their own resistance for the plantar flexors stretches with the instructions to stretch the muscles to the point of discomfort.

For the control condition, subjects performed the 5-min cycle warm-up and were allowed to rest for approximately 26 min between the pre- and posttesting periods. The 26-min rest period provided similar pre- to posttest durations for the stretching and control conditions. The order of control and experimental stretch conditions was randomized.

Testing. An orientation session involving multiple attempts (minimum three attempts) for all measures was organized for all subjects 3–5 d before testing. The order of testing was randomized. The stretching intervention commenced 2 min after the pretesting session. Postintervention testing began within 1 min after the stretching routine. The duration of pre- and posttesting was approximately 20 min each.

For leg extension MVC force, subjects sat on a bench with hips and knees flexed at 90°, and the upper leg and hips restrained by two straps. The ankle was inserted into a padded strap attached by a high-tension wire to a Wheatstone bridge configuration strain gauge (Omega Engineering Inc., LCCA 250). Prestretching, subjects performed two leg extension MVC. If there was more than a 5% difference in maximum force output, another MVC was performed. Only two contractions were permitted poststretching to reduce the chance of fatigue. Three-minute rest periods were allocated between contractions. The day-to-day reliability of the strength test using an intraclass correlation coefficient (ICC) was determined to be 0.9, with a between test (single session) reliability of 0.93.

All torques 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 stored on a computer at a sampling rate of 2000 Hz. Data were recorded and analyzed with a commercially designed software program (AcqKnowledge III, Biopac Systems Inc.).

The matching force task used the same set-up as the MVC test. Once the MVC force was established, grid lines were provided on the computer, which outlined 30% and 50% of the MVC force. Subjects were asked to exert sufficient isometric leg extension force over a 5-s period to match the gridlines. Visual feedback was always given for the first three trials of a particular relative force (30% or 50% MVC), while the computer screen was obstructed from view for the subsequent three trials. Two-minute rest periods were permitted between attempts. The order of the relative force matching tasks was randomized. The day-to-day reliability of the matching force test using an ICC was determined to be 0.8, with a between test (single session) reliability of 0.88.

A balance ratio (contact with floor to no contact time) was calculated by a software program (Innervations, Muncie, IN) from a 30-s wobble board test (Kinematic Measurement Systems, Muncie, IN). A metal plate connected to the computer hardware was placed under the wobble board. When the perimeter of the wobble board made contact with the metal plate, the duration and frequency (during the 30-s test) of contact was recorded by the software. Subjects received an orientation session for the balance board on a separate day as well as one to two practice attempts on the day of testing. The day-to-day reliability of the balance test using an ICC was determined to be 0.81, with a between test (single session) reliability of 0.86.

RT and MT were measured by an apparatus developed by the Memorial University of Newfoundland Technical Services (Electronics, Newfoundland, Canada). The testing apparatus consisted of a stop clock (58007, Lafayette Instrument Company, Lafayette, IN), an analog timer (L15–365/099, Triton Electronics, UK), a stop clock latch (58027, Lafayette Instrument Company) that connected the stop clock and the analog timer, a custom-designed box (62 cm (length) × 15.5 cm (width) × 9 cm (height)) with the distance of 50 cm from center of start button to the center of the stop button, and a trigger plate for the start of the task. With the device situated on the floor, the task entailed movement of the dominant foot in response to the illumination of an incandescent light bulb. The subject would start with the nondominant foot on the floor and the dominant foot (ball of foot) placed on the start button. Upon illumination of the light signal, the subject would release the start button and move their foot forward to touch the stop button (50 cm). RT was measured as the time between the illumination of light stimulus and release of the start button. MT was measured as the time between the initiation of movement and the depressing of the stop button. The actions involved hip flexion, knee extension and plantar flexion. In order to move as quickly as possible, the quadriceps and plantar flexors would initiate the movement, while the hamstrings would aid with the deceleration of the leg to accurately touch the stop button. Three trials of RT and MT were performed with 30-s rest periods. The day-to-day reliability of the RT and MT tests using an ICC was determined to be 0.60 and 0.89 respectively with no significant ($P < 0.05$) difference between values for test versus retest. Between test (single session) ICC reliability measures of 0.79 and 0.93 were recorded for RT and MT, respectively.

Statistical analysis. Data were analyzed using a two-way ANOVA repeated measures design. The factors included condition (stretching vs control) and testing (pre- and postcondition). An alpha level of $P < 0.05$ was considered statistically significant. If significant differences ($P < 0.05$) were detected, a Bonferroni-Dunn's procedure was used to identify the significant change. The means and SEM are illustrated in Table 1. Reliability was assessed using an alpha (Cronbach) model ICC (25) with all 16 subjects. Repeated tests were conducted within 48–72 h.

RESULTS

Overall, significant differences from the control condition due to the stretching protocol occurred with measures of static balance, RT and MT.

Force. There was no significant difference between stretching and control conditions in force output. The stretch and control conditions experienced similar 6.9% and 5.6% force decrements, respectively, from the pretest to the posttest.

Perceived force. Whether visual feedback was or was not provided, there were no significant differences in the ability to match 30% and 50% MVC between control and stretch conditions during the pretest or posttests. The control condition demonstrated a nonsignificant 18.8% and 10.7% greater accuracy for maintaining 30% and 50% MVC posttest.

Balance. Balance scores moved in opposing directions resulting in a significant change ($P < 0.009$) for the pre- to posttest differences between control and stretch conditions (effect size = 0.11: small). In comparison with the precontrol sessions, the control condition demonstrated a significant ($P < 0.05$) 17.3% improvement in balance scores postcontrol, whereas the stretch condition showed a nonsignificant 2.2% decrease in balance scores poststretching routine (Table 1).

Reaction and movement time. Similar to balance scores, reverse trends for the stretch and control conditions resulted in significant change for the pre- to posttest differences with both reaction ($P < 0.01$, effect size = 1.11:

TABLE 1. Balance, reaction and movement time data (means ± SEM).

	Pretest Control Condition	Posttest Control Condition	Pre- to Posttest Difference	Pretest Stretch Condition	Posttest Stretch Condition	Pre- to Posttest Difference
Wobble board contacts	10.8 (±2.0)	8.9 (±1.5)	1.9 917.3%*	8.8 (±1.7)	9.0 (±1.8)	0.2 82.2%
Reaction time (RT)	294 ms (±27.5)	277 ms (±10.7)	17 ms 95.8% $P = 0.16$	283 ms (±16.6)	294 ms (±15.8)	11 ms 84.0%
Movement time (MT)	427 ms (±37.5)	403 ms (±30.2)	24 ms 95.7% $P = 0.18$	418 ms (±32.6)	426 ms (±39.1)	8 ms 81.9%

* Asterisk indicates a significant difference from the pre-test condition. Significant differences were detected in the pre- to posttest differences between control and stretch conditions for balance (power: <50%), RT (power: >95%), and MT (power: <50%).

moderate-large) and movement ($P < 0.01$, effect size = 0.65: moderate) time, respectively (Table 1). In reference to the pretest control session, RT and MT improved (decreased) by 5.8% ($P = 0.16$) and 5.7% ($P = 0.18$), respectively. However, compared to the pretest stretch condition, RT and MT were impaired (increased) by 4.0% and 1.9% poststretch, respectively (nonsignificant).

DISCUSSION

The most important findings in this study were the impairments in balance, RT and MT, due to prior stretching. The control condition which involved a 5-min cycle warm-up, submaximal and maximal leg extension contractions, three trials each of rapid leg movement (RT and MT), and balance on a wobble board followed by a 26 min rest period improved performance in the balance, RT and MT tests. Inserting a stretching routine within the rest period not only nullified the beneficial effects of the warm-up but also produced small performance decrements in relation to the pretest scores.

These decrements reflect impairments associated with recent studies that have reported stretch-induced decreases in force (4,13,14), power (11,40), and muscle activation (2,4,13). Although isometric forces decreased 6.9% after stretching in the present study, the decrement was not significantly greater than the 5.6% impairment in the control condition. The lack of a significant loss of isometric force may be attributed to the moderate volume of stretching imposed. In contrast to other similar studies that have stretched a single muscle group for 15–30 min (4,13,14), the present study involved only 135 s of intermittent stretching for each of the three muscle groups.

Balance involves the interaction of automatic postural and voluntary motor commands of both the trunk and limb musculature (6,30). Balancing on a wobble board can involve unanticipated perturbations to equilibrium that are adjusted through contractions of both trunk and limb muscles. Bloem and colleagues (6) speculated that lower leg inputs act to modulate automatic postural responses. They also found that the knees, hips, and trunk initiated movement before the automatic postural responses. The CNS performs anticipatory postural adjustments when expecting self-inflicted postural perturbations (1). However, Aruin and colleagues (1) suggested that under conditions of high instability that the CNS may suppress anticipatory postural adjustments as protection against their possible destabilizing effects. Consequently, voluntary responses of trunk and limb muscles to postural challenges would play a prominent role. Shiratori and Latash (30) in a subsequent study from the same laboratory reported that distal muscles (tibialis anterior and soleus) cope with asymmetrical perturbations and modulate the anticipatory postural adjustments in novel situations (i.e., wobble board). Furthermore, Lipshits et al. (22) described how perturbing balance by rapidly raising a hand was initially counteracted by activation of lower limb muscles. Therefore, it is apparent the important role that lower limbs play in maintaining balance. Modifications to either the afferent limb muscle responses or the mechanical output would be expected to affect the ability of the peripheral neuromuscular system to adapt effectively to stability challenges.

Stretching has been reported to alter the length and stiffness of the affected limb MTU. Although the exact mechanisms responsible for increases in range of motion after stretching are debatable, the increase is commonly attributed to decreased MTU stiffness (37,39). Fowles et al. (13) demonstrated an 8-mm increase in fascicle length of the soleus and lateral gastrocnemius with 30 min of stretching. Studies have reported both decreases (24,35) and no change (23) in MTU passive resistance or stiffness with stretching. Changes in MTU stiffness might be expected to affect the transmission of forces, the rate of force transmission and the rate at which changes in muscle length or tension are detected. A more slack 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. In addition, the detection and monitoring of the muscle tension by the Golgi tendon organs (GTO) would be delayed since a more compliant tendon would not transmit the tension information to the GTO as rapidly as a stiffer MTU. Furthermore, increases in MTU length and decreases in MTU stiffness could also alter the perception of the intrafusal stretch receptors and thus perturb the afferent responses to both changes in muscle length, rate of length change, and tension (GTO). Therefore, stretch-induced changes in muscle compliance might affect both the muscle afferent input to the CNS and muscle output for counteracting unexpected perturbations to balance.

Further evidence for the detrimental effect of an acute bout of stretching on the CNS has been provided by Avela et al. (2). They investigated the effects of passive stretching of the triceps surae muscle on reflex sensitivity. After 1 h 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. They 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.

Stretch-induced impairments in RT and MT may be related to similar mechanisms as the disturbance in balance. As mentioned previously, a more compliant MTU could compromise the rate of tension development. Although it is highly unlikely that the visual detection of the light stimulus and the subsequent initiation of CNS motor programs to move the leg would be adversely affected by stretching, a prolonged electromechanical delay could negatively affect both RT and MT. Although not monitored in the present study, other studies have reported decreases in muscle activation after stretching (2,4,13). Increases in motoneuron inhibition are more likely to affect the high-threshold fast-contracting motor units that could also play a role in stretch-induced RT and MT impairments.

An interesting development in the present study was the control condition's improvements in balance scores, RT and MT. This finding may provide support for the beneficial effect of a short duration, combination of general (cycle warm-up and leg extension contractions) and specific (pretest wobble board, RT and MT tests) activities. However, because there was no condition in which a cycle warm-up was not included, the contribution of the cycling cannot be precisely deduced from the present study.

Young and Behm (41) reported similar results in a study where subjects participated in five different warm-ups in a randomized order before the performance of two jumping tests. The warm-ups were: a) control, b) 4-min run, c) static stretch, d) run and static stretch, and e) run and static stretch and practice jumps. Generally, the stretching warm-up produced the lowest values and the run or run and stretch and jumps warm-ups produced the highest values of explosive force production. Thus, it should not be surprising that the control condition's dynamic warm-up and static leg extension contractions facilitated subsequent performance.

Numerous studies have investigated the effects of actively warming-up on subsequent performance, yielding mixed results. Although the majority of the research has demonstrated that an increase in temperature facilitates human performance (9,29,32), other studies have shown inhibitory effects (5,16) as well as no effect (7) of warming-up on subsequent performance. These conflicting results may be attributed to discrepancies in the type of exercise, intensity, duration, or any combination of these variables utilized in the warm-up procedure. Studies have demonstrated that warming-up can result in increased nerve conduction velocity (31). Increases in nerve conduction velocity could facilitate the response speed to perturbation in balance as well as contributing to the improvements in RT and MT.

Another mechanism that may help explain the control condition's improvement in RT, MT, and balance may be the effect of postactivation potentiation (PAP). PAP can be defined as an increase in the efficiency of the muscle to produce submaximal force after a voluntary contraction. PAP has been attributed to regulatory light chain (RLC) phosphorylation (17,20,21,33), which increases the number of force-producing crossbridges under conditions of suboptimal Ca^{2+} activation (33). Suboptimal Ca^{2+} activation may be present with lower-frequency stimulation such as the lower-intensity contractions associated with static balance. Potentiation also involves an increase in the rate constant of crossbridge attachment (20). The increased rate constant would allow a greater number of crossbridges to form during a specific time period resulting in increased force and rate of force development capabilities. Furthermore, at the supraspinal level, motor-evoked potential facilitation has been reported after different durations (5, 15, and 30 s) and intensities (10%, 25%, and 50%) of thenar muscle voluntary contractions (3). A number of studies have suggested that an improved neuromuscular activation can occur after a few MVC (18,40). Evidence of this postcontraction neural potentiation is provided by increased H-reflex amplitudes (18) that may persist for 10 min after the contractions (36). Thus, pretest contractions in the control condition may have elicited a PAP response providing both a facilitation of the motoneuron excitation and RLC phosphorylation contributing to the significant improvements in RT and MT. Indirectly, the PAP-induced augmentation of RT and MT would also benefit balance by allowing more rapid responses to the perturbations of the unstable environment. The stretching condition may have nullified the beneficial effects of PAP contributing to the 2.2% decrement in balance scores.

ICC (reliability) for the dependent measures were all in the good to excellent category (0.80–0.93) except for the day-to-day reliability of RT that scored 0.60 (moderate). A paired samples *t*-test was then conducted on the RT measures. The lack of significant difference between the measures suggested that the low RT ICC may be attributed to the low between subject variability. Another contributing factor for this less than optimal reliability may be due to the test set-up. The RT test for the lower limb necessitated that the individuals place most of their mass on the nondominant limb creating a degree of instability. Even with an orientation session, the lack of familiarity with this type of movement and the greater instability may have led to a less consistent action.

CONCLUSION

In summary, the findings of the present study demonstrate that a moderate bout of stretching (three repetitions per muscle group) held to the point of discomfort can adversely affect performance on tests of static balance, RT and MT. The stretch-induced impairments are hypothesized to be related to changes in muscle compliance with the stretching that may adversely affect the ability to detect and respond to changes in muscle length, and rate of change in muscle length and forces. Furthermore, it was found in the present study that a warm-up consisting of general and specific activities related to the tasks may improve performance even after 20 min of recovery. Considering the minute differences between winning and losing in both individual and team sports as well as the precarious balance or stability of the elderly, the low but significant percentage changes in RT, MT, and balance could result in serious consequences.

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