The Acute Effects of Static Stretching on Speed and Agility Performance Depend on Stretch Duration and Conditioning Level

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Running title: Stretching and power performance
ABSTRACT

Although static stretching (SS) is an integral part of physical preparation before training and competition, its usefulness in regards to power performance improvement has been questioned. The aim of this study was to investigate the effect of six static stretching (SS) durations on speed and agility performance. According to a cross-over design, 34 trained males (age 20.5±1.4 years, height 1.81±0.2 m, weight 77.2±2.6 kg, body fat 8.2±2.6%) participated in a control session (no stretch) and six experimental conditions (10, 15, 20, 30, 40, 60 sec) performed in randomized order. Performance in speed (10 and 20 m) and agility (T-test) was measured after the control and experimental conditions. SS, consisting of stretches for hip extensors, hip adductors, knee extensors, knee flexors and ankle sole flexors, was performed after light cardiovascular exercise (8 min). A one-way repeated measures ANOVA showed that speed was improved only by SS of short duration (15/20 sec) whereas agility remained unaffected by all SS trials. When participants' speed and agility level was taken into account, it was revealed that only those of moderate performance demonstrated an improved speed (in 15- and 20-sec trials) and agility (in 10- and 15-sec trials) performance. These results suggest that short duration SS protocols induce an acute improvement of speed and agility performance whereas longer duration has neither positive nor negative effect. Furthermore, it appears that individuals of lower speed and agility performance level are more likely to benefit by a short duration SS protocol.

Key words: warm-up; T-test; flexibility; sprinting; athletes
INTRODUCTION

Stretching is an integral part of the warm-up process and is placed between the general and specific warm-up prior to participation in training or competition. Stretching and warm up are used to increase core and muscle temperature, muscle flexibility, muscle-tendon unit (MTU) length and performance (39). Sport practitioners routinely use various type of stretching such as static stretching (SS), dynamic stretching (DS), and proprioceptive neuromuscular facilitation stretching (PNF) (38). Static stretching is widely used as it has been shown to reduce muscle tension resulting in an increase of joint range of motion (ROM) and may decrease the risk of injury of muscle-tendon unit (MTU) (38,39). Static stretching is usually implemented as stretches of 15-60 sec duration for each muscle group performed at or below pain or discomfort limits (POD) (38,39).

Recent evidence, however, suggested that SS may negatively affect neuromuscular performance and power performance manifestations such as speed, agility and jumping (4;40). Most published studies in this field during the last decade have shown a deterioration of power performance of up to 10% in subjects that performed SS routines as compared to their control counterparts (5,6,11,15,17,31,33,37). These studies examined the effects of duration, experience and type of stretching on speed (the time to complete distances of 10 to 50 m) and agility performance (Illinois test and T-test) according to a repeated measures design. With the exception of two studies that used a large set of subjects (31,37), the vast majority of studies have used small samples that ranged from eight to 22 subjects. Furthermore, previous investigations employed SS protocols of one to six sets with durations of at least 20 sec per repetition and total stretching duration from 30 to 150
sec for each muscle group. To our knowledge, no study have examined the effects of SS protocols of shorter total duration (<30 sec) for each muscle group on speed and agility performance according to a cross-over, repeated measures design with the same participants completing all experimental conditions (total duration of stretch). Therefore, the present study attempted to determine (i) the effect of a wide range of SS durations used consistently by sport practitioners on sprint and agility performance and (ii) to examine the whether the effects of SS duration on speed and agility depends on the level of muscle power performance.

METHODS

Experimental Approach to the Problem
To determine the effect of SS duration on sprint and agility performance a cross-over, repeated measures design was employed. Participants performed seven experimental trials in a random order (Figure 1). Each trial consisted of cardiovascular warm-up period (jogging on a basketball court, 8 min) at moderate intensity, a 3-minute rest, stretching (in the control trial participants rested), a 4-minute post-stretching rest and evaluation of either sprint or agility performance. Cardiovascular warm-up intensity was self-selected. However, intensity was recorded continuously by heart rate monitoring (Polar Electro, Kempele, Finland) in order to ensure that participants received the same cardiovascular stimulus in respect to intensity, duration and total distance covered during warm-up across trials. All trials were performed at the same time of day. Stretching exercises were performed on a wooden floor (basketball court) and were designed to stretch the hip extensors, hip adductors, knee extensors, knee flexors and ankle sole flexors (Table 2). All stretches were performed by both legs in an alternate fashion until pain of discomfort developed. There was no rest between
different stretching exercises. To determine the effect of performance level at different SS durations on sprint and agility performance, participants were classified as high performers (HP, N=25) or moderate performers (MP, N=25) based on their performance in speed and agility tests using the statistical median.

**Subjects**

Fifty healthy, trained athletes (age 20.5±1.4 years, age range 19.1-22.0 years, height 1.81±0.2 m, weight 77.2±2.6 kg, body fat 8.2±2.6 %) volunteered to participate in this study (Table 1). Inclusion criteria included: 1) absence of musculoskeletal injuries for at least six months prior to the study, 2) active participation in sport training (≥4-6 times per week 3) lack of any physical activity/exercise for at least 48 hours before each trial and 4) high speed (10 m time < 1.94 s; 20 m time < 3.1 s) and agility (T-test time < 10 s) performance according to NSCA standards and previous studies that used elite athletes (3,5,16,17). After receiving a detailed verbally and writing explanation of the study’s benefits and risks, each participant signed up an informed consent. The study has the approval of university’s institutional review board and ethical committee and procedures were in accordance with the Helsinki declaration.

**Procedures**

*Anthropometric profile*

Body mass was measured to the nearest 0.5 kg (Seca 710, United Kingdom) with subjects wearing the underclothes and bare-footed. Standing height was evaluated to the nearest 0.5 cm (Seca stadiometer 208). Percent body density and fat was calculated from 7 skinfolds measures using a Harpenden caliper (John Bull United
Kingdom). Each skinfold measured at the right body side and average of two measurements was recorded.

**Sprint and agility performance evaluation**

At baseline (control trial) and at the end of each experimental trial, participants completed speed and agility testing. A familiarization period on sprint and agility testing was used three weeks prior to the study in order to avoid a learning effect on performance. Infrared light sensors (Newtest, Finland) were used to measure time to complete a 20-m sprint (with split at 10-m) and a T-test (16). Sprint and agility testing was performed from a standing start position. To control the effect of possible metabolic fatigue, each participant performed each test twice with a 4-min rest in between. Speed and agility testing order was randomly selected, i.e. speed and agility testing was performed according to one of 4 sequence schemes: 1) speed-speed-agility-agility 2) speed-agility-speed-agility 3) agility-speed-agility-speed and 4) agility-agility-speed-speed. The best time recorded was used for statistical analysis. Interclass coefficient (ICC) between measurements speed testing ranged between 0.90 and 0.95 for MP and 0.92 and 0.95 for HP whereas ICC for agility testing ranged between 0.91 and 0.96 for MP and 0.93 and 0.95 for HP.

**Statistical Analyses**

A one-sample Kolmogorov–Smirnoff test verified data normality and thus the use of non-parametric tests was not necessary. A one-way repeated measures ANOVA was used to establish the effect of static stretching duration on speed and agility testing. In order to estimate the effect of speed/agility performance level (HP vs. MP), a two-way (group x time) repeated measures ANOVA with planned contrasts on different
time points was used for data analysis. A Bonferonni test was utilized for post-hoc analysis when a significant effect was detected. Significance was accepted at $P<0.05$. For effect size determination generalized Eta Squared values ($\eta^2_G$) for repeated measures was calculated (2). Data are presented as means±SE.

RESULTS

Data analysis revealed that sprint performance of 10 m and 20 m was enhanced by 2.8%-3.2% ($p<0.001$; $\eta^2_G=0.12$ for 10 m, $\eta^2_G=0.11$ for 20 m) in response to 15 and 20 sec SS trials as compared to the C (Figure 2A-B). Sprint performance remained unchanged in all other trials. Agility performance remained unaffected in all trials (Figure 2C).

The second objective of the study was to determine whether the effect of SS duration depends on the level of performance (speed and agility) of participants. Thus, the statistic median was used to classify participants as either HP or MP. The statistic median was 1.82 sec for 10 m speed testing, 3.01 sec for 20 m speed testing and 9.86 sec for T-test agility testing. HP participants demonstrated a better performance in speed (10 m and 20 m) and agility testing in all trials ($p<0.001$, $\eta^2_G=0.97-0.98$ for speed testing and $\eta^2_G=0.9$ for agility testing) than MP. Post-hoc analysis revealed that MP improved ($p<0.001$; $\eta^2_G=0.25$ for 10 m testing, $\eta^2_G=0.35$ for 20 m testing) their performance in both speed tests in the 15-s and 20-s trials by 4.2% and 4.1%, respectively (Figure 3A-B). Speed performance in HP remained unaltered in all trials. In respect to agility performance, MP demonstrated an improved ($p<0.05$; $\eta^2_G=0.36$) performance in T-test in response to the 10-s (by 3.3%) and 15-s trials (by 3.6%). In contrast, agility performance in HP remained unchanged in all trials (Figure 3C).
DISCUSSION

Results of the present investigation suggest that the effects of SS exercises on speed and agility performance may be duration-dependent. Shorter stretch durations (i.e. ≤ 20 sec) may result in acute improvement of the time to complete the speed and agility tests. Furthermore, it appears that the effects of SS on speed and agility performance are evident only in MP participants. Highly conditioned (in speed and agility) individuals may not benefit from this type of stretching routine.

Previous research has produced contradictory results in regards to the effects of SS and other forms of stretching on speed performance. Specifically, speed has been found to increase (23), decrease (6,12,13,15,17,29,37) or remain unaffected (5,10,34). This discrepancy may be attributed to differences in SS durations or differences in conditioning levels of participants or muscle groups stretched in these studies.

Previous research has utilized SS of less than 30 sec (short duration), between 30 sec and 60 sec (moderate duration) and over 60 sec (long duration). Most studies suggest that longer durations (90 sec to 20 min) of SS seem to induce speed or strength impairment for as long as 10-60 min post-stretching (8,9,26,30) while one study (20) showed that long duration SS may not affect power performance. This study showed that longer duration (60 sec) leave speed unimpaired. Shorter SS durations have been shown to improve (23), deteriorate (12,13) or leave speed or sport-specific performance unimpaired (18,27). Our results indicate that durations short SS durations (15 and 20 sec) may actually improve speed acutely. These results coincide with previous findings suggesting that short SS durations may not disrupt the viscoelastic properties, sarcomeric cross-bridge kinetics and stiffness of MTU (8,24,25,36). In contrast, longer durations of SS may reduce optimal cross-bridge overlap that, according to length–tension relationship, could diminish muscle force.
output (14). In addition, prolonged static MTU elongation may reduce its passive or active stiffness (21) and thus its force-generating capacity for as long as 15 min post-stretching (14). However, SS durations >60 sec although used to increase muscle's stretching potential, they are not used before competition or training which require maximal force generation. Long SS durations in this study were of smaller magnitude than those used in previous studies reaching several minutes. A plausible explanation for the improved speed performance in response to the short SS protocols is that 10-20 sec SS may not interfere with MTU properties. Moderate SS durations (30-60 sec) did not affect speed performance in this study which is in contrast with previous studies that reported an impairment of 10-30 m sprint performance in response to 40-50 sec SS (6,15,29). However, others also reported no effect of moderate SS duration on sprint, reaction time and other power-related performance such as explosive force and vertical jump performance (1,5,34,35).

Differences in speed performance may also obscure observed changes in response to SS protocols of various lengths. Elite sprinters seem to be more sensitive to changes in the MTU's viscoelastic properties and stiffness in response to SS (14,32) and thus the rate of force transmission, essential in sprinting, may be more susceptible to impairment in HP participants. In fact, leg stiffness has been associated with maximum sprint velocity (7,22). However, Knudson et al. (19) reported that SS-induced decrements in power performance (i.e. vertical jumping) may be related to neuromuscular inhibition rather than changes in muscle stiffness. Flexibility level may also contribute to differences in speed responses to SS protocols since it has been reported that those with higher sit-and-reach performance tend to demonstrate a greater degree of impairment to SS (10). Discrepancies among studies may also be attributed to the different population used by various studies. This study and others
used trained individuals (11,15,17,23) whereas other investigators have utilized adolescent athletes (27,29).

The effects of SS on agility performance have received less attention in the literature. Some studies have reported deterioration (13,15) or no effect (5,23,33) of short-to-moderate duration SS on agility performance. However, these studies examined effects of only one SS duration on agility performance. Our results indicate that all agility performance remained unaffected by SS independent of total duration. Gelen et al. (15) reported a deterioration effect of SS (50 sec) by using a dribbling test suggesting that the movement pattern may affect the final outcome. Chaouachi et al. (5) also showed that agility remains unaltered by SS but they tested speed and agility on different days whereas we and others (15) tested them on the same day. However, this factor may have minimal effect since in this study the order speed and agility testing was randomized. A factor that may be critical for the relationship between SS and agility performance is agility level since MP participants did demonstrate an improvement at short durations (10-15 sec) whereas HP participants did not, independent of duration length. In accordance with our results, numerous studies have suggested that power performance of elite athletes such as agility may not be affected (5,10,33) or even deteriorate by SS (12,13,15,17). Studies that used highly trained athletes showed that SS deteriorated speed performance (28,37). Nevertheless, the significance and the repeatability of this finding remain to be explored by future investigations.

This study showed that SS duration of 10-20 sec may actually improve speed and agility performance whereas longer stretch durations do not affect, negatively or positively, the performance outcome. This effect may be related to the level of speed
and agility performance since those at moderate level demonstrated the greater gains whereas those at higher conditioning level did not.

**Practical Applications**

Information produced by this study is critical for athletes and practitioners since stretching is an integral part of athlete’s preparation for training and competition. It appears that SS of short-to-moderate duration (<60 s) may not be detrimental for power performance (i.e. speed and agility) as studies that examined longer durations (>60 sec) have previously suggested. It must be noted, that according to these results, athletes with high initial speed (<1.82 s for 10 m testing and <3.01 s in this study) and agility (<9.86 s in this study) performance may not be benefited by short duration SS. In contrast, our results indicate that athletes of lower initial speed (>1.82 s for 10 m testing and >3.01 s in this study) and agility (>9.86 s in this study) performance may be benefited by short SS duration protocols. However, this information must be evaluated by future investigations.
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Figure 1: Experimental design. 1Seven experimental trials performed in a random order.

Figure 2: The effect of static stretching duration on 10 m speed testing (A), 20 m speed testing (B) and agility testing (C). 1Significant differences with control trial, p<0.05; C, control condition; 10-s, 10 second trial; 15-s, 15 sec trial; 30-s, 30 sec trial, 40-s, 40 sec trial, 60-s, 60 sec trial.

Figure 3: The effect of static stretching duration in speed (A, 10 m speed; B, 20 m speed) and agility (C) performance in respect to participants' conditioning level. 1Significant differences in performance between the groups p<0.05; 2Significant differences with control trial p<0.05; C: control condition; 10-s, 10 second trial; 15-s, 15 sec trial; 30-s, 30 sec trial, 40-s, 40 sec trial, 60-s, 60 sec trial; HP: high-conditioned; MP: moderate-conditioned.
**Table 1.** Participants’ physical characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>HP</th>
<th>MP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20.5 ± 1.4</td>
<td>20.4 ± 1.5</td>
<td>20.6 ± 1.2</td>
</tr>
<tr>
<td>Training age (yrs)</td>
<td>11.2 ± 2.9</td>
<td>11.3 ± 0.9</td>
<td>11.2 ± 2.9</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.81 ± 0.2</td>
<td>1.82 ± 0.3</td>
<td>1.78 ± 0.1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>77.2 ± 2.6</td>
<td>78.1 ± 10.8</td>
<td>76.1 ± 9.6</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>23.6 ± 2.8</td>
<td>23.4 ± 2.1</td>
<td>23.7 ± 2.5</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>8.2 ± 2.6</td>
<td>6.1 ± 1.7</td>
<td>8.0 ± 2.9</td>
</tr>
<tr>
<td>10m (sec)</td>
<td>1.83 ± 0.08</td>
<td>1.76 ± 0.08</td>
<td>1.89 ± 0.09</td>
</tr>
<tr>
<td>20m (sec)</td>
<td>3.09 ± 0.11</td>
<td>2.97 ± 0.11</td>
<td>3.21 ± 0.12</td>
</tr>
<tr>
<td>T-test (sec)</td>
<td>9.81 ± 0.55</td>
<td>9.39 ± 0.43</td>
<td>10.29 ± 0.45</td>
</tr>
</tbody>
</table>

Total: Characteristics in total number of participants; HP: High Performers; MP: Moderate Performers.
<table>
<thead>
<tr>
<th>Target muscles</th>
<th>Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip extensors</td>
<td>Knee flexion at a supine position: Participants flexed their knee and hip joints with the thigh approaching the abdomen region (up to the point of a mild discomfort) while the opposite leg remained extended and in touch with the floor.</td>
</tr>
<tr>
<td>Hip adductors</td>
<td>Butterfly: participants sat on the floor, brought their feet together, against each other, by abducting the hips and flexing the knees and slowly lowered their knees (using their hands) sideways, up to a point of mild discomfort.</td>
</tr>
<tr>
<td>Knee extensors</td>
<td>Side quadriceps stretch: Participants laid down on the floor rolling on one side having their non-exercising leg extended and in touch with the floor. With one of their hands (that of the other side) flexed the knee of the other leg (top leg) by grasping the ankle and pulling it towards the buttock region up to a point of mild discomfort.</td>
</tr>
<tr>
<td>Knee flexors</td>
<td>Semistraddle (emphasis on inner and outer hamstrings): participants sat on the floor with one leg extended on the floor and the other flexed at the knee with the foot placed against the knee of the extended leg, bent their trunk forward to grasp the ankle of the extended leg (first with the right hand and then with the left).</td>
</tr>
<tr>
<td>Plantar flexors</td>
<td>Calf stretch: participants were standing straight (knees fully extended) on a 30-cm step platform that was in touch with the wall. Participants performed the stretch by maintaining one of the legs extended at the knee while the other leg was placed with the toe at the back edge of the step moved downwards with the knee initially extended (gastrocnemius stretch) and then flexed (soleus stretch).</td>
</tr>
</tbody>
</table>

All stretches were performed by both legs in an alternate fashion.
8 minutes cardiovascular warm-up period at
moderate self-determined intensity

3 min rest

Experimental trials:
C: 10-s 15-s 20-s 30-s 40-s 60-s

4 min rest

Testing
Speed
Agility
(10 and 20m) (T-test)