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Acute effects of passive muscle stretching on sprint performance

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Abstract

The results of previous research have shown that passive muscle stretching can diminish the peak force output of subsequent maximal isometric, concentric and stretch-shortening contractions. The aim of this study was to establish whether the deleterious effects of passive stretching seen in laboratory settings would be manifest in a performance setting. Sixteen members (11 males, 5 females) of a Division I NCAA track athletics team performed electronically timed 20 m sprints with and without prior stretching of the legs. The experiment was done as part of each athlete's Monday work-out programme. Four different stretch protocols were used, with each protocol completed on a different day. Hence, the test period lasted 4 weeks. The four stretching protocols were no-stretch of either leg (NS), both legs stretched (BS), forward leg in the starting position stretched (FS) and rear leg in the starting position stretched (RS). Three stretching exercises (hamstring stretch, quadriceps stretch, calf stretch) were used for the BS, FS and RS protocols. Each stretching exercise was performed four times, and each time the stretch was maintained for 30 s. The BS, FS and RS protocols induced a significant ($P < 0.05$) increase (~0.04 s) in the 20 m time. Thus, it appears that pre-event stretching might negatively impact the performance of high-power short-term exercise.

Keywords: *Flexibility, sprinting, stretching, track and field, warm-up*

Introduction

Passive muscle stretching just before engaging in physical activity is a common practice among athletes because stretching is thought to promote better performances and reduce the risk of injury (for reviews, see Shellock & Prentice, 1985; Smith, 1994). Convincing experimental evidence, however, does not support these beliefs. Moreover, there is evidence that acute muscle stretching might be detrimental to performances for which success is related to maximal force or torque output (Avela, Kyrolainen, & Komi, 1999; Cornwell, Nelson, Heise, & Sudaway, 2001; Fowles, Sale, MacDougall, 2000; Kokkonen, Nelson, & Cornwell, 1998; Nelson & Kokkonen, 2001; Nelson, Allen, Cornwell, & Kokkonen, 2001a; Nelson, Guillory, Cornwell, & Kokkonen, 2001b; Young & Behm, 2003). Stretching has been shown to elicit a strength deficit in concentric muscle actions. Kokkonen *et al.* (1998) found that maximal performance of both knee flexion and knee extension one-repetition maximum (1-RM) lifts declined (by 7.3% and 8.1%, respec-

tively) significantly when executed 10 min after static stretching of the quadriceps and hamstring muscle groups. Nelson and Kokkonen (2001) reported similar results when ballistic stretching was substituted for static stretching. Furthermore, Nelson *et al.* (2001b) reported a loss in isokinetic torque at slower speeds of movement, and both Avela *et al.* (1999) and Fowles *et al.* (2000) found a reduction (23.2% and 28%, respectively) in maximal isometric plantar flexion torque about the ankle joint after the plantar flexors were passively stretched. Nelson *et al.* (2001a) reported that the loss in isometric torque was joint-angle specific. Finally, prior stretching has been shown to reduce the height of a vertical jump; Cornwell *et al.* (2001) found that pre-event stretching induced a significant decrease in jump height for both the standing jump (4.4%) and counter-movement jump (4.3%). Young and Behm (2003) also compared various warm-up protocols, and found that static stretching had a negative influence on vertical jump performance.

Given the deleterious effect of passive muscle stretching in a laboratory setting on skills relying on

the rate of force production and peak force generation, one could assume that pre-performance stretching would negatively influence the performance of explosive sports. What is found in the laboratory, however, does not always directly transfer to sport performance. Since pre-performance stretching is universally practised, we wished to determine whether the negative influence would be manifest in athletic performance. Given the explosive nature of the sprint start, sprinting performance could be negatively influenced by static stretching. Moreover, since each step during the sprint requires an explosive take-off, any negative impact seen at the start could be carried through the whole race. The main aim of this study was to ascertain whether pre-event stretching would slow a person's start out of the blocks and thus result in a poor race performance. Since most studies mentioned above stretched both legs, a secondary aim was to determine if stretching either the right of left leg alone would yield similar results as stretching both legs.

Methods

Participants

The participants were recruited from members of Louisiana State University's nationally ranked track and field team, who were all currently competing in the 2003 NCAA outdoor season. Eleven males (mean $\pm$ s: age 21 ± 2 years; height 1.83 ± 0.08 m; mass 77.0 ± 6.8 kg) and five females (age 19 ± 1 years; height 1.73 ± 0.1 m; mass 67.6 ± 6.8 kg) completed the study. All of the athletes competed in multiple events (e.g. sprints, jumps, decathlon) and had practised sprint starts almost daily for at least 2 years. Informed written and verbal consent was obtained from each participant before taking part in the experiment, and the appropriate institutional human participants review committee approved the study. The participants were not informed of the results until the study was completed.

Task and apparatus

Following each of four stretching protocols, each participant performed three timed 20 m sprints. To minimize variation in climatic conditions, all sprints were performed on an indoor rubberized track. The sprints were initiated from standard starting blocks set to individual preferences, and were timed with an automated timer (Speedtrap II, Brower Timing Systems, Draper, UT, USA). This timer utilized a pressure pad placed under the fingers of the sprinter's right hand in the starting position. The timing device started when the sprinter lifted the fingers off of the pressure pad, and stopped when the sprinter broke a single laser light beam projected across the track 20 m from the starting line. To control for error, the laser beam was positioned so the height above the ground approximated the height of the runner's waist.

Procedures

The sprint tests were performed as part of each athlete's Monday work-out programme. Four different stretch protocols were used, with each protocol being performed on a different day. Hence, the tests were performed over 4 weeks. The four stretching protocols were: no-stretch of either leg (NS), both legs stretched (BS), forward leg in the starting position stretched (FS) and rear leg in the starting position stretched (RS). Potential order effects were minimized by counterbalancing the stretching protocols and randomly assigning (by the drawing of lots) the athletes to treatment orders. Prior to being stretched, each athlete did the following warm-up: jog 800 m, forward skips 4×30 m, side shuffles 4×30 m, backwards skips 4×30 m. Except for the stretching protocol, no other activity was allowed.

The stretching protocols included three passive (partner-assisted) activities designed to stretch the calf and thigh muscles. The stretching activities were ones that the athletes normally used in their daily warm-up rituals, pictorial representations of which can be found in Alter (1988). The first activity was a hamstring stretch. The athletes adopted a supine position on the ground with one leg extended. The other leg was flexed at the knee ($\sim 90°$) and hip ($\sim 45°$), and the sole of the foot was planted firmly on the ground. From this position, the extended leg was raised (hip flexion) to the vertical position or beyond. During the stretch, the buttocks remained in complete contact with the ground, and the knee of the stretched leg was fully extended. The second activity was performed while the athlete's leg was in the vertical position. While the leg was vertical, the ankle was dorsi-flexed by pushing down on the ball of the foot. The third and final activity was adapted from Alter's (1988) stretch number 196. Again, the stretch started with the person lying supine with one leg flexed and one extended. The extended leg was then flexed at both the knee and hip, simultaneously pushing the heel into the buttocks and the knee towards the chest. For each activity, the range of motion was increased until the person acknowledged a stretch-induced discomfort similar to that normally felt during their daily stretching activities. At this point, the stretch was maintained for 30 s. The three activities were performed in the order listed above, with a $10-20$ s rest period separating each activity. Once one cycle of stretches was completed, the leg

was rested for an additional 20–30 s and then the cycle was repeated until each of the three activities had been performed four times. When both legs were being stretched, the four cycles were completed on one leg before the other leg was stretched. After the stretching regime was completed, the athletes relaxed (i.e. sat, stood quietly or meandered around the starting line) for 5–10 min before commencing the sprint starts.

Following the relaxation period, each athlete performed three 20 m sprints. A minimum of 1 min recovery separated each trial. All sprints were initiated from standard starting blocks that each athlete set to their personal preference. The athletes were allowed to perform their usual pre-start ritual, with the exception of any muscle stretching or shaking of the limbs. Once the athletes were set, they started at their own volition.

Data analysis

The reliability of the three 20 m times for each stretch condition was calculated using an intraclass correlation coefficient.

The three 20 m times for each stretch condition were averaged, with the mean value being used in the statistical analyses. A one-way analysis of variance (ANOVA) with repeated measures was used to compare the times for each stretch condition. Since

almost a month elapsed between the first and last test day, the possibility existed that the differences between treatments might have been influenced by the conditions on a specific day. Therefore, an additional one-way ANOVA with repeated measures was used to determine whether there was a difference between the four different days (i.e. the results of the various treatments were collapsed across days). Where appropriate, *post-hoc* ANOVA analysis involved the use of Tukey's multiple comparisons test. Statistical significance was set at $P < 0.05$.

Results

The reliability of the run time for each condition was very high. In each case, the intraclass correlation coefficient was 0.999. There were no significant differences between any of the four days ($F_{3,15} = 1.048$, $P = 0.381$).

The average 20 m sprint times for each stretch condition are presented in Table I, and the individual responses to the no-stretch (NS) and both legs stretched (BS) protocols are shown in Figure 1. The main effect for treatments was significant ($F_{3,15} = 4.31$ $P = 0.009$). The *post-hoc* analysis revealed that there was no difference between the three stretch conditions (BS, FS, RS), but the times for the three stretch conditions were all significantly slower than in the no-stretch condition.

Table I. The effect of stretch treatment on 20 m sprint time (mean $\pm$ *s*)

	Treatment			
	NS	BS	FS	RS
Time (s)	3.17 $\pm$ 0.04*	3.21 $\pm$ 0.04	3.21 $\pm$ 0.04	3.22 $\pm$ 0.04

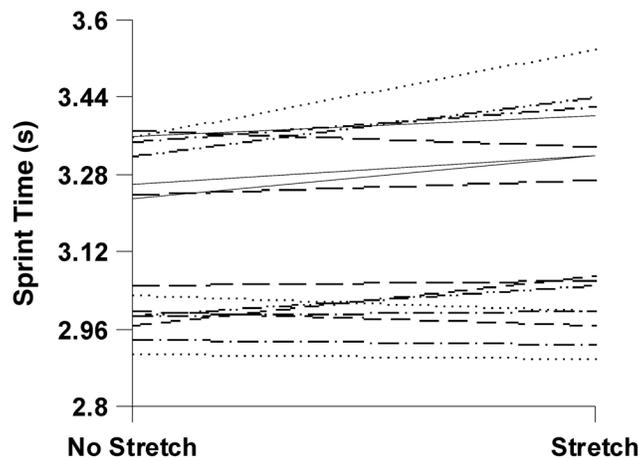* Significantly different ($P < 0.05$) from the other protocols.

Figure 1. Individual 20 m times following the no-stretch and two-leg stretch regimens. Each different line style represents a unique individual. Because the single-leg stretches were almost identical to the two-leg stretch, the single-leg stretches are not included.

In addition to the above analysis on the average 20 m sprint times, a *post-hoc* analysis was done on the best time for each trial. The same statistical method was used, and nearly identical results to those reportede above were obtained.

Discussion

It has previously been shown that an acute bout of passive muscle stretching can impede maximal force production in both isometric and concentric contractions (Avela *et al.*, 1999; Fowles *et al.*, 2000; Kokkonen *et al.*, 1998). In addition, prior stretching can also compromise the performance of a skill for which success is dependent on the rate of force production or power, rather than just the ability to maximize force output (Cornwell *et al.*, 2001, Young & Behm, 2003). Our results show that the time of a 20 m sprint was significantly increased when sprints were performed after stretching whether the stretch included both legs or just one leg. Thus, it appears that pre-performance stretching exercises might negatively impact skills that require multiple repetitive high power outputs in addition to those that depend mainly on maximizing a single output of peak force or power. Moreover, it is interesting to note that this decrement in speed occurred without stretching one of the prime movers – the quadriceps – utilized in sprinting. Since both Cornwell *et al.* (2001) and Young and Behm (2003) reported decreases in jump height after stretching mainly the quadriceps, it is reasonable to assume that sprint performance could only become worse if quadriceps stretching had been added to the other three stretches. Finally, it would appear that for activities that utilize both legs, stretching just one leg is sufficient to adversely affect performance.

Wilson, Murphy and Pryor (1994) suggested that for concentric muscle actions, a stiffer system would improve contractile component force production by allowing more favourable length and velocity conditions. Specifically, they proposed that at a given state of contraction, a stiffer musculotendinous unit should give rise to a greater length and a decreased shortening velocity of the contractile component, thereby placing the contractile component at a more optimal point on both the force–velocity and force–length curve in terms of force production. This is because there is not as much ''slack'' in a stiffer system that has to be taken up during the initial part of the contraction. Extrapolating to the present study, stretching might have altered sprinting by preventing the knee and hip extensors from operating over the most favourable parts of their force–length and force–velocity curves.

An alternative possibility is that performance may have been hindered during the running portion of the sprint by a decreased ability of the musculotendinous unit to store elastic energy following a stretch-induced increase in musculotendinous compliance. Both muscular and tendinous tissues have the ability to store elastic strain energy after being stretched by an external force. Although disputed by some (Bobbert, Gerritsen, Litgens, & van Soest, 1996; van Ingen Schenau, 1984; van Ingen Schenau, Bobbert, & de Haan, 1997), many authors report that the stretch–shortening phenomenon might be partly explained by the release of elastic energy that is stored in the musculotendinous structures during the eccentric phase of stretch–shortening cycle exercises such as running, a mechanism referred to as elastic potentiation (e.g. Asmussen & Bonde-Petersen, 1974; Aura & Komi, 1986; Bosco & Komi, 1979; Cavagna, Komarek, Citerrio, & Margaria, 1971; Hof, 1998; Hof, Geelen, & van den Berg, 1983; Komi & Bosco, 1978; Svantesson, Ernstoff, Bergh, & Grimby, 1991). The amount of elastic energy that can be stored in the musculotendinous unit is a function of the unit's stiffness and the extension produced by an imposed force (Shorten, 1987; van Ingen Schenau, 1984). Belli and Bosco (1992) suggested that an optimum stiffness might exist that maximizes the magnitude of elastic energy return. Furthermore, they demonstrated that the active stiffness of the triceps surae, measured using a vertical oscillation technique with motion restricted to the ankle joint only, was in fact lower than the theoretical optimal stiffness calculated for their participants. Consequently, an acute bout of passive muscle stretching might compromise the effect of a stretch–shortening cycle by decreasing active musculotendinous stiffness, thereby reducing the amount of elastic energy that can be stored and re-utilized. A stretch-induced decrease in musculotendinous stiffness has been demonstrated in some studies (Magnusson, Simonsen, Aagaard, & Kjaer, 1996; Rosenbaum & Hennig, 1995), but not in others (Halbertsma, van Bolhuis, & Goeken, 1996). In addition, McNair and Stanley (1996) found passive stretching to have no effect upon the stiffness of the lower limb muscles during an isometric contraction at 30% maximal effort. However, none of these studies measured stiffness under dynamic conditions of repeated stretch–shortening cycles, and so the impact of passive stretching under actual sprinting remains to be determined. Interestingly, Nelson *et al.* (2001b) showed that static stretching did not hinder maximal voluntary isokinetic knee extension torque production at faster speeds of movement. Since the movement speeds examined by Nelson *et al.* (2001b) were slower than the limb movement speeds in sprinting, one could have speculated that stretching would have little impact on sprinting. Maximal voluntary isokinetic knee extension torque produc-

tion, however, does not employ the stretch – shortening cycle, whereas sprinting does.

There are also neurological mechanisms that could account for a stretch-induced decline in performance. One of these involves the disruption of stretch reflex activity. Bosco, Tarkka and Komi (1982a) and Bosco, Viitasalo, Komi and Luhtanen (1982b) have proposed that the eccentric phase of a stretch – shortening movement initiates a myoelectric potentiation (i.e. a stretch reflex that increases muscle activation during the period of concentric work). Rosenbaum and Hennig (1995) demonstrated that muscle stretching could diminish the strength of the stretch reflex, elicited by an Achilles tendon tap. Thus, pre-exercise stretching might negatively impact the performance of skills that involve a stretch – shortening cycle by impeding myoelectric potentiation. Another potential neural mechanism is related to the acute response of muscle and/or joint proprioceptors (e.g. Golgi tendon organs) to sustained stretch. Golgi tendon organs respond to tension by initiating a reflex inhibition (autogenic inhibition) of the muscle being stretched and its synergists in both the ipsilateral and contralateral legs (Moore, 1984).

It is interesting to note that both the mechanical and neurological mechanisms acting alone or in combination can also explain why a single leg stretch was as deleterious as a double leg stretch. It is easy to see how the reduced performance of a single leg would increase running time, whether it reduced the "explosion" out of the blocks or simply was less powerful than the other leg along the whole 20 m distance. In fact, the researchers noted that many of the athletes had an altered running form after a single leg stretch. The style was reminiscent of a person running with a limp. In addition, a stretch-induced autogenic inhibition could negatively influence both legs.

Notwithstanding the statistical significance of this study's findings, their universal applicability could be questioned in terms of both magnitude and duration of the stretch-induced inhibition. Because the participants performed the sprints within 10 min of the last stretch, we cannot be certain if a similar effect would have been evident 30 min later. Moreover, the 20 m sprint was much shorter than the standard competition sprints (100 m and 200 m). Hence, it is not known whether the 0.04 s difference seen between the stretched and no-stretched conditions would accumulate, remain static or decrease over a longer distance. However, Fowles *et al.* (2000) found that a 9% decrement in maximum isometric plantar flexion torque was present 60 min following an aggressive 30 min stretching of the plantar flexors. Thus, it appears that the capacity of pre-event stretching to have a negative impact could endure for a time much longer than that of even the longest sprints. The durations of the stretches used in this study, however, were shorter than those of Fowles *et al.* (2000). Hence, one would presume that the magnitude of any decrease and its duration would be less than reported by Fowles *et al.* (2000). Clearly, further research is required to establish both the magnitude of pre-stretching necessary to cause a deleterious effect, and the time-course between the maintenance of the increased range of motion and the resumption of the capacity to generate maximal power.

Although the mechanisms responsible for the performance decrements cannot be unequivocally established, the results of this study nevertheless have important ramifications. This study shows that passive muscle stretching can negatively impact the performance of a skill that demands repetitive high power outputs. This effect may influence movements performed with either a purely concentric contraction (i.e. explosive take-off out of the starting blocks), a concentric phase followed by repetitive stretch – shortening cycle actions, or both. The performance of other skills, therefore, might be affected if an acute bout of stretching is undertaken immediately before engaging in activity (e.g. long jumping, high jumping, pole vaulting). Thus, in addition to establishing the underlying mechanisms, further research should be conducted to determine if this study's findings could be generalized across a variety of skills. Presently, it can only be recommended that the knee and hip muscles should not be passively stretched just prior to performing sprints if the intent is to maximize speed. This recommendation opposes the general perception that passive stretching before vigorous exercise is always a prudent practice. In fact, the athletes in this study were very uneasy at the start of each of the no-stretch sprints. Thus, the negative impact of physiological/mechanical impacts of stretching must be greater than any negative psychological feelings in the no-stretch condition.

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