THE EFFECTS OF STATIC STRETCHING ON RUNNING ECONOMY AND ENDURANCE PERFORMANCE IN FEMALE DISTANCE RUNNERS DURING TREADMILL RUNNING

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ABSTRACT

Mojock, CD, Kim, J-S, Eccles, DW, and Panton, LB. The effects of static stretching on running economy and endurance performance in female distance runners during treadmill running. J Strength Cond Res 25(8): 2170–2176, 2011—Stretching can lead to decreased muscle stiffness and has been associated with decreased force and power production. The purpose of this study was to investigate the acute effects of static stretching (SS) on running economy and endurance performance in trained female distance runners. Twelve long distance female (30 ± 9 years) runners were assessed for height (159.4 ± 7.4 cm), weight (54.8 ± 7.2 kg), % body fat (19.7 ± 2.8%), and maximal oxygen consumption (V\textsubscript{O2max}: 48.4 ± 5.1 ml kg\textsuperscript{-1} min\textsuperscript{-1}). Participants performed 2 sessions of 60-minute treadmill runs following a randomly assigned SS protocol or quiet sitting (QS). During the first 30 minutes (running economy), expired gases, heart rate (HR), and rating of perceived exertion (RPE) were recorded while the participant ran at 65% V\textsubscript{O2max}. During the final 30 minutes (endurance performance), distance covered, speed, HR, and RPE were recorded while the participant covered as much distance as possible. Repeated measures analyses of variance were performed on the data. Significance was accepted at p < 0.05. The SS measured by sit-and-reach increased flexibility (SS: 29.8 ± 8.3 vs. QS: 33.1 ± 8.1 cm) but had no effect on running economy (V\textsubscript{O2}: 33.7 ± 3.2 vs. 33.8 ± 2.3 ml kg\textsuperscript{-1} min\textsuperscript{-1}), calorie expenditure (270 ± 41 vs. 270 ± 41 kcal), HR (157 ± 10 vs. 160 ± 12 b min\textsuperscript{-1}), or endurance performance (5.5 ± 0.6 vs. 5.5 ± 0.7 km). These findings indicated that stretching did not have an adverse effect on endurance performance in trained women. This suggests that the performance decrements previously associated with stretching may not occur in trained women.

KEY WORDS flexibility, sit and reach, stiffness, warm-up, musculotendinous unit

INTRODUCTION

A number of studies have shown that the proposed benefits of static stretching (SS) before event participation, such as increased range of motion (ROM), injury prevention, and performance enhancement, are in fact deleterious to performance and decrease power (4,7,34), maximum strength (20,22,34), and sprint performance (13,14). The decreases in performance associated with SS have been attributed to declines in musculotendinous unit (MTU) stiffness (7,18,24,35,36,39,41) and decreased neural activation of the skeletal muscles (24,29,34,41). Lower stiffness leads to increased ground contact time (4), which may allow a greater percentage of energy stored within tendinous tissue to dissipate into the ground during the support phase of running. It has been shown that the largest contributor to increased aerobic demand during running is the increased muscle force required by the knee when the muscle length is increased (28).

Stretch durations as short as 10–15 seconds (21,27) at intensities as low as 50% of the point of discomfort (4) with as little as 1 stretch per muscle group (10) have been shown to increase muscle length, effectively reducing MTU stiffness and neural activation. As potential energy decreases in the elongated muscle, there may be greater reliance on intrinsically generated force from muscular contraction leading to greater fatigue and decreased performance. After an acute bout of SS, the compliant MTU increases slack on the tendon and does not allow the force generated by the contractile component to be transmitted to the skeletal system as effectively as a stiff unit, thus decreasing running economy (39,41).

Other work in the field of endurance performance has identified maximal oxygen uptake (V\textsubscript{O2max}) and running economy as primary limiting factors (3,33). Studies have
shown that a positive linear relationship exists between leg stiffness and economy, measured by metabolic energy costs ($O_2$ consumed) at a given velocity, running (8,16). The most economical runners typically show higher contraction strength, greater stiffness, and higher energy storage capacity in their lower body musculature when compared to runners with similar $V_O_{2max}$ values (1). Greater MTU stiffness provides more benefit from passive elastic mechanisms and thus lowers energy costs during distance events (16,37).

In a recent study from our laboratory, evidence suggested deleterious effects on performance and running economy after an acute bout of SS in male distance runners (9). Because women have been shown to be less stiff than their male counterparts, if MTU stiffness plays a major role in running performance, then SS may have less impact on running economy and performance (15,43). Therefore, the purpose of this study was to investigate the effects of SS on running economy and endurance performance during treadmill running in trained female runners.

**METHODS**

**Experimental Approach to the Problem**

Because economy has been identified as a primary limiting factor of performance (3,33), dependent variables associated with energy cost, heart rate (HR), rating of perceived exertion (RPE), calorie expenditure and relative $V_O_2$ were measured at a constant velocity during the first 30 minutes of the trial. If SS alters the energy cost of transport per unit distance, this will increase the total amount of energy required to cover the fixed distance (33). To assess running performance, the dependent variables of distance, speed, HR, and RPE were measured during the final 30 minutes of the treadmill run. If the acute bout of stretching decreases MTU stiffness causing increased ground contact time, step frequency, a major component of running speed, will be reduced and result in impaired performance.

The independent variable was the nonstretcher (i.e., quiet sitting [QS]) or SS condition. After a randomized, counterbalanced order, participants acted as their own controls and performed either SS or QS before performing a 60-minute treadmill run. At the second trial, separated by at least 21 days, participants returned to the laboratory to perform the remaining experimental condition and a second 60-minute treadmill run. To control for hormonal fluctuations, the experiments were performed between days 3 and 7 of the participant’s menstrual cycle (11,23,32).

**Subjects**

Fourteen trained, nonsmoking women, currently running at least 20 miles per week for at least 6 months, volunteered to participate in the study. All participants had recent experience competing in distance races of at least 10 km in length. One participant dropped out after developing oligomenorrhea and another because of schedule conflicts. The remaining 12 participants completed the entire protocol (Age: 30 ± 9 years; Height: 159.4 ± 7.4 cm; Weight: 54.8 ± 7.2 kg; % body fat: 19.7 ± 2.8%; $V_O_{2max}$: 48.4 ± 5.1 ml kg$^{-1}$ min$^{-1}$; HRmax: 190 ± 6 h$^{-1}$). This study was approved by the Institutional Review Board (IRB) of The Florida State University. Each subject was informed of all experimental procedures and risks associated with participation in the study and completed IRB approved informed consent forms and health history questionnaires before participation in the study.

**Procedures**

Participants reported to the laboratory for preliminary testing and to familiarize themselves with the treadmill protocol. After a 3-hour fast on the first, and all subsequent visits, body composition was measured by determining height, weight (Seca scale, Hanover, MD, USA), and body density. Body density was estimated using the sum of 3 skinfolds (triceps, suprailliac, and anterior thigh) (19). $V_O_{2max}$ was then determined using a modified progressive graded exercise test to exhaustion.

**Maximal Oxygen Uptake Testing.** For all exercise sessions, gas exchange and ventilatory parameters were measured by indirect calorimetry using a metabolic cart system (Truemax 2400 Metabolic Measurement System, Consentius Technologies, Sandy, UT, USA). Environmental temperature, humidity, and barometric pressure were measured using an indoor climate monitor (Perception II TM, Davis Instruments, Hayward, CA, USA). The participants were fitted with a headpiece and nose clip. A mouthpiece (Survivair BLUE 1, Comasac Inc., Endfield, CT, USA) attached to a 9-foot breathing tube (no. 112263 2700B and 666021, Hans Rudolph Inc., Kansas City, MO, USA) was used to collect expired air and deliver it to the metabolic measurement system during all the exercise sessions. The HR was monitored using a Polar® heart rate monitor.

On the first visit, after a 3-hour fast, the $V_O_{2max}$ was determined using a modified progressive exercise test to exhaustion protocol. $V_O_{2max}$ was determined on a Woodway Treadmill (Waukesha, WI, USA). The initial velocity and inclination was 10 km·h$^{-1}$ and a 1% gradient (31). Every minute the treadmill speed was increased by 2 km·h$^{-1}$ until 75% of age-predicted HRmax was achieved; beyond this point speed remained constant, and the grade was increased 1% every minute until fatigue. The criterion for achievement of $V_O_{2max}$ was fulfilled by reaching at least 3 of the following: (a) a plateau in oxygen consumption for an increase in exercise intensity (<2.0 ml·kg$^{-1}$·min$^{-1}$ increase), (b) respiratory exchange ratio ≥ 1.1, (c) HR ≥ 85% of an age-predicted maximum (as determined by 220 – participant’s age), (d) voluntary cessation of the test by the participant, and (e) an RPE > 18 (17). The participants were verbally encouraged during the $V_O_{2max}$ test by the experimenters.

**Preload Determination.** After $V_O_{2max}$ determination, and after 10 minutes of rest, participants were placed back on the treadmill and monitored by the metabolic cart to identify the
Static Stretching and Trained Female Distance Runners

speed associated with 65% of the recently determined \( VO_2_{\text{max}} \). The preload speed was determined by estimating the participant’s 65% intensity from the recently performed \( VO_2_{\text{max}} \) test then increasing or decreasing treadmill speed until 65% \( VO_2_{\text{max}} \) was achieved and maintained (<2.0 \( \text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \) increase) for a period of 2 minutes.

**Sit-and-Reach.** Sit-and-reach measurements were conducted using a sit-and-reach box at each visit. The most distant point reached with the fingertips was recorded as the score. On nonstretching days, a baseline measurement was recorded after the anthropometric data were collected and before the QS. A final sit-and-reach test was performed after the performance run. On SS days, a sit-and-reach test was performed before and immediately after the SS protocol. Again, a final sit-and-reach test was performed after the performance run. Only 1 attempt was executed at each of the sit-and-reach measurements to minimize any lasting effects of the sit-and-reach test on the nonstretching condition.

**Preload and Performance Runs.** The first assigned protocol was performed after at least 1 week of recovery from the \( VO_2_{\text{max}} \) test between days 3 and 7 after the onset of menses. The second experimental protocol was completed at least 21 days after the first experimental protocol between days 3 and 7 after the onset of menses. Participants wore the same clothes and running shoes and replicated their diet and hydration status for all sessions. The exercise tests were performed at the same time of the day for all testing sessions. The experimental protocol consisted of a 30-minute preload and 30-minute performance run. On nonstretching days, participants sat quietly for 15 minutes before the exercise protocol. On SS days, SS was preceded by 5 minutes of treadmill walking at 5.5 km \( \text{h}^{-1} \). Four repetitions of each of 5 SS exercises were then performed with an average total SS time of 18 minutes.

Immediately after the QS or SS, participants began with a preload run for 30 minutes at 65% of their predetermined \( VO_2_{\text{max}} \). Participants straddled the treadmill belt while it was SS, were given a countdown, jumped on the treadmill, and started running. Expired gases were collected the entire 30 minutes using a metabolic cart system. The HR was recorded every minute, whereas RPE was recorded every 5 minutes. Running economy was determined by measuring total kilocalorie expenditure and \( VO_2 \) during the 30-minute preload run at each participant’s 65% \( VO_2_{\text{max}} \) value.

Participants were given a 10-minute rest between the preload and performance runs; the volume of water consumed during the rest was recorded during the second visit and replicated in the third visit. In the final 30 minutes, a performance bout was conducted where participants attempted to cover as much distance as possible by controlling their own speed on the treadmill. During the performance run, participants were allowed to view the time display but not the distance covered or speed at which they were currently running. The HR and RPE were recorded in the same manner, while running speed was recorded every minute. Performance was measured as the total distance covered during the final 30 minutes. For both the preload and performance runs, HR and RPE were averaged over each 30-minute trial and then analyzed.

**Table 1.** Acute changes in flexibility after the static stretching protocol (n = 12).*

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Sit-and-reach (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonstretch</td>
<td>Baseline 30.7 ± 8.5</td>
</tr>
<tr>
<td></td>
<td>Postrun 31.4 ± 7.8</td>
</tr>
<tr>
<td>SS</td>
<td>Baseline 29.8 ± 8.6</td>
</tr>
<tr>
<td></td>
<td>Postrun 32.0 ± 8.3</td>
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</tbody>
</table>

*Values expressed as mean ± SD. SS = static stretching.

†Significantly greater than stretch baseline value (p < 0.05).
‡Significantly greater than nonstretch baseline value (p < 0.05).

**Table 2.** Preload run variables (n = 12).*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Nonstretch</th>
<th>SS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range  Mean ( \pm SD )</td>
<td>Range  Mean ( \pm SD )</td>
</tr>
<tr>
<td>HR (b·min(^{-1}))</td>
<td>138–169 157 ± 10</td>
<td>138–173 160 ± 12</td>
</tr>
<tr>
<td>RPE (Borg scale)</td>
<td>8–16 12 ± 2</td>
<td>9–15 12 ± 1</td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>202–348 270 ± 41</td>
<td>197–344 270 ± 41</td>
</tr>
<tr>
<td>65% ( VO_2 ) (ml·kg(^{-1})·min(^{-1}))</td>
<td>28.6–37.3 33.7 ± 3.1</td>
<td>29.2–37.6 33.8 ± 2.3</td>
</tr>
</tbody>
</table>

*HR = heart rate; RPE = rating of perceived exertion. SS = static stretching.
Stretching Protocol. The first stretch was the sit and reach in which participants sat on the floor, extended their legs, and lowered their head toward their knees. The second stretch consisted of participants standing on 1 extended leg, while grasping the heel with their contralateral arm and pulling their knee joint into flexion until their heel touched their buttocks. For the plantar flexors, participants stood with one leg extended, and foot flat on the ground. The opposite leg was then placed on a block raising the ball of the foot above the heel. Once achieved, participants moved forward until they developed maximum tension. The fourth stretch was the lunge. The final stretch, for the gluteal musculature, involved participants crossing their ankle over the contralateral, proximal border of the patella and pulling the rear leg into their chest while supine on the floor.

Dietary Analysis. Participants kept a record of their diet (food and water) for 72 hours before the first experimental run. The record was then given to the participants with instructions to replicate consumption for 72 hours before the second randomly assigned run. After the second run, food logs were collected from each participant.

Statistical Analyses
Statistical analysis was performed using SPSS version 15. Sample size estimation was determined a priori as a function of the significance criterion ($\alpha$), statistical power, and effect size (ES). For this experiment, an ES of 0.8 was used, based on Nelson et al. (30) who examined strength endurance as measured by the number of repetitions performed using knee flexion under SS and nonstretching conditions. Statistical significance was set at $\alpha = 0.05$, ES = 0.8, and a statistical power of 0.80, which yielded a minimum of 12 subjects. Possible effects of the independent variable, SS or nonstretching, on the dependent variables, energy expenditure ($\dot{V}O_2$ and calories), distance covered, HR, and RPE were evaluated statistically by a repeated measures analysis of variance to measure differences between conditions. Data are presented as mean $\pm$ SDs. All significance was accepted at $p \leq 0.05$.

| Table 3. Performance run variables ($n = 12$).* |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| **Variables**   | **Nonstretch**  | **SS**          | **Nonstretch**  | **SS**          |
| Range           | Mean $\pm$ SD   | Range           | Mean $\pm$ SD   |
| Distance (km)   | 4.80–6.55       | 5.53 $\pm$ 0.60| 4.67–6.82       | 5.52 $\pm$ 0.69|
| Speed (km·h$^{-1}$) | 9.7–13.2        | 11.1 $\pm$ 1.2 | 9.4–13.7        | 11.1 $\pm$ 1.4 |
| HRmax (b·min$^{-1}$) | 174–195        | 187 $\pm$ 8    | 178–197         | 188 $\pm$ 7    |
| RPEmax (Borg scale) | 14–20          | 18 $\pm$ 2     | 16–20           | 18 $\pm$ 1     |
| HR (b·min$^{-1}$) | 161–189        | 175 $\pm$ 9    | 168–187         | 177 $\pm$ 6    |
| RPE (Borg scale) | 13–18          | 16 $\pm$ 1     | 15–17           | 16 $\pm$ 1     |

*HRmax = heart rate at end of performance run; RPEmax = rating of perceived exertion at end of performance run; HR = average heart rate over 30 minutes; RPE = average rating of perceived exertion over 30 minutes; SS = static stretching.
Static Stretching and Trained Female Distance Runners

**RESULTS**

**Sit-and-Reach**

The SS protocol caused a significant increase in flexibility between the pre and poststretching conditions as measured by the sit-and-reach test (Table 1). 29.8 ± 8.6 cm vs. 33.1 ± 8.1 cm (F(1,11) = 63.85; p ≤ 0.05; ES = 0.85). There was no significant difference in baseline flexibility between the SS and nonstretch visits, 29.8 ± 8.6 cm vs. 30.7 ± 8.5 cm, respectively. In addition, when the poststretch values were compared to the nonstretch baseline measurements, the resulting increase in flexibility attributed to the SS protocol remained significant (Table 1), 30.7 ± 8.5 cm vs. 33.1 ± 8.1 cm (F(1,11) = 10.72; p ≤ 0.05; ES = 0.49).

**Preload and Performance Runs**

There were no significant differences between HRs (157 ± 10 b min⁻¹) or RPEs (12 ± 2 vs. 12 ± 1) during the preload run in the nonstretched and SS conditions, respectively. In addition, there were no differences in calorie expenditure (270 ± 41 kcal) or relative VO₂ at 65% (33.2 ± 3.1 vs. 33.8 ± 2.3 ml kg⁻¹ min⁻¹) during the preload run in the nonstretched and SS conditions (Table 2), respectively.

During the performance run, the variation in distance covered during the exercise protocol ranged from a minimum run of 4.67 km to a maximum performance run of 6.82 km. There were no significant differences in total distance covered during the performance run in the nonstretched and SS conditions (5.53 ± 0.60 vs. 5.52 ± 0.69 km), respectively. Visual inspection of Figure 1 shows little variation between the SS and nonstretched conditions on a case-by-case basis with decreased performance in half of the participants. As would then be expected, there were no differences in running speed during the performance run under the nonstretched and SS conditions (11.1 ± 1.2 vs. 11.1 ± 1.4 km h⁻¹). There were also no significant differences in HRs (187 ± 8 vs. 188 ± 7 b min⁻¹) or RPEs (18 ± 2 vs. 18 ± 1) in the nonstretched and SS conditions at the end of the 30-minute run, nor were there significant differences in the average HRs (175 ± 9 vs. 177 ± 6 b min⁻¹) and RPEs (16 ± 1 vs. 16 ± 1) during the 30-minute performance run in the nonstretched and SS conditions (Table 3), respectively.

**DISCUSSION**

The purpose of this study was to compare the effects of an SS protocol on running economy and distance performance in trained female distance runners. The main findings were that, in female runners, SS increased flexibility significantly, as measured by a sit-and-reach test, but the increased ROM did not have any significant effect on running economy or distance performance. These findings are contrary to a comparable study performed in our laboratory that found a significant decrease in running economy and distance performance in trained male runners (42).

As previously stated, work in the field of strength, power, and muscular endurance, has found decreases in performance after acute bouts of SS and attributes the decline in performance to viscoelastic changes in MTU stiffness and neural alterations in motor unit activation and reflex sensitivity (4,7,20,22,30,34,39,44). Although aerobic endurance performance has not been extensively tested to determine the effects of SS on performance, components of aerobic performance have been tested. Also, studies have found decreased running economy after SS, primarily attributing these declines to alterations in the viscoelastic properties of the MTU (1,5,8). A positive relationship was found between stiffness and running economy when comparing runners with similar VO₂max values; Craib et al. found that 47% of the variation in running economy could be explained by changes in flexibility. Although flexibility was significantly increased in our study, there were no changes in running economy at 65% of VO₂max.

Even though decreased performance has been seen in slower movement muscular contractions (6), it is possible that increased lower body flexibility may further decrease the amount of elastic energy storage and lead to increased motor unit activation and additional muscle activity in an attempt to stabilize the body during higher speed running (5,8). However, even during the final 30-minute performance run, at an average intensity of 94% of HRmax, there was no difference between the presumably stiffer nonstretched and SS conditions. At this intensity, fluctuations in HR are primarily responsible for differences in VO₂ and because running speeds were similar between trials, it can be assumed that there was no difference in economy at the higher intensity.

One limitation of this study was that we did not control for the type of distance runner. In a study by Daniels and Daniels, the investigators found that the running speed during economy measurements significantly impacted which type of runner was most economical. The runners were separated into short distance (800–1,500 m), medium distance (3,000–5,000m), and long distance (marathon) athletes. When the speed of the economy trials was set at race pace or faster, the short distance athletes were most economical. When the speed tested was slower than race pace, the long distance athletes were most economical (9). Because we did not separate runners into these groups, differences in specificity may have masked possible effects on running economy.

In addition to the differences between aerobic and the predominantly anaerobic activities of past research, previous work has shown significant gender differences in the viscoelastic properties of the MTU between men and women (15,25,43). In a study by Granata, mean leg stiffness values were almost 29% greater in men (33.9 ± 8.7 kN m⁻¹) than in women (26.3 ± 6.5 kN m⁻¹) (15). If MTU stiffness plays a major role in performance during running, men may benefit more from the energy stored in passive elastic components. However, numerous studies investigating the effects of SS on
muscular power and strength in women have shown decreases in performance similar to that of men (2,13,40).

Studies showing decreased efficiency, peak torque, and power in women may be the result of impairments to immediate short-duration muscular activity (2,13,38,40). Depino et al. found that alterations in flexibility after SS were transient and disappeared after 6 minutes of recovery after the stretching protocol (12). In our research design, the SS was followed by a sit-and-reach measurement, attaching our runners to the metabolic cart and then exercising at a submaximal intensity. It is possible that any effect of the SS was no longer present when averaged over a 30-minute period. Also, if women are less stiff than men, they may recover faster from any negative effects on the viscoelastic properties of the MTU.

Finally, to control for hormonal fluctuations experienced by female athletes, 3–4 weeks separated experimental sessions. When compared to the week of separation from previous aerobic performance studies in men, our design leaves a great deal of room for training effects between visits. Although we controlled for training history, we did not control for volume beyond setting a minimum requirement of 20 miles per week. Significant variation in previous training volume and potential underreporting of training volume between visits could lead to significant variability in performance measurements and may have hidden any effect of the SS protocol on running economy and endurance performance. Future research, with different measures of stiffness, should be performed in larger sample sizes of trained male and female runners to determine if gender continues to have an effect on economy and performance.

**Practical Applications**

The proposed mechanisms associated with declines in performance, decreased neural activation, and MTU stiffness may not impact female athletes competing in longer duration aerobic activities. If the effects of SS do not last more than 5–10 minutes and have no impact on economy or performance, it may not be necessary for female endurance athletes to abandon SS. The negative psychological impact of altering precompetition routine may outweigh any possible benefit associated with removing SS from their warm-up. However, it should be noted that no performance or injury prevention improvements have been seen after acute bouts of SS. Therefore, to maximize effectiveness preperformance, SS should be phased out of current programs and not added to future training programs.

**References**


