Effects of Static Stretching on Energy Cost and Running Endurance Performance

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Abstract

Wilson, JM, Hornbuckle, LM, Kim, J.-S, Ugrinowitsch, C, Lee, S.-R, Zourdos, MC, Sommer, B, and Panton, LB. Effects of static stretching on energy cost and running endurance performance. *J Strength Cond Res* 24(9): 2274–2279, 2010—Stretching before anaerobic events has resulted in declines in performance; however, the immediate effects of stretching on endurance performance have not been investigated. This study investigated the effects of static stretching on energy cost and endurance performance in trained male runners. Ten trained male distance runners aged 25 ± 7 years with an average $\dot{V}O_2max$ of 63.8 ± 2.8 ml/kg/min were recruited. Participants reported to the laboratory on 3 separate days. On day 1, anthropometrics and $\dot{V}O_2max$ were measured. On days 2 and 3, participants performed a 60-minute treadmill run randomly under stretching or nonstretching conditions separated by at least 1 week. Stretching consisted of 16 minutes of static stretching using 5 exercises for the major lower body muscle groups, whereas nonstretching consisted of 16 minutes of quiet sitting. The run consisted of a 30-minute 65% $\dot{V}O_2max$ preload followed by a 30-minute performance run where participants ran as far as possible without viewing distance or speed. Total calories expended were determined for the 30-minute preload run, whereas performance was measured as distance covered in the performance run. Performance was significantly greater in the nonstretching (6.0 ± 1.1 km) vs. the stretching (5.8 ± 1.0 km) condition ($p < 0.05$), with significantly greater energy expenditure during the stretching compared with the nonstretching condition (425 ± 50 vs. 405 ± 50 kcals). Our findings suggest that stretching before an endurance event may lower endurance performance and increase the energy cost of running.

Key Words muscle stiffness, flexibility, economy, sit-and-reach, rating of perceived exertion

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24(9)/2274–2279

Journal of Strength and Conditioning Research

Introduction

The ability to effectively use energy is a critical component of endurance performance, particularly among elite athletes. In fact, previous studies have reported a strong association between running economy (RE) (i.e., lower energy consumption at a given velocity) and long-distance performance (15,19). Furthermore, RE seems to be the most important variable to discriminate top-level athletes in a homogeneous group of long-distance runners. Thus, training routines should avoid exercises that may increase the energy cost needed to maintain a given velocity or to complete a performance task (5).

Static stretching exercises are a common part of the warm-up routine of several athletes and physical activity practitioners in an attempt to improve performance and reduce the risk of injuries. However, static stretching appears to acutely decrease muscle-force production capacity. For instance, static stretching has been shown to decrease leg press 1-repetition maximal tests (3), 20-m sprint performance (16), vertical jumping height (21), and knee-extensor concentric torque (6). In addition to this acute effect, Fowles (9) reported a residual effect in which maximum plantar flexion torque remained depressed even 60 minutes after the stretching routine.

These decrements in performance are attributed to greater stress relaxation of the muscle tissue, which leads to lower muscle-tendon stiffness and strength (13,14). Decreasing strength and muscle-tendon stiffness may be prejudicial to endurance runners because Arampatzis et al. (1) reported that individuals with high muscle strength and muscle-tendon stiffness are more efficient (i.e., higher RE) than individuals with low muscle strength. Therefore, it seems reasonable to suggest that as static stretching decreases force production and muscle-tendon stiffness, for up to 1 hour, it may increase energy consumption during an endurance event, decreasing the performance of trained athletes. The purpose of the present study was to investigate the effects of static stretching on endurance performance and total energy cost measured in calories expended on a treadmill in trained long-distance male runners.

Methods

Experimental Approach to the Problem

This study had a crossover design in which participants underwent a control and an experimental condition in a balanced fashion. In the control condition, participants had sit-and-reach performance assessed before and after quiet sitting, followed by a 30-minute preload run at 65% of the $\dot{V}O_2$max and a 30-minute performance run at a self-selected speed. In the experimental condition, participants followed the same procedures but performed passive static stretching exercises between the sit-and-reach assessments instead of sitting quietly. Caloric expenditure during the preload and performance runs were compared between the control condition and the static stretching condition to evaluate eventual losses of running efficiency.

Subjects

Ten male middle- and long-distance runners (aged 25 ± 7 years) with an average $\dot{V}O_2$max of 63.8 ± 2.8 ml/kg/min and body fat % of 6.9 ± 2.0 % were recruited for the study from Florida State University running and triathlon teams. Criteria for acceptance in the study included a $\dot{V}O_2$max ≥ 55 ml/kg/min, a minimum training average of 20 miles/wk, and recent (≤3 months) participation in a competitive endurance running event (>5 km). Screening for weekly mileage run and recent competitive history was obtained by phone before any testing. All runners were members of the Florida State University track and field team and had a daily endurance-training schedule, as part of their off-season training routine. In addition, they performed stretching exercises on a daily basis. Participants were informed of the experimental risks and signed an informed consent document before the investigation. The investigation was approved by an Institutional Review Board for use of Human subjects.

Preliminary Measurements

Participants reported to the laboratory on 3 separate occasions, separated by a minimum of 1-week interval to control for the specific day and time the experimental protocol was performed. Subjects were asked to refrain from intense exercise 48 hours before each visit. On the first visit, subjects' body composition was estimated using the sum of 3 skinfolds for men (12). $\dot{V}O_2$max was determined on a motor-driven treadmill (ErgoXELG3, Woodway Waukesha, WI) using a progressive exercise test to exhaustion protocol as described previously (18). Gas exchange, caloric expenditure, and ventilatory parameters were measured by indirect calorimetry using a metabolic measurement system (Parvomedics Truemax 2400, Consentius Technologies, Sandy, UT). Heart rate was monitored using a heart-rate monitor (Polar Electro, Lake Success, NY). After the $\dot{V}O_2$max test, the running speed corresponded to 65% of participants $\dot{V}O_2$max was determined by walking the participants at 6.4 km/h for 1 minute, followed by a 0.8 km/h increase each minute until the subject's $\dot{V}O_2$ values reached a steady state at 65% of his previously recorded $\dot{V}O_2$max.

Experimental Protocol

The experimental protocol took place on visits 2 and 3 and consisted of a 60-minute run on the same treadmill. The 60-minute run was fractionated into a preload and performance run (20). Participants began with a preload run for 30 minutes at 65% of their $\dot{V}O_2$max in which metabolic measurements for caloric expenditure was determined by open circuit indirect calorimetry continuously and averaged over 30-second intervals (20). Total caloric expenditure was obtained through the sum total of the caloric expenditure averages obtained on each 30-second interval. On completion of the preload run, the treadmill was stopped and participants were disconnected from the metabolic cart. Between the preload and performance runs, participants were permitted up to 2 minutes to drink water with the stipulation that they would need to drink the same amount of water during the rest period before their second performance run at their next laboratory visit. During the 30-minute performance run, participants were asked to cover the longest distance possible. They were allowed to view the time display and to control the treadmill speed. However, participants were prohibited to know the distance covered and the speed at which they were running, to avoid psychological conditioning between the control and the stretching trials (7). In addition, heart rate and ratings of perceived exertion (RPE) were taken every 5 minutes for both the preload and performance runs.

Stretching Protocol

The stretching protocol that was used in the present study was similar to that of Nelson et al. (17) and Egan et al. (8) but with a few modifications. Four, 30-second repetitions each of 5 stretching exercises were performed with an average total stretching time of 16 minutes (17). For the hip extensors and knee flexors, participants performed the sit-and-reach, while the plantar flexors were stretched by standing and lowering both heels on the edge of a block. The following stretches were performed separately on both legs. For the knee-extensor muscles, participants stood on one leg, while grasping the ankle of the opposite leg and pulling their knee joint into flexion until their heel touched their buttocks. For the hip flexors, participants moved into a lunge position with 1 knee in contact with the mat, while gently shifting their weight forward until they could feel a stretch of mild discomfort in the hip flexors. For the gluteus maximus, participants crossed their left foot over their right knee while clasping their hands behind the right thigh and gently pulling the leg in toward their chest. On completion, these stretches were repeated on the opposite side. On nonstretching days, participants sat quietly for 16 minutes before the exercise protocol (17). A sit-and-reach test using a Figure Finder Flex-Tester sit-and-reach box (Novel Products, Inc., Rockton, IL) was performed before the 16-minute protocols and immediately after to determine changes in range of motion. The score of the sit and reach was determined from the best of 3 reaches.

Dietary Control

To control for diet, participants kept a record of their diets (all food and beverages) for 72 hours before the first experiment they participated in. The diet was then given to the subject with instructions to replicate the food consumption for 72 hours before the second assigned experiment (2). Participants were also instructed to keep activity to a minimum and to not perform any strenuous exercise 48 hours before the testing period.

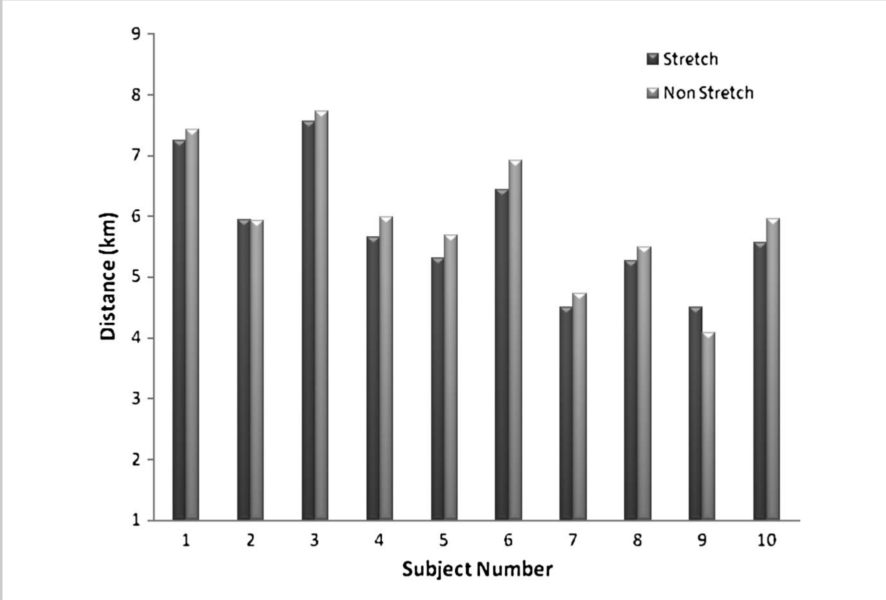

Figure 1. Distance run in 30 minutes for each subject under stretching and nonstretching conditions.

Statistical Analyses

The influence of the static stretching routine on the sit-and-reach performance was tested with a 2 × 2 (trial × time) repeated measures analysis of variance (ANOVA). Possible effects of static stretching on total caloric expenditure, on both the preload and performance runs, were evaluated using paired *t*-tests (i.e., no stretching × stretching condition). A 2 × 7 (group × time) repeated measures ANOVA and a 2 × 6 (trial × time) repeated measures ANOVA were used to test for differences in heart rate and RPE, respectively, during both the 30-minute preload and 30-minute performance runs. Whenever a significant *F*-value was obtained, a Tukey post hoc test was performed for multiple comparison purposes. Significance was accepted at $p \leq 0.05$. Data are reported as mean and *SD* in the tables and as mean and standard errors in the figures. The statistical procedures were performed using the software Statistica and the level of significance was set at $p < 0.05$.

Results

Flexibility

Sit-and-reach average values increased significantly after the stretching exercises from 24.7 ± 14.6 to 27.2 ± 14.6 cm ($p \leq 0.05$) and did not change (25.2 ± 14.6 to 25.5 ± 14.6 cm, $p > 0.05$) after the quiet sitting.

Distance Run

After the stretching exercises, the mean distance run was significantly greater (3.4 %) in the nonstretching (6.0 ± 1.1 km) vs. the stretching (5.8 ± 1.0 km) condition ($p \leq 0.05$). Individual subject data are plotted in Figure 1, which graphically demonstrates that 8 of 10 participants ran further after quietly sitting as compared with a bout of stretching with a range of 0.2–0.5 more kilometers covered.

Energy Cost

The average velocity run at 65% $\dot{V}O_2$max was 10.1 ± 1.6 km/h (Table 1). After the stretching exercises, the mean energy expended was significantly greater in the stretching (425 ± 55 kcals) vs. the nonstretching (405 ± 53 kcals) condition ($p \leq 0.05$). Figure 2 depicts total caloric expenditure in each subject during the 30-minute run at 65% $\dot{V}O_2$max. These results show that 8 of 10 participants expended more calories after stretching when compared with the nonstretching condition with absolute differences ranging from 7 to 47 more kilocalories.

Table 1. Subject characteristics.

Age (y)	Height (cm)	Weight (kg)	%BF	$\dot{V}O_2$max (ml/kg/min)	65% $\dot{V}O_2$max speed (km/h)
25.0 ± 7.0	173.4 ± 11	65.0 ± 18	6.9 ± 2.0	64.0 ± 2.8	10.1 ± 1.6

Values are means ± *SD*.
%BF = percent body fat; $\dot{V}O_2$max = maximal oxygen uptake; and max = maximal.

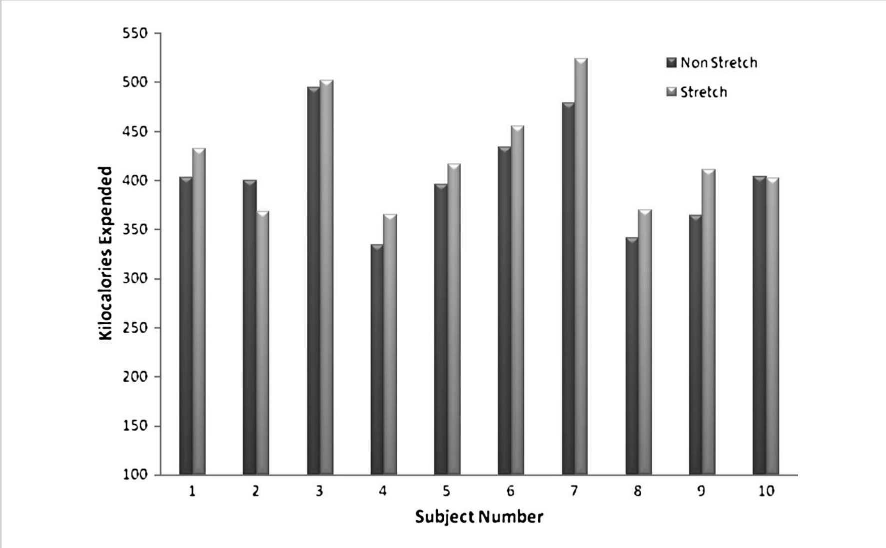

Figure 2. Energy expended (kcals) in each subject under stretching and nonstretching conditions.

Heart Rate and Ratings of Perceived Exertion

There was no group × time interaction for heart rate during the preload or performance runs; however, there were significant time effects for both ($p \leq 0.05$). Mean heart-rate values peaked at 170 ± 5 and 167 ± 6 b·min^{-1} in the stretching and nonstretching conditions, respectively, during the preload run (Figure 3) and at 193 ± 2 and 188 ± 4 b·min^{-1} in the stretching and nonstretching conditions, respectively, during the performance run (Figure 3). Similarly, no group × time interaction was found for RPE during the preload or performance runs; however, there were significant time

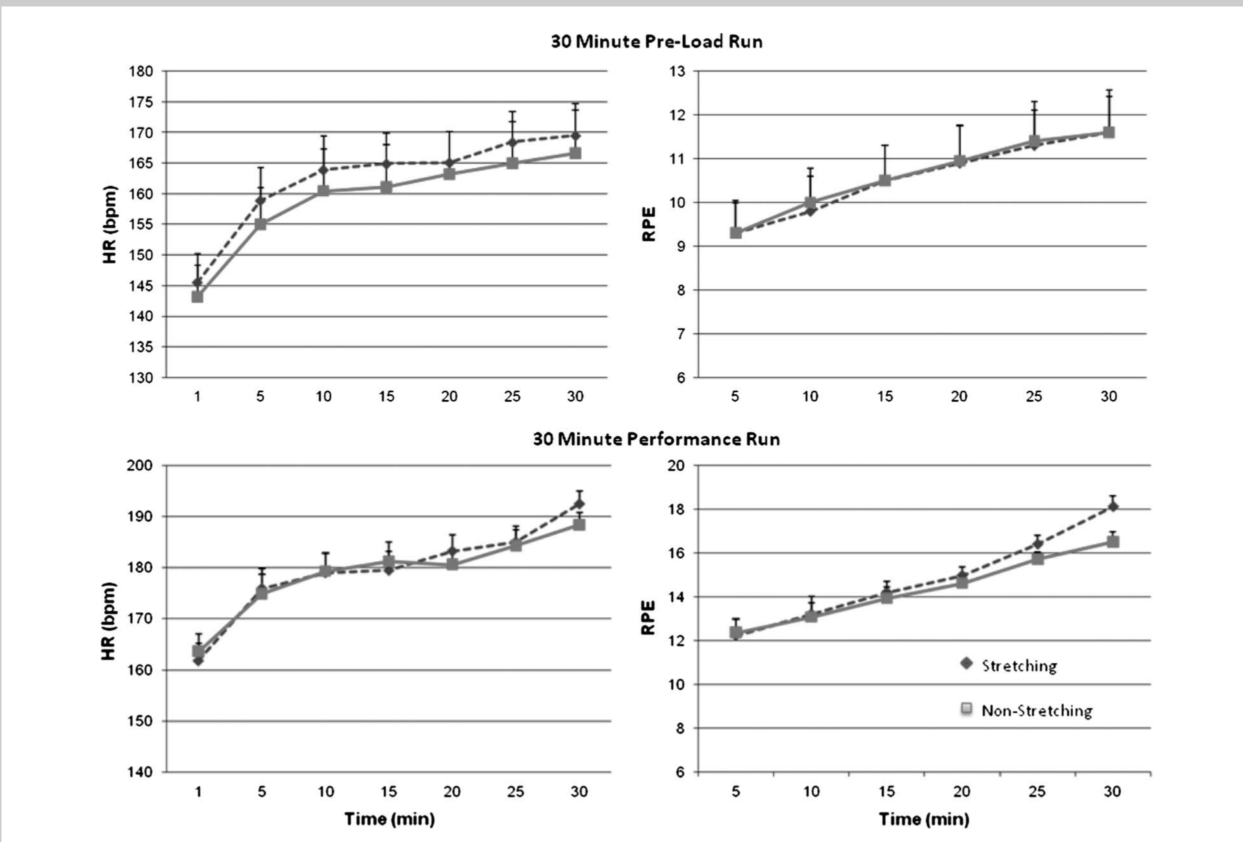

Figure 3. Heart rate (b·min^{-1}) and ratings of perceived exertion values from minutes 1 to 30 under stretching and nonstretching conditions during both the preload and performance runs. Values are mean ± *SE*, $^*p \leq 0.05$, significantly different from 0 time point, there were no differences among conditions.

effects for both ($p \leq 0.05$). Mean RPE values peaked at 12 ± 1 and 12 ± 1 in the stretching and nonstretching conditions, respectively, during the preload run (Figure 3), and at 18 ± 1 vs. 17 ± 1 in the stretching and nonstretching conditions, respectively, during the performance runs (Figure 3).

Discussion

The purpose of this study was to investigate the effects of static stretching on endurance performance and total calories expended on a treadmill in trained male runners. The main findings in this study were that stretching lowered distance covered during a 30-minute performance run (Figure 1) and increased the energy cost of running at 65% of the $\dot{V}O_2max$ trial (Figure 2).

Bacurau et al. (3) reported a 12% increase in the sit-and-reach performance after a static protocol. The reported increment was slightly lower than ours (17%); however, they indicate that static stretching has the ability to acutely increase the range of motion in the target joints. It is also interesting to notice that acute stretching studies often do not report the changes in range of motion after stretching protocols, which limits the ability to interpret our data.

The higher energy consumption during the preload trial may indicate a decreased mechanical efficiency of the muscle system, which seems to be supported by the lower distance covered in the performance trial. A possible explanation for performance deterioration is that static stretching negatively affects the ability of the muscle tissue to produce force (6). The decrement in passive torque after this type of stretching indicates a decreased viscosity of the muscle tissue due to a greater stress relaxation (13,14). These changes are responsible for the lower muscle-tendon stiffness observed after stretching (14). Arampatzis et al. (1) reported a strong positive association between muscle-tendon stiffness and energy cost at a given velocity. Thus, it is possible that decrements in muscle-tendon stiffness after static stretching may have induced an increment in the number of motor units recruited to perform the same mechanical work. Activation of more motor units in a given condition may increase energy expenditure and anticipate fatigue onset. Another possible explanation is that the decline in muscle-tendon stiffness may have changed the stride frequency during the running trials. It has been reported that endurance athletes have preferred stride frequency and amplitude in which energy consumption is minimized (11).

One limitation in our study was that it only included male participants. This is important as the negative relationship found between energy cost and flexibility in men does not appear to be present in female athletes (4). Moreover, research indicates stiffness values that are 29% lower in women as compared with men (10). Given that stiffness seems to play a role in performance and energy cost and that it is a major variable affected acutely by stretching, it is conceivable that differences between men and women may modulate the response of stretching on the variables measured in our study. A second limitation includes a general lack of objective measures such as changes in stiffness and ground contact times to determine the actual mechanisms underlying stretching effects on both the performance and the energy cost of running.

In summary, this study provides 2 key findings concerning endurance performance after a bout of static stretching. First, it extends the detrimental effects of stretching from activities requiring high force and velocity components to the domain of muscle endurance performance. Second, this research suggests that static stretching increases the energy cost of running at moderate-intensity exercise. Therefore, in events such as long-distance running, where success is related to producing work with minimal energy cost, it may be unfavorable for coaches to have athletes warm up in a manner that has them perform long, static stretches immediately before a middle- or long-distance running event. Further studies should address the mechanism behind the decrements in endurance performance after static stretching exercises.

Practical Applications

Static stretching has been used during the warm-up routine of several athletes. However, our results show that static stretching may impair endurance performance up to 60 minutes and increase caloric expenditure. Even though the increments in caloric expenditure were low (~5%), it may produce some advantage to the runner at the end of close competitions. Therefore, static stretching should be avoided before endurance events, at least for young male endurance runners. The effect of other forms of stretching (i.e., dynamic stretching) on endurance performance remains to be tested.

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