Effect of Warm-Ups Involving Static or Dynamic Stretching on Agility, Sprinting, and Jumping Performance in Trained Individuals

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ABSTRACT

Chaouachi A, Castagna C, Chtara M, Brughelli M, Turki O, Galy O, Chamari K, and Behm DG. Effect of warm-ups involving static or dynamic stretching on agility, sprinting, and jumping performance in trained individuals. J Strength Cond Res 23(1): 000–000, 2009—The objective of the present study was to investigate the effects of static and dynamic stretching alone and in combination on subsequent agility, sprinting, and jump performance. Eight different stretching protocols: (a) static stretch (SS) to point of discomfort (POD); (b) SS less than POD (SS<POD); (c) dynamic stretching (DS); (d) SS POD combined with DS (SS POD + DS); (v) SS<POD combined with DS (SS<POD + DS); (vi) DS combined with SS POD (DS + SS POD); (vii) DS combined with SS<POD (DS + SS<POD); and (viii) a control warm-up condition without stretching were implemented with a prior aerobic warm-up and followed by dynamic activities. Dependent variables included a 30-m sprint, agility run, and jump tests. The control condition (4.2 ± 0.15 seconds) showed significant differences (p = 0.05) for faster times than the DS + SS<POD (4.28 ± 0.17) condition in the 30-m (1.9%) sprint. There were no other significant differences. The lack of stretch-induced impairments may be attributed to the trained state of the participants or the amount of time used after stretching before the performance. Participants were either professional or national level elite athletes who trained 6–8 times a week with each session lasting ~90 minutes. Based on these findings and the literature, trained individuals who wish to implement static stretching should include an adequate warm-up and dynamic sport-specific activities with at least 5 or more minutes of recovery before their sport activity.

KEY WORDS flexibility, stretch sequence, stretch intensity

INTRODUCTION

The recent stretch literature includes many studies which report that prior static stretching can impair isometric (5,23,33) and isokinetic (39) force, jump height (16,54,65,66), sprint time (21,22,40), muscle activation as measured by electromyography (5,42,44) and the interpolated twitch technique (5,42), reaction and movement time and balance (4). Even when combined with an aerobic warm-up (4,5,12,21,29,42,55), dynamic warm-up (59), or skill rehearsal (66), static stretching exerted negative influences upon subsequent performance. However, there are a few studies that have indicated no effect of static stretching on performance. Indeed, Hayes and Walker (27) reported no static stretch (SS)-induced impairment on subsequent sub-maximal intensity running economy. Other authors have found a volume effect with no significant impairments in jump performance with a lower volume (2–4 sets of 15-second stretches or 2 minutes of stretching at 90% intensity, respectively) of static stretching (43,64). A number of other cross-sectional studies using elite or trained athletic populations have shown no effect of static stretching on sprint times of highly trained male professional soccer players (34), isokinetic torque of American University Division I (19) and vertical jump height of Division III (54) women university basketball players. Another cross-sectional study of recreationally active women showed no effect of static stretching on eccentric isokinetic torque but detriments on concentric isokinetic torque (17). In addition, a longitudinal study that trained 13- to 15-year-old youth with stretching and sprinting for 6 weeks reported that the trained youth were more resistant to the SS-induced deficits when running (15).
Sequencing of Dynamic and Static Stretching

Although there is extensive literature illustrating the negative effects of prior stretching, there seem to be a number of variables such as volume, intensity of stretch, and trained state that may prevent or minimize the stretch-induced deficits.

Variables associated with static stretching are often examined in research studies in isolation. Since static stretching can be performed with prior aerobic warm-ups, dynamic stretching (DS), or subsequent sport-specific activities, the interaction of these different variables must be examined to ensure that SS-induced detriments to performance do exist in more natural settings.

Research examining the effect of DS on subsequent performance illustrates less impairments or even facilitation of performance. Dynamic or ballistic stretching has been shown to enhance performance in subsequent dynamic concentric external resistance (62), power (38,61), agility (34,38), sprint time (21,22), vertical jump height (60), as well as increased electromyographic activity during an isometric maximal voluntary contraction (MVC) (28). Nevertheless, there have been other studies that have reported no change in MVC force (28) and countermovement and drop jump heights (54) with prior DS. Bradley et al. (10) indicated that ballistic stretching resulted in a smaller decrease in vertical jump height than static or proprioceptive neuromuscular facilitation stretching. As mentioned previously, almost all studies have compared dynamic and static stretching as separate conditions (in isolation). There have been very few studies that have combined dynamic and static stretching in the same warm-up (21). Fletcher and Anness (21) organized their study such that static stretching preceded active DS. It would be important to investigate whether the sequencing of static stretching and DS within a warm-up would have an effect on the commonly found SS-induced deficits or conversely would static stretching impede the DS-induced facilitation of performance found in other studies?

Another controversy in the stretching literature is the effect of stretching intensity, or stretching maximally or to the point of discomfort (POD) vs. submaximal intensity static stretching on subsequent performance. Young et al. (64) identified a volume and intensity effect to their stretching regime. A greater duration of stretching resulted in greater deficits. In addition, static stretching at 90% of POD provided increases in range of motion (ROM) with no deleterious jump performance effects. In this context, Knudson and colleagues published 2 studies (31,32) where the subjects were stretched to a point “just before” discomfort. Neither study showed significant decreases in performance. Behm and Kibele (6) conversely found SS-induced impairments in jump performance with maximal (100% or POD) and submaximal (50 and 75% of POD) intensity stretching. With respect to the very limited information regarding submaximal intensity static stretching, it would be important to investigate the effects of submaximal intensity static stretching on dynamic jump activities.

Hence, the objective of the present research was to (a) compare the effects of prior static and/or DS, (2) examine the effects of sequencing static and DS within a warm-up, and (c) comparing maximal (stretch to the POD) and submaximal intensity static stretching on sprint time, agility, and jump performance. It was hypothesized that DS alone would result in enhanced performance compared with static stretching. When DS is combined with static stretching, it is hypothesized that the anticipated SS-induced deficits would be diminished and finally that submaximal intensity stretching would cause less impairment than stretching to the POD (maximal intensity).

Methods

Experimental Approach to the Problem

The present study compared the effects of 8 different stretching warm-up protocols on sprint time, agility, and jump performances relative to a control warm-up protocol without stretching. These warm-ups were designed based on their content (i.e., type of stretch, intensity of stretch, sequencing of static stretching and DS, or exclusion of stretches). The 8 protocols were (a) warm-up with a SS to POD (SS POD); (b) warm-up with SS less than POD (SS<POD); (c) warm-up with DS; (d) warm-up with SS at POD combined with dynamic stretch (SS POD + DS); (e) warm-up with SS less than POD combined with dynamic stretch (SS<POD + DS); (f) warm-up with DS combined with SS at POD (DS + SS POD); (g) warm-up with DS combined with SS less than POD (DS + SS<POD); and finally (h) a control warm-up condition without stretching. These combination of warm-ups would include most of the variables that might be encountered with athletic team warm-ups. The agility, sprinting, and jumping tests provided functional measures to assess the effectiveness of these variables to provide suggestions for an optimal warm-up procedure. The experimental procedure is summarized in Figure 1.

Subjects

Twenty-two highly trained male student-athletes in Sports Sciences pursuing degrees in Exercise Science and Physical Education at the University of Sports of Tunisia (age: 20.6 ± 1.2 years; height: 179.4 ± 6 cm; body mass: 71.9 ± 8.1 kg; % body fat: 10.6 ± 2.9) volunteered to participate in this study. All subjects were active elite athletes performing in different professional teams or individual sports of the national first division of Tunis; many of them were members of the national team in their respective sport. They performed ~10 hours per week of various physical activities as part of their university course, including ball games, swimming, athletics, gymnastic, combat sports, music, and dance. Apart from their education program, all subjects were starters in their team sports and participated in a regular training and competition schedule in either team or individual sports. During the competitive season, subjects trained 6–8 times a week, each session lasting...
~90 minutes with competitions taking place during the weekend. All subjects performed aerobic and anaerobic (i.e., jumping and sprinting) training as general and specific conditioning for the respective sport activity. Subjects were accustomed to flexibility training (i.e., static stretching and DS) being part of their training routines. Testing procedures took place during the postcompetitive phase of the season. None of the participants reported any current or ongoing neuromuscular diseases or musculoskeletal injuries specific to the ankle, knee, or hip joints and none of them were taking any dietary or performance supplements that might be expected to affect performance during the study. The study was approved by the Memorial University Human Investigations Ethic Committee and the Tunisian National Center of Medicine and Science in Sports. After receiving a detailed explanation of the potential benefits and risks associated with participation in the study, each participant signed an informed consent form before experimentation. Three subjects were removed from the study for missed testing sessions. Hence, the data from 19 participants were used for analysis. There were no subjects injured during the warm-up conditions or performance testing.

**Procedures**
Participants attended a total of 10 data collection sessions including a 2-part orientation session. During the orientation phase, each subject was familiarized with the stretching exercises and the 4 performance measures (sprint run, vertical and horizontal jump, and T-drill) until their scores no longer improved. Each subject’s age, height, and body mass were collected. The remaining 8 sessions were completed during the course of the subsequent 16 days so that approximately 48 hours separated each test day. This procedure was chosen to minimize any performance changes that could occur over a longer time period. The order of the warm-up protocol assignment and the tests were counterbalanced per person and per day to avoid carryover effects. All warm-ups with subsequent data collection and testing occurred in an indoor court of the National Center of Medicine and Science in Sports to eliminate wind resistance or inclement weather.

After completing one of the warm-up conditions, subjects proceeded to the performance testing stations. The time between finishing the warm-up and beginning the performance testing was approximately 2 minutes.

**Warm-up protocols**
Subjects executed the general and specific warm-up session collectively with the primary investigator and 3 others associate investigators leading the different stretching warm-up protocols separately in small groups. The order in which the subjects performed the 8 warm-up protocols was counterbalanced to avoid potential biasing effects associated
Sequencing of Dynamic and Static Stretching

TABLE 1. Description of the stretching routines.

<table>
<thead>
<tr>
<th>Static stretching exercises</th>
<th>Dynamic stretching exercises</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantar flexors: The subject stood in an upright position, lowered</td>
<td>Plantar flexors: Initially, the subject raised one foot from the</td>
</tr>
<tr>
<td>the heel off the edge of a step to the maximal range of motion with</td>
<td>floor and fully extended the knee. Then, the subject</td>
</tr>
<tr>
<td>legs fully extended</td>
<td>contracted the dorsiflexors so that foot/toes were pointing</td>
</tr>
<tr>
<td>Hip extensors and quadriceps: The subject stood in an upright</td>
<td>upward</td>
</tr>
<tr>
<td>position with the one hand against a wall for balance, grasped the</td>
<td>Hip extensors: The subject contracted the hip flexors with knee</td>
</tr>
<tr>
<td>ankle with the ipsilateral hand attempting to fully extend the hip</td>
<td>flexed and flexed the hip joint so that the thigh swung up to</td>
</tr>
<tr>
<td>joint</td>
<td>the chest</td>
</tr>
<tr>
<td>Hamstrings (hurdler stretch): From a seated position, the subject</td>
<td>Hamstrings: The subject contracted the hip flexors with knee</td>
</tr>
<tr>
<td>extends a single leg and flexes the other leg until the foot is in</td>
<td>extended and flexed the hip joint so that the leg swung forwards</td>
</tr>
<tr>
<td>contact with the thigh. Subject flexes forward from the waist</td>
<td>to the anterior aspect of his body</td>
</tr>
<tr>
<td>Adductors: The subject stood with feet as wide apart as is</td>
<td>Adductors (side-to-side leg swings): The subject leaned against</td>
</tr>
<tr>
<td>comfortable, shifting body weight from one side to the other</td>
<td>a pole, dynamically adducting and abducting the leg as high as</td>
</tr>
<tr>
<td>as knee flexed and then the subject reached towards extended foot</td>
<td>possible</td>
</tr>
<tr>
<td>and held</td>
<td>Quadriceps: The subject contracted the hamstrings and flexed the</td>
</tr>
</tbody>
</table>

...with test sequence. Each warm-up session lasted about 20–22 minutes. Aside from the stretching, each warm-up followed the exact procedure, consisting of the following given below. Subjects performed at least a 5-minute self-paced general warm-up (EG1) consisting of low- to moderate-intensity aerobic exercise including 3 minutes of forward jogging, 1 minute of sidestepping, and 1 minute of jogging backwards, followed by 10 minutes of a designated stretching protocol (or 10 minutes of rest for the control group) before completing a specific explosive warm-up (EG2) consisting of 5- to 7-minute incremental intermittent sprint and agility runs. These sprint and agility runs included three-quarter pace running: 10-m forwards, repeated twice; 10-m sidestepping, repeated 5 times; 30-m forward, repeated 3 times, a set of 8 single hop jumps, and a set of 8 alternate leg bounds (side hop), repeated twice; and 45-m forward run with 5 × 90° changes of directions, repeated twice. Intensity was then increased: three-quarter pace for 10 m and full pace for 20 m, repeated twice, and full pace for 30 m. This type of explosive warm-up after stretching has been shown to cause minimal decrements to power-based performance (34). Furthermore, it is a common practice for athletes to finish the warm-up with sport-specific intensity activities to both physiologically and psychologically prepare for the subsequent activity (63).

**Stretching**

The stretching warm-up consisted of 5 different stretching exercises designed to stretch the plantar flexors (principally gastrocnemius and soleus), hip flexors (quadriceps), hamstrings, hip extensors (gluteals), and adductors (see Table 1 for a description of the stretches). Both static stretching and DS protocols stretched the same groups according to the previously repeated procedures of Little and Williams (34).

**TABLE 2.** The table describes the statistical analyses used for the independent variables.*

<table>
<thead>
<tr>
<th>Repeated measures ANOVA</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Way ANOVA: all conditions</td>
<td>SS POD + DS, SS&lt;POD + DS, SS POD, SS&lt;POD, DS + SS POD, DS + SS&lt;POD, DS, control</td>
</tr>
<tr>
<td>2-Way ANOVA: stretch sequencing</td>
<td>SS POD + DS, SS&lt;POD + DS, SS POD, SS&lt;POD vs. DS + SS POD, DS + SS&lt;POD, DS, control</td>
</tr>
<tr>
<td>effect (2 × 4)</td>
<td>2-Way ANOVA: stretch intensity effect (2 × 3)</td>
</tr>
<tr>
<td>2-Way ANOVA: stretch intensity</td>
<td>SS POD, DS + SS POD, SS POD + DS vs. SS&lt;POD, DS + SS&lt;POD, SS&lt;POD + DS</td>
</tr>
<tr>
<td>effect (2 × 3)</td>
<td>*ANOVA = analysis of variance; SS = static stretching; DS = dynamic stretching; POD = point of discomfort; &lt;POD = less than point of discomfort.</td>
</tr>
</tbody>
</table>
and Yamaguchi and Ishi (61) and were performed in the same order.

The static stretching and DS exercises were repeated 2 times on each leg and were performed for a duration of 30 seconds with 10-second recovery period between each exercise. No rest period was allowed when changing the limb. Stretching intensity was held at the POD for the maximal intensity condition and at less than POD (<90% of POD) for the submaximal intensity condition. For the submaximal intensity stretches, an initial reliability study was conducted to ensure the prescribed intensity of stretch was valid and consistent. All subjects performed the sit and reach test (11), stretching to maximum intensity (POD) and then subjectively decreasing the tension by 10%. The change in the ROM was then measured. There was excellent reliability for both the maximal and submaximal intensity stretches (see Results). The dynamic stretches (controlled movement through the active ROM for one or more joints) (21,22) were performed slowly, smoothly, and continuously so that no ballistic or abrupt movements occurred at any time.

In the combined static stretching and DS protocols, the number of sets of static stretching and DS was reduced from 2 sets to 1 set for each muscle group of both legs to equalize the total time of stretching.

### Performance testing

The present investigation used straight sprint, horizontal and vertical jump tests, and agility T-drill tests as the measure of sprint, power, and agility performance. The countermovement jump (CMJ) and 5 jump test (5JT) were chosen as measures of functional leg power (13). The T-drill was chosen primarily as a measure of agility. All tests were conducted at the same hour of day between 2 and 4 PM.

The subjects performed three maximal 30-m sprints (with 5- and 10-m split times) on an indoor synthetic court. During the recovery period (2–3 minutes), the subjects walked back to the starting line and then waited for the next sprint. Time was recorded using photo-cell gates (Brower Timing Systems, Salt Lake City, UT; accuracy of 0.01 seconds) placed 0.4 m above the ground. The subjects commenced the sprint when ready from a standing start 0.5 m behind the first timing gate. Stance for the start was consistent for each subject. The run with the fastest 30-m time was selected and the analysis used the affiliated split times for the 5 and 10 m.

Vertical jump performance was assessed using a portable force platform (Quattro Jump; Kisler, Winterthur, Switzerland). Participants performed CMJ and squat jumps according to Bosco et al. (9). Before testing, participants performed self-administered submaximal CMJs (2–3 repetitions) as practice and specific additional warm-up. Subjects were asked to keep hands on their hips (akimbo) to prevent influence of arm movements on vertical jump and to avoid coordination as a confounding variable influence (8). Each subject performed 3 maximal CMJs starting from a standing position, with ~2 minutes recovery. Participants were asked to jump as high as possible. The best jump height was used for calculations.

A 5JT was also performed by each player (13). The 5JT involved the subject attempting to cover the greatest horizontal distance possible by performing a series of 5 forward jumps with alternate left and right foot contacts. During the 5JT, players began with feet together at the start and the end of the jumps. From the starting feet position, the participant was not allowed to perform any back step with any foot; rather he had to directly jump to the front with a leg of his choice. The 5JT performance was measured with a tape

### Tables

**Table 3.** Between sessions (day) sit and reach flexibility test reliability scores (n = 22).*

<table>
<thead>
<tr>
<th>Test</th>
<th>Intensity</th>
<th>Mean (cm) ± SD</th>
<th>Extent of ROM (%)</th>
<th>ICC</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>maximal</td>
<td>22.17 ± 6.59</td>
<td>100</td>
<td>0.94</td>
<td>1.58</td>
</tr>
<tr>
<td>2</td>
<td>maximal</td>
<td>22.88 ± 6.48</td>
<td>100</td>
<td>0.96</td>
<td>1.12</td>
</tr>
<tr>
<td>1</td>
<td>submaximal</td>
<td>19.41 ± 5.42</td>
<td>90.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>submaximal</td>
<td>20.7 ± 5.85</td>
<td>89.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*ROM = range of motion; ICC = intraclass correlation coefficient; POD = point of discomfort; SEM = standard error of measurement.

**Table 4.** Test-retest reliability of tests.*

<table>
<thead>
<tr>
<th>Criterion measures</th>
<th>ICC</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprint 30 m</td>
<td>0.954</td>
<td>0.0338 s</td>
</tr>
<tr>
<td>5-Jump test</td>
<td>0.964</td>
<td>0.101 s</td>
</tr>
<tr>
<td>CMJ</td>
<td>0.957</td>
<td>0.191 m</td>
</tr>
<tr>
<td>CMJ</td>
<td>0.962</td>
<td>1.033 cm</td>
</tr>
</tbody>
</table>

*CMJ = countermovement jump; ICC = intraclass correlation coefficient; SEM = standard error of measurement.
ruler from the front edge of the player’s feet at the starting position to the rear edge of the feet at the final position. The starting position was settled on a fixed point. The assessor at landing had to focus on the last stride of the player to exactly determine the last footprint as the players could not always stay on their feet at landing. The starting position was settled on a fixed point. Subjects were allowed 3 trials, with the longest distance used for analysis. It has been proposed that the 5JT is an appropriate alternative to traditional jumping exercises for estimating lower limb explosive power in various athletes (13,14). Reliability of 5JT expressed as intra-class correlation coefficients and typical error of measures have been reported to range between 0.91 and 0.94% and 2.2 and 2.3%, respectively (13,14).

The T-test was administered using the protocol described by Semenick (47). Three test trials were performed, and times were recorded using an electronic timing system (Brower Timing Systems, accuracy of 0.01 second) placed 0.4 m above the ground. The subjects commenced the sprint when ready from a standing start 0.5 m behind the first timing-gate. Reliability and validity of the T-test were reported by Pauole et al. (41).

**Statistical Analyses**

A number of statistical analyses were performed with the data (Table 2). There were 4 independent variables (SS POD, SS<POD, DS, and control) with the other conditions being variations in the sequencing of the variables. Initially a 1-way analysis of variance (ANOVA) for repeated measures was conducted to compare the 8 conditions. To apprise for a main effect for the sequencing or order of stretching, a 2-way repeated measures ANOVA (2 × 4) was also included (Table 2). The variables were arranged such that conditions involving SS alone or SS performed first in the sequence of stretching were compared with DS alone, control, or conditions where DS was performed first in the sequence. To determine possible main effects for stretching intensity, another 2-way repeated measures ANOVA (2 × 4) was also included (Table 2). The conditions were arranged such that warm-up conditions that involved SS to the POD (SS POD) were compared with warm-up conditions that involved SS below or less than the POD (SS<POD). When significant interactions (p ≤ 0.05) occurred, a Bonferroni post hoc test was used to determine the possible interactions. Data reported include mean ± SD.

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**Table 5.** Data in this table illustrate the mean and SD of the run-related measures (n = 22).*

<table>
<thead>
<tr>
<th></th>
<th>5-m sprint (s)</th>
<th>10-m sprint (s)</th>
<th>30-m sprint (s)</th>
<th>Agility (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.02 ± 0.066</td>
<td>1.74 ± 0.07</td>
<td>4.20 ± 0.15†</td>
<td>9.78 ± 0.4</td>
</tr>
<tr>
<td>DS</td>
<td>1.03 ± 0.03</td>
<td>1.76 ± 0.06</td>
<td>4.22 ± 0.15</td>
<td>9.61 ± 0.39</td>
</tr>
<tr>
<td>SS to POD</td>
<td>1.03 ± 0.06</td>
<td>1.77 ± 0.08</td>
<td>4.24 ± 0.15</td>
<td>9.67 ± 0.49</td>
</tr>
<tr>
<td>SS&lt;POD</td>
<td>1.04 ± 0.05</td>
<td>1.78 ± 0.07</td>
<td>4.27 ± 0.16</td>
<td>9.65 ± 0.42</td>
</tr>
<tr>
<td>DS + SS POD</td>
<td>1.03 ± 0.06</td>
<td>1.76 ± 0.09</td>
<td>4.23 ± 0.19</td>
<td>9.67 ± 0.50</td>
</tr>
<tr>
<td>SS POD + DS</td>
<td>1.04 ± 0.05</td>
<td>1.77 ± 0.08</td>
<td>4.25 ± 0.17</td>
<td>9.68 ± 0.37</td>
</tr>
<tr>
<td>DS + SS&lt;POD</td>
<td>1.04 ± 0.04</td>
<td>1.79 ± 0.07</td>
<td>4.28 ± 0.17†</td>
<td>9.78 ± 0.48</td>
</tr>
<tr>
<td>SS&lt;POD + DS</td>
<td>1.04 ± 0.04</td>
<td>1.78 ± 0.06</td>
<td>4.25 ± 0.14</td>
<td>9.68 ± 0.48</td>
</tr>
</tbody>
</table>

* DS = dynamic stretch; SS = static stretch; POD = point of discomfort.
† Significant differences (p < 0.05) between the 2 variables in that column.

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**Figure 2.** Individual subjects’ data points for the 30-m sprint time.
Test-retest reliability of the tests was determined by intraclass correlation coefficients (ICC) via 1-way ANOVA with a value of 0.7–0.8 being questionable, and >0.9 indicating high reliability (56). To objectively identify reliability, it is suggested to combine ICC calculations (which represent a dimensionless measure of reliability) with the standard error of measurement (SEM) (which quantifies the precision of individual scores on a test reported by the tester and is referred to as the typical error) (57). The SEM shares a unit of measurement of the data and allows calculating a range wherein the subject’s true score is located. The SEM was estimated through the usual formula (i.e., by multiplying the SD of the scores by the square root of 1 minus the ICC, SEM = SD*(1 − ICC)^0.5) (57). Paired samples t-tests were also performed to determine the stability of all the measurements. These calculations were performed for all outcome measures supplied by the test. Statistical analyses were performed using SPSS software statistical package (SPSS Inc., Chicago, IL, version 14.0).

### RESULTS

There were no main effects for the sequencing of SS and DS or were there main effects for the stretch intensity.Tables 3 and 4 illustrate the excellent reliability of the maximal (POD) and submaximal (~90%) intensity stretches as well as the criterion measures. ICCs and SEMs for these mean scores of sprint 30 m, T-test, 5JT, and CMJ are presented in Table 4. The ICC values for all measures demonstrated “high reliability” (ICC range: 0.954–0.964). Furthermore, a paired t-test showed no significant differences between the scores recorded during test and retest for all the variables measured.

The control (no stretch) condition had significantly (p < 0.05) faster times (1.9%) than the DS + SS<POD condition in the 30-m sprint. There were no other significant differences for sprint or agility measures (Table 5). However, the control condition numerically (but not statistically significantly) presented the fastest times for the 5-, 10-, and 30-m sprint times. Figure 2 illustrates the highly consistent response of subjects to the interventions with the 30-m sprint. There were no significant differences among the jump measures (Table 6).

### DISCUSSION

The most interesting findings of this research were that in highly trained, nonsprint-trained, university age physical education students, static stretching at maximal or submaximal intensity did not adversely affect performance. Secondly, DS did not enhance nor impede performance whether conducted separately or in conjunction with static stretching.

No sequencing effect of DS and static stretching was found in the present study as there were no statistically significant impairments associated with static stretching or were there impairments or facilitation associated with DS. Although the majority of studies report static stretching–induced impairments, there are studies that have shown no deficits for running economy (27), sprint time (55), and jump performance (42,43,64). Nevertheless, DS or ballistic stretching has been reported to enhance performance in power (38,61,62), agility (34,38), sprint time (21), and vertical jump (60). Alternatively, other studies have reported no change in MVC force (28), countermovement, and drop jump heights (54) with prior DS. Hence, the present study is in agreement with the number of the studies found in the literature on the effects of prior stretching. The lack of stretch-induced disruptions found in other studies may be related to a number of factors including the age and trained status of the group, volume and intensity of the stretching protocol, and recovery interval between stretching and testing. These factors are addressed in the following discussion.

Whereas there are a number of studies documenting SS-induced impairments in jump height (16,55,65,66) and sprint time (21,22,34,40), there is also evidence that more highly trained individuals are more resistant to these

<table>
<thead>
<tr>
<th>Table 6. Data in this table illustrate the mean and SDs of the jump-related measures (n = 22).*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5 jump test (s)</strong></td>
</tr>
<tr>
<td>Control</td>
</tr>
<tr>
<td>DS</td>
</tr>
<tr>
<td>SS to POD</td>
</tr>
<tr>
<td>SS &lt; POD</td>
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<tr>
<td>DS + SS POD</td>
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<tr>
<td>SS POD + DS</td>
</tr>
<tr>
<td>DS + SS&lt;POD</td>
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<tr>
<td>SS&lt;POD + DS</td>
</tr>
</tbody>
</table>

*DS = dynamic stretch; SS = static stretch; POD = point of discomfort.
Sequencing of Dynamic and Static Stretching

Stretch-induced deficits. Little and Williams (34) reported no effect of static stretching on sprint times of highly trained male professional soccer players. The running economy of competitive male middle distance runners (average of 6 years of training) was not adversely affected by prior static stretching or DS (27). Also, actively trained college-aged women did not experience any significant impairment in vertical jump (54) or peak torque or mean isokinetic power (19) following static or ballistic stretching. Both Unick et al. (54) and Egan et al. (19) suggested that trained athletes might be less susceptible to the stretching-induced deficits than untrained. Chaouachi et al. (15) found that after 6 weeks of training, the stretch- and sprint-trained participants were more resistant to stretch-induced sprint deficits. Hence, a stretch and sprint training program in 13- to 15-year-olds diminished the detrimental effects of static stretching compared with a sprint-only training program. In this context, it has to be noted that the participants in the present study were highly trained physical education students, which could help to explain the absence of effects observed.

Reported changes in muscle compliance and activation could adversely affect power and ground contact time. Studies have reported both decreases (37,52) and no change (35,36) in musculotendinous unit (MTU) passive resistance or stiffness with an acute bout of static stretching. Changes in MTU stiffness might be expected to impact the transmission of forces and the rate of force transmission, which are essential variables in sprinting (18). However, research examining the effect of prior static stretching on sprint performance has been equivocal. Winchester et al. (59) reported that when static stretching was included with a dynamic warm-up, it inhibited sprint performance in collegiate athletes (~20 years old). Similarly, Fletcher and Anness (21) reported decreased sprint performance in 19- to 20-year-old track and field athletes when static stretching was combined with DS. Conversely, static stretching did not appear detrimental to high-speed sprint performance in professional soccer players (34). Vetter (55) implemented a variety of warm-ups that included DS and static stretching routines in a heterogeneous group of college age men and women. The warm-up with a static stretching component negatively impacted jump performance, but not sprint time.

Godges et al. (25) and Gleim et al. (24) had subjects perform static stretching before running and reported contradictory findings with improved and impaired energy efficiency, respectively, when tested at submaximal running intensities. Whereas Gleim et al. (24) used highly trained runners who likely would have had brief foot contact times, the Godges’ group (25) used recreational runners who would probably have longer ground contact times. A more compliant muscle may actually be beneficial to performance by increasing the duration of energy storage during a more prolonged stretch-shortening cycle. Wilson et al. (58) reported greater forces produced with a rebound chest press with a prior SS than no SS. The duration of the amortization or transition period (contact time with the chest) would have been substantially longer than the foot contact time of an elite sprinter. Thus, there would be a benefit associated with a longer period of energy storage during this prolonged stretch-shortening cycle. Although the university physical education students participating in the present study were highly trained athletes, they were not trained specifically as sprinters. Their sprint times and hence their foot contact time may be prolonged in comparison with elite sprinters. The lack of sprint impairment may be more characteristic of highly trained nonsprint-trained athletes (present study, [34]) as compared with the detriments experienced by sprint trained–specific athletes (21,59). Similar to the study of Godges et al. (25), which showed a beneficial effect of static stretching with recreational adult runners, the participants in the present study may have had a foot contact time that would have been facilitated or unaffected by prior stretching to ameliorate energy storage and transfer.

The present study revealed that the control condition with no stretching but including a general active aerobic warm-up followed by a specific explosive dynamic warm-up significantly improved times in the 30-m sprint ($p = 0.05$). While numerically superior but not statistically significant, the control condition had faster times than all other conditions during the sprints. A warm-up has the common goal of increasing muscle temperature in preparation for exercise by literally warming up the muscle to increase metabolic rate as well as attempting to increase muscle extensibility (7). Warming-up can result in decreased muscle viscosity (48), increased variables such as oxygen uptake during subsequent exercise (30), nerve conduction velocity (50), glycolysis (49), ROM (51), anaerobic performance (51), and muscle tensile strength (45). Hence, the faster sprint times in the control condition may be attributed to the increased muscle temperature without the interference of stretching.

Postactivation potentiation (PAP) may be a contributing factor to the faster sprint times with the control condition as well as the lack of stretch-induced deficits in the other conditions (46). All experimental conditions included not only a preliminary aerobic style warm-up but also higher intensity explosive contractions with dynamic actions such as sprints, agility runs, hopping, and bounding. PAP can produce improvements in the rate of force development (3,46), reaction and processing time (20), vertical jump height, and explosive force (26) and can be induced by intermittent activity (1) and all 3 types of contractions (concentric, isometric, and eccentric) (2). Hence, the expected stretch-induced deficits in run and jump measures (based on previous literature) may have been offset by the PAP effects of the prior high-intensity sprints, agility runs, hops, and bounding.

The volume and timing of stretching may also be a factor. No significant impairments in jump performance were reported with a lower volume (2–4 sets of 15-second stretches or 2 minutes of stretching at 90% intensity, respectively) of
Static stretching (43,64). While Winchester et al. (59) reported stretch-induced sprint decrements with 10 minutes of stretching, the present study with 8 minutes of static stretching and other stretch and running studies that included 4 (55) and 7 (53) minutes of stretching did not show significant running decrements. Furthermore, highly trained track athletes’ sprint testing of Winchester et al. (59) was conducted 5 minutes following their stretching protocol. In the present study, static stretching was followed by 5–7 minutes of dynamic sport-specific activity, 2-minute recovery and a randomized allocation of assorted sprint, agility, and jump testing that could have placed the sprint testing for some participants approximately 20 minutes after the warm-up procedure. Knudson et al. (53) concur by stating that a time of 5 minutes or longer after stretching may allow the body to dissipate any negative effects. Hence, lower volumes of static stretching and longer recovery periods may diminish stretch-induced impairments.

There has been some evidence in the literature to suggest that less than maximal intensity stretching might not produce stretch-induced deficits (31,32,64). Young et al. (64) manipulated the volume of stretching and in one condition had the participants stretch to 90% of POD. The submaximal intensity stretch of the plantar flexors was calculated by decreasing the ROM by 10% from the angle achieved when the subjects were stretched at the POD. They found that 2 minutes of static stretching at 90% intensity had no effect on muscle performance (concentric calf raise and drop jump height). Knudson et al. published 2 studies (31,32) where the subjects were stretched to a point “just before” discomfort. Neither study showed significant decreases in performance. In one study (31), there was a trend toward impaired vertical jump height (3%), while the other study reported no change in tennis serve velocity (32). Behm and Kibele (6) conversely did find SS-induced deficits in jump performance when stretching at the POD as well as at the 50 and 75% of the POD. In the present study, there were no effects with either maximal or submaximal intensity static stretching that could be attributable to the participants’ trained state or recovery interval between stretching and testing.

The present study did not show significant impairments in sprint time associated with prior static stretching or DS except for one condition (DS + SS<POD). Whereas the majority of studies report SS-induced impairments, there are similar studies without stretch-induced disruptions. Similar to other studies, the present study’s lack of impairments may be attributed to the trained state of the participants, volume of stretching, or recovery interval between stretching and testing. There was no significant effect of sequencing the stretches on subsequent performance.

**Practical Applications**

Based on the present study and previous studies, static stretching and DS may be implemented before running and jumping in highly trained athletes if preceded by an aerobic warm-up that increases muscle temperature and followed by higher intensity dynamic or explosive activities. Since the literature is not unanimous, athletes should be cautious when static stretching before an event. Static stretching before an event may not be a necessity for all activities as an aerobic warm-up alone has been shown to increase ROM (63) and in the present study and other studies improves performance (63). Although the present study did not reveal detriments with stretching to the POD, to be conservative, from a performance standpoint, static stretching should be performed with less than maximal tension (below POD) on the muscle (31,32,64), be of short duration (less than 30 seconds), low volume (less than 6 repetitions (43) or 60 seconds per muscle) and provide a prolonged recovery period between static stretching and performance (>5 minutes) (53).

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