TITLE

Acute effect of dynamic stretching on endurance running performance in well-trained male runners

BRIEF RUNNING HEAD

Effect of dynamic stretch on endurance performance

LABORATORY WHERE THE RESEARCH WAS CONDUCTED

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ABSTRACT

The purpose of the present study was to clarify the acute effect of dynamic stretching (DS) on relative high-intensity endurance running performance. The endurance running performances of seven well-trained middle or long distance male runners were assessed on a treadmill following two types of pretreatment. The pretreatments were non-stretching (NS) and DS treatment. In the DS treatment, DS was performed as one set of 10 repetitions as quickly as possible for the five muscle groups in lower extremities. The endurance running performances were evaluated by time to exhaustion (TTE) and total running distance (TRD) during running at a velocity equivalent to 90% maximal oxygen uptake ($\dot{V}o_2max$) in each subject. The oxygen uptake ($\dot{V}o_2$) during running was measured as an index of running economy (RE). The TTE (928.6 ± 215.0 seconds) following DS treatment was significantly ($p<0.01$) prolonged compared with that (785.3 ± 206.2 seconds) following NS. The TRD (4301.2 ± 893.8 meters) following DS treatment was also significantly ($p<0.01$) longer than that (3616.9 ± 783.3 meters) following NS. The changes in the $\dot{V}o_2$ during running, however, did not significantly ($p>0.05$) differ between the pretreatments. The results demonstrated that the DS treatment improved the endurance performance of running at a velocity equivalent to 90% $\dot{V}o_2max$ in well-trained male runners, although it did not change the RE. This running velocity is equivalent to that for a 3000 or 5000 meter race. Our finding suggests that performing DS during warm-up before a race is effective for improving performance.

KEYWORDS

warm-up, middle or long distance running, running economy

INTRODUCTION

Stretching exercises are incorporated into warm-up protocols of general sports. The purposes are the prevention of sports-related injuries and the improvement of sports performance (20). Recent studies, however, reveal that the static stretching utilized during general warm-up protocols acutely impairs explosive (2,9,10,17,21) or endurance performance (3,12,17,25). On the other hand, several studies (2,9,17,19,26,27,28) have clarified that dynamic stretching acutely improves explosive performance. Only two studies (5,29), however, investigated the acute effects of dynamic stretching on endurance running performances. Hayes and Walker (5) found that slow velocity dynamic stretching did not acutely change running economy during treadmill running at an intensity of 75% maximal oxygen uptake ($\dot{V}O_{2}max$) in well-trained runner. In contrast, Zourdos et al. (29) found that dynamic stretching as two sets of four repetitions acutely impaired running economy during treadmill running at an intensity of 65% $\dot{V}O_{2}max$ in well-trained runner. Zourdos et al. (29), however, indicated that the total distance during running as fast as possible for 30 minutes on a treadmill did not change following the dynamic stretching. Thus, it has not been demonstrated in the previous studies that dynamic stretching acutely improved the endurance running performances in well-trained athletes. Nevertheless, it was recommended to utilize dynamic stretching during warm-up in endurance running events as if the positive acute effect of dynamic stretching on explosive performance was applied to endurance performance. Actually, endurance athletes and their coaches also utilize dynamic stretching during actual warm-ups. Judge et al. (8) reported that the coaches of endurance athletes utilized dynamic stretching (41.5%) or a combination of static stretching and dynamic stretching (44.7%).

The protocols for dynamic stretching in the two previous studies (5,29) might not be suitable for acutely improving endurance running performance. Hayes and Walker (5) utilized slow-velocity dynamic stretching. Zoudors et al. (29) utilized dynamic stretching in only two sets of four repetitions. A systematic review (26) investigated the optimal protocol for dynamic stretching to acutely improve explosive performance, but not endurance performance. The review suggested that dynamic stretching should be performed “as quickly as possible” and that the optimal volume of dynamic stretching was “one-two set(s)” of “10-15 repetitions”. The systematic review (26) also indicated that the optimal dynamic stretching improved 2.6-10.6% in jump performances. Hudgins et al. (6) demonstrated that three-step jump performance have positive relations with endurance running performance in 800 m (r = 0.83), 3000 m (r = 0.72) and 5000 m (r = 0.71). Spruss et al. (22) revealed that plyometric training improved jump and endurance running performance without any changes in $\dot{V}o_2max$. These findings let us suppose that the optimal protocol for dynamic stretching to acutely improve explosive performance may acutely improve endurance running performance.

Previous studies have investigated the acute effects of dynamic stretching on running economy at 60% (29) or 75% (5) of $\dot{V}o_2max$. Furthermore, in a previous study (29) that examined the acute effect of dynamic stretching exercises on endurance running performance, the total running distance for 30 minutes at self-controlled velocity in each subject was evaluated as an index of endurance running performance. The exercise intensity of running were equivalent to approximately 80% $\dot{V}o_2max$ (average $\dot{V}o_2$ during running·average $\dot{V}o_2max^{-1}\cdot 100$). However, high-level endurance runners have to run at higher exercise intensities during actual track-and-field endurance running events (7). For instance, the exercise intensity of the marathon is equivalent to 85% $\dot{V}o_2max$ (7). The exercise intensities of other long or middle distance events are equivalent to more than 90% $\dot{V}o_2max$ (7). Therefore, it was reasonable to think that the previous findings might not directly influence performance in the marathon or in long or middle distance running events. Thus, the previous studies are not sufficient to infer the acute effects of dynamic stretching techniques on endurance running performances in well-trained long or middle distance runners.

The purpose of the present study was to clarify the acute effect of the optimal protocol for dynamic stretching to improve explosive performance on endurance running performance in well-trained long or middle distance runners. The present study examined the acute effect on endurance running performance at an exercise intensity of 90% $\dot{V}o_2max$, which is assumed to be that achieved in 3000-5000 meter distance running events (7). We hypothesized that the protocol of dynamic stretching may improve endurance running performance.

METHODS

Experimental Approach to the Problem

In order to determine the validity of our hypothesis, experiments consisting of three testing days interspersed with more than two days of rest were performed. On day one, each subject visited our laboratory to receive instructions. A test of $\dot{V}o_2max$ with maximum incremental exercise test utilizing a respiratory gas analyzer and a treadmill was conducted in order to determine each subject's relative running velocity while measuring their endurance running performance. On day two (Figure 1), each subject visited the laboratory and rested. After resting, a blood lactate accumulation was assessed and then the mask of the respiratory gas analyzer and transmitter of heart rate were worn. Endurance running performance was assessed after one of two types of pretreatment: (a) non-stretching by resting in a sitting position, or (b) performing dynamic stretching of lower extremities. Pretreatment on day two was determined at random for each subject. The running velocity during the assessment of the endurance running performance was equivalent to 90% of the $\dot{V}o_2max$ assessed on day one for each subject. Each subject continued running to exhaustion on the treadmill set at the running velocity. The time to exhaustion and total running distance were assessed as indices of the endurance running performance. The $\dot{V}o_2$ from rest to exhaustion was measured as an index of running economy using the respiratory gas analyzer. Immediately after exhaustion, lactate accumulation and heart rate were measured. On day three, the endurance running performance was also assessed after the opposite pretreatment from day two. Data were compared between the non-stretching and dynamic stretching pretreatments in order to examine the acute effects of dynamic stretching on endurance running performance and metabolism. The experiments of both pretreatments for each subject were performed at the same time of day in consideration of circadian rhythm. The temperature of the laboratory was set to 20-24 degrees Celsius throughout all experiments.

(Figure 1 about here)

Subjects

Seven healthy well-trained middle or long distance male runners [average ± standard deviation: age 21.3 ± 2.1 years (19-24 years) ; height 170.3 ± 3.1 centimeters; body mass 60.0 ± 5.5 kilograms; $\dot{V}o_2$max 4.35 ± 0.53 liters·minute^{-1}; $\dot{V}o_2$max·body mass^{-1} 72.3 ± 3.7 milliliters·kilogram^{-1}·minute^{-1}] took part in the present study. They belonged to the Track and Field Club of Hokkaido University. All subjects were free of injuries in their lower extremities. All experiments were carried out between February and March. Since the period was off-season, the subjects did not perform any vigorous training. We cautioned each subject to avoid performing intense exercises or training (e.g., running, resistance or stretching) on the day of each experiment or the previous day. Moreover, we instructed each subject to eat similar meals on the day of each experiment and on the previous day, and to finish meal of that day two hours before experiment. In addition, we warned each subject to avoid drinking alcohol on the previous day and caffeine on the experimental day. All subjects were informed of the protocol, purpose, and risks of the present study, and informed consent was obtained from all subjects. The study was approved by the ethics committee of Rakuno Gakuen University.

Procedures

Maximum incremental exercise test

The maximum incremental exercise test was performed using a motor-driven treadmill (Nishikawa Iron Co. Ltd., Kyoto, Japan) to determine the $\dot{V}o_2max$ and the relative running velocity at 90% $\dot{V}o_2max$ for each subject in reference to the protocols in previous study (24). Each subject continued to run for four minutes at each velocity with rest a period of one minute between velocities. The first running velocity was 167 meters·minute^{-1} (six minutes·kilometer^{-1}). Then, the running velocities were increased as below; 200 meters·minutes^{-1} (five minutes·kilometer^{-1}), 222 meters·minutes^{-1} (four minutes and 30 seconds·kilometer^{-1}), 250 meters·minutes^{-1} (four minutes·kilometer^{-1}), 273 meters·minutes^{-1} (three minutes and 40 seconds·kilometer^{-1}), 300 meters·minutes^{-1} (three minutes and 20 seconds·kilometer^{-1}), 333 meters·minutes^{-1} (three minutes·kilometer^{-1}), and 364 meters·minutes^{-1} (two minutes and 45 seconds·kilometer^{-1}). The criterion of finishing the test was 1) when the heart rate exceeded the predicted maximal heart rate of each subject (220 beats·minutes^{-1} - age), 2) when the respiratory quotient (RQ) exceeded 1.1, or 3) when the subject could not continue to run. All subjects finished by criteria no. 3). $\dot{V}o_2$ was measured every ten seconds by the mixing chamber method utilizing a respiratory gas analyzer ($\dot{V}$O2000, S&ME Co. Ltd., Tokyo, Japan) throughout the running test. The maximum $\dot{V}o_2$ value for ten seconds in the maximum increment exercise test was assessed as $\dot{V}o_2$max. Reliability of the $\dot{V}o_2$max was ascertained by two tests interspersed with more than two days of rest. The reliability of $\dot{V}o_2$max was assessed using an interclass correlation coefficient (ICC) and a coefficient of variation (CV). The ICC and CV were 0.787 and 1.9%, respectively. The running velocity at 90% $\dot{V}o_2$max for each subject was calculated from the relationship between the running velocities and the $\dot{V}o_2$ obtained by the running test. The average running velocity at 90% $\dot{V}o_2$max was 280.5 ± 25.6 meters · minutes^{-1} (three minutes and 35.4 ± 19.6 seconds·kilometer^{-1}).

Pretreatment

In the dynamic stretching treatment (Figure 2), the subjects performed dynamic stretching of five target muscles, i.e., hip extensors and flexors, leg extensors and flexors, and plantar flexors, in upright positions in reference to the protocols in previous studies (27,28). The volume of dynamic stretching was utilized one set of 10 repetitions that were the minimum optimal volume of dynamic stretching to improve explosive performance suggested in previous review (26). The subjects performed 10 repetitions of each stretch synchronized with the tempo of a digital metronome at 30 beats·minute^{-1} (0.5 Hertz). Prior to performing each stretch, we explained to the subjects the muscle groups that should be contracted (i.e., antagonist of target muscle groups). The contraction was carried out as quickly and powerfully as possible without bouncing so that subject's target muscle groups were stretched as quickly as possible (19,27,28). Each stretch was performed for one set on both lower extremities, and then on the next target muscle group without a rest. The total duration of the dynamic stretching treatment was three minutes and 37 ± 12 seconds. The endurance running performance was assessed five minutes after beginning to perform the dynamic stretching treatment (i.e., one minute and 23 ± 12 seconds after dynamic stretching). The order of dynamic stretching was: 1) Hip extensors; the subject leaned forward and raised his foot from the floor with his hip and knee joint lightly flexed. Then, the subject contracted his hip joint extensors and extended his hip joint so that his leg was extended to posterior aspect of his body (Figure 2a). 2) Hip flexors; the subject contracted his hip joint flexors with his knee joint flexed and flexed his hip joint so that his thigh came up to his chest (Figure 2b). 3) Leg extensors; the subject contracted his hamstrings and flexed his knee joint so that his heel kicked his buttock (Figure 2c). 4) Leg flexors; the subject contracted his hip joint flexors and flexed his hip joint, raising his thigh parallel to the ground with his knee joint flexed at about 90 degrees. Then, the subject contracted his quadriceps with the height of his thigh maintained and extended his knee joint so that his leg extended to the anterior aspect of his body (Figure 2d). 5) Plantar flexors; the subject raised one foot from the floor and fully extended the knee joint. Then, the subject contracted his dorsiflexors and dorsiflexed his ankle joint so that his toe was raised (Figure 2e).

In non-stretching, each subject rested in a sitting position for five minutes that was equivalent to duration in the dynamic stretching treatment. The endurance running performance was assessed immediately after that.

(Figure 2 about here)

Measurements during endurance running performance

Each subject continued running to exhaustion on the treadmill set at a velocity equivalent to his 90% $\dot{V}o_2max$. The criterion of exhaustion was 1) when each subject could not continue to run, or 2) when each subject could not stay in our defined position for more than 10 seconds. The defined position was a range of anteroposterior one meter from center of the treadmill. The continuous time of running to exhaustion was assessed as an index of endurance running performance. The total running distance also was calculated by the running velocity at 90% $\dot{V}o_2max$·the time to exhaustion. In addition, the $\dot{V}o_2$ during rest, pretreatment and running were sampled every 10 seconds with the respiratory gas analyzer ($\dot{V}O2000$). In both the pretreatments, the average $\dot{V}o_2$ for one minute was calculated at rest for one minute before treatment and at from the start of running to one minute before exhaustion. The $\dot{V}o_2$ during running was taken as an index of running economy. In the dynamic stretching treatment, the average $\dot{V}o_2$ while performing dynamic stretching was also calculated. Blood sampling were performed from the earlobe at rest and immediately after running to exhaustion. The blood lactate accumulations were measured with an analyzer (Lactate Pro, LT-1710, Arkray, Kyoto, Japan) and heart rates were measured with transmitter (T31, Polar Oy, Kempele, Finland) and were sampled synchronizing with $\dot{V}o_2$ in order to confirm the running intensities and metabolism responses.

Statistical Analyses

All data were normally distributed and homogeneity of variance by using Chi square tests for goodness of fit and Bartlett's tests, respectively. Paired t-tests were utilized to examine the differences in time to exhaustion and total running distance between the non-stretching and the dynamic stretching treatment. The effect sizes were calculated using Kline's equation (11) (d = mean difference·standard deviation of mean difference^{-1}; small d < 0.50, moderate d = 0.50-0.80, and large d > 0.80) in consideration of using the paired t-test. Repeated measures analysis of variance (pretreatments x times) was utilized to compare changes in the $\dot{V}o_2$, the blood lactate accumulation and heart rate. The effect sizes were calculated as General η^2 (1) (η_g^2; small $\eta_g^2 = 0.02$, moderate $\eta_g^2 = 0.13$, and large $\eta_g^2 = 0.26$ (15)). Power (1-β) of all analyses were calculated. All variable data were expressed as the average ± standard deviation, and the significance level was set at $p \leq 0.05$. Reliabilities of measures during endurance running for a constant velocity equivalent to 90% $\dot{V}o_2$max were assessed using ICCs and CVs comparing repeated test measures interspersed with more than two days of rest. Reliabilities were the time to exhaustion (ICC = 0.982; CV = 8.7%), the total distance (ICC = 0.985; CV= 9.0%), the average $\dot{V}o_2$ (ICC = 0.995; CV = 1.4%), the blood lactate accumulations at exhaustion (ICC = 0.800; CV= 13.7%), the heart rate at exhaustion (ICC = 0.957; CV = 1.7%).

RESULTS

The time to exhaustion following the dynamic stretching treatment was longer than that following the non-stretching for all subjects (Figure 3). The average time to exhaustion after the dynamic stretching treatment was 928.6 ± 215.0 seconds, and it was significantly ($p < 0.01$) longer than that (785.3 ± 206.2 seconds) after the non-stretching (Figure 3). The effect size was large ($d = 1.56$). The power was 0.93. The total distance for all subjects was also longer following the dynamic stretching treatment, compared with the non-stretching (Figure 4). The average total distance (4301.2 ± 893.8 meters) following dynamic stretching treatment was significantly ($p < 0.01$) longer than that (3619.9 ± 783.3 meters) following the non-stretching (Figure 4). The effect size was large ($d = 1.55$). The power was 0.92.

(Figure 3 and 4 about here)

The average relative $\dot{V}o_2$ was 84% $\dot{V}o_2max$ at two minute after beginning to run, 90% $\dot{V}o_2max$ at three minutes, and then increased gradually from 92% $\dot{V}o_2max$ to 99 %$\dot{V}o_2max$ four minutes later (Figure 5). The average $\dot{V}o_2$ following both the pretreatments increased drastically from rest to two minutes after beginning to run, and then increased slightly (Figure 5). The changes in average $\dot{V}o_2$ following both the pretreatments did not show a significant interaction (pretreatments x times: $F = 0.61$, $p = 0.77$). The effect size was small ($\eta_g^2 = 0.011$). The power was 1.00. The average blood lactate accumulations and heart rate were elevated following both the pretreatments from rest to exhaustion (Table 1), although the changes in average blood lactate accumulation and heart rate did not show a significant interaction (blood lactate accumulation, pretreatments x times: $F = 0.35$, $p = 0.57$; heart rate, pretreatments x times: $F = 0.18$, $p = 0.67$). The effect sizes were small (blood lactate accumulation, $\eta_g^2 = 0.014$; heart rate, $\eta_g^2 = 0.005$). The power were 0.99 in blood lactate accumulation and heart rate.

(Table 1 about here)

DISCUSSION

The present study investigated the acute effect of dynamic stretching comprising one set of 10 repetitions in volume and as quickly as possible in velocity on relative high-intensity endurance running performance in well-trained middle or long distance runners. The present results indicated that dynamic stretching acutely prolonged the time to exhaustion (Figure 3; +18.2%) and extended the total distance (Figure 4; +18.9%) of endurance running for a constant velocity equivalent to 90% $\dot{V}o_2$max. The effect sizes of the improvements in time to exhaustion and total distance were large ($d = 1.56$ and $d = 1.55$, respectively) although the number of subjects was small. The $\dot{V}o_2$, blood lactate accumulation and heart rate at exhaustion did not differ between the pretreatments (Table 1). It was reasonable to suppose that each subject continued running to exhaustion with a similar effort following the two pretreatments. We previously examined acute effects of 15 minutes warm-up running for a constant velocity equivalent to 70% $\dot{V}o_2max$ recommended generally on time to exhaustion during running equivalent to 90% $\dot{V}o_2max$ in same well-trained runners as the present study (23). The result indicated that the time to exhaustion in warm-up running did not significantly differ from it in no warm-up, i.e., sitting rest (= non-stretching in the present study), although it tended to improve. The improvement in time to exhaustion (+4.3%) was relatively smaller than it (+18.2%) following dynamic stretching in the present study. The average $\dot{V}o_2$ during the dynamic stretching in the present study was 24.9 ± 3.1% $\dot{V}o_2max$, it was relatively lower and easier than generally recommended intensity (70% $\dot{V}o_2max$) during warm-up running. The total duration in performing dynamic stretching was three minutes and 37 ± 12 seconds, it was relatively shorter than generally recommended duration (> 10 minutes) in warm-up running. From the standpoints of intensity and duration, the dynamic stretching in the present study was also superior to general warm-up running. The running intensity of 90% $\dot{V}o_2max$ is equivalent to that of 3000-5000 meter distance running events in track and field (7). To take our previous study into consideration, the results of the present study suggest that using this dynamic stretching protocol during actual warm-up for well-trained runners would improve their endurance running performance in distance running events than using only general warm-up running. The present study was the first study revealed that dynamic stretching acutely improves endurance running performance.

Hayes and Walker (5) compared the acute effects of five exercises of dynamic stretching of the lower extremities for two sets of 30 seconds and controlled slow velocity, normal- and progressive static stretching for two sets of 30 seconds and non-stretching on $\dot{V}o_2$ during treadmill running for 10 minutes at an intensity of 75% $\dot{V}o_2max$. They found that the $\dot{V}o_2$ did not significantly differ among the pretreatments, suggesting that differences in stretching technique did not acutely affect running economy. In contrast, Zourdos et al. (29) found that 10 exercises of dynamic stretching were performed as two sets of four repetitions in the lower extremities acutely increased energy expenditure (+4.4%) during treadmill running for 30 minutes at an intensity of 65% $\dot{V}o_2max$, compared with non-stretching. Zourdos et al., (29) however, indicated that the total distance during running as fast as possible for 30 minutes on a treadmill with the velocity and distance display concealed did not significantly differ between pretreatments. Previous results have thus suggested that the dynamic stretching did not acutely affect endurance running performance although it impaired running economy during constant velocity running.

We considered two reasons for the differences between our findings and those of previous studies (5,29). First, the dynamic stretching protocol in the present study differed from those in the previous studies. Hayes and Walker (5) utilized dynamic stretching controlled at a slow velocity. Zourdos et al. (29) utilized less dynamic stretching in two sets of four repetitions. A systematic review (26) to find the optimal protocol for dynamic stretching to acutely improve explosive performance suggested that dynamic stretching should be performed “as quickly as possible in velocity” and “one-two set(s) of 10-15 repetitions in volume”. The hypothesis of the present study was that the optimal protocol for dynamic stretching to acutely improve explosive performance might also acutely improve the endurance running performance. Our results confirmed the validity of this hypothesis. On the other hand, the present study investigated a peculiar acute effect of dynamic stretching on endurance running performance. In a general warm-up, athletes usually perform running prior to dynamic stretching. Moreover, the present study utilized “stationary” dynamic stretching, i.e., without movement. Fletcher and Jones (4) revealed that dynamic stretching with movement acutely significantly improved the 20 meters sprint time, although dynamic stretching without movement did not. The results suggested that dynamic stretching with movement was superior to dynamic stretching without movement. Therefore, it was necessary to examine the acute effect of dynamic stretching with movement following warm-up running on endurance running performance. In addition, the present study utilized only one set of 10 repetitions as volume of dynamic stretching. The previous systematic review (26) revealed that one-two set(s) of 10-15 repetitions as dynamic stretching was an optimal volume to acutely improve explosive performance. Further studies will be needed to clarify more effective protocols as to velocity or volume of dynamic stretching to acutely improve various endurance running performances.

Second, there were differences in the exercise intensities during assessing the endurance running performance. The exercise intensity of the study of Hayes and Walker (5) was 75% $\dot{V}o_2$max. In the study of Zordous et al. (29), the exercise intensity was 65% $\dot{V}o_2$max at constant velocity and approximately 80% $\dot{V}o_2$max at self-controlled velocity. In the present study, the endurance running performance was evaluated during running at constant velocity at an exercise intensity equivalent to 90% $\dot{V}o_2$max. The exercise intensity of 90% $\dot{V}o_2$max was set based on 3000-5000 meter running events in track and field (7). To begin with, well-trained runners run at intensities of more than 85% $\dot{V}o_2$max even in marathons - the lowest intensity running event among middle- and long-distance events (7). It is reasonable to suppose that the present findings are relevant to actual middle- or long-distance running events. Future studies, however, will need to investigate the acute effect of this dynamic stretching protocol on actual running times in 3000 or 5000 meter time trials.

The present study measured $\dot{V}o_2$ as an index of running economy in order to consider why dynamic stretching acutely changes endurance running performance. The present results demonstrated that the changes in $\dot{V}o_2$ did not differ between dynamic stretching treatment and non-stretching (Figure 5). The effect size was also small (η_g^2 = 0.011). The present finding suggested that running economy evaluated by $\dot{V}o_2$ does not explain why dynamic stretching acutely improved the endurance performance. The endurance running performance at the exercise intensity of 90% $\dot{V}o_2$max or 3000-5000 m running is decided by running economy evaluated by not only $\dot{V}o_2$ but also effective utilization of the stretch-shortening cycle (13,18) or the improvement of neuromuscular activation (14,16). Unfortunately, the present study did not measure data for these mechanisms. Future studies need to investigate the contact time or the flight time by analysis of movement and the electromyographic activities of various muscle groups in the lower extremities during performance running, and to clarify the reason why the dynamic stretching protocol utilized in the present study acutely improved the endurance running performance at an exercise intensity of 90% $\dot{V}o_2$max.

PRACTICAL APPLICATIONS

The present study indicated that the dynamic stretching for one set of 10 repetitions as quickly as possible acutely improved endurance running performance at an exercise intensity equivalent to 90% $\dot{V}o_2$max (7). This finding suggests that this dynamic stretching routine if used during actual warm-ups for well-trained runners might improve their race times in 3000-5000 meters events in track and field. Thus, we recommend that well-trained runners and their coaches utilize the dynamic stretching protocol described in the present study.

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FIGURE LEGENDS

Figure 1

Experimental protocols for days two and three.

Figure 2

Protocols of the dynamic stretching treatment on each target muscle group; a. hip joint flexors, b. hip joint extensors, c. leg extensors, d. leg flexors, e. plantar flexors.

Figure 3

Comparison of running times to exhaustion following both pretreatments. Each line is the time for a subject. Bars are the average value following each pretreatment. ** indicates that the time following dynamic stretching treatment was significantly ($p < 0.01$) longer than that following non-stretching.

Figure 4

Comparison of total running distances following both pretreatments. Lines indicate the distance for each subject. Bars show the average value following each pretreatment. ** indicates that the distance following dynamic stretching treatment was significantly ($p < 0.01$) longer than that following non-stretching.

Figure 5

Comparison of changes in oxygen uptake ($\dot{V}o_2$) following both pretreatments. R: rest, S: stretching, E: exhaustion. The changes in $\dot{V}o_2$ following the pretreatments showed no significant interaction.

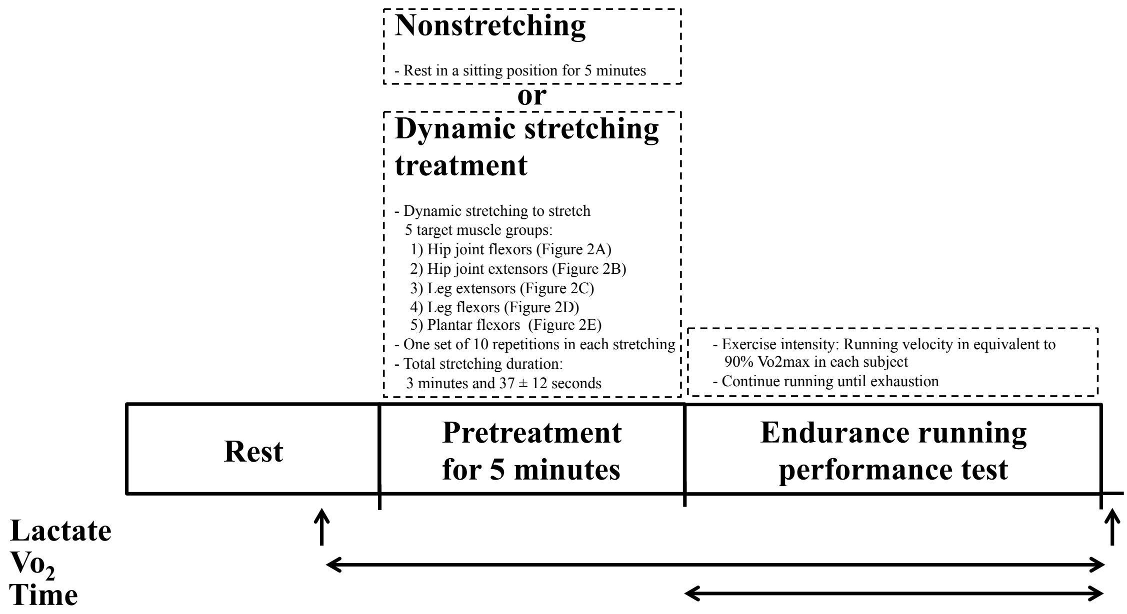
Nonstretching
- Rest in a sitting position for 5 minutes
or
Dynamic stretching treatment
- Dynamic stretching to stretch 5 target muscle groups:
1) Hip joint flexors (Figure 2A)
2) Hip joint extensors (Figure 2B)
3) Leg extensors (Figure 2C)
4) Leg flexors (Figure 2D)
5) Plantar flexors (Figure 2E)
- One set of 10 repetitions in each stretching
- Total stretching duration: 3 minutes and 37 ± 12 seconds
- Exercise intensity: Running velocity in equivalent to 90% Vo2max in each subject
- Continue running until exhaustion
Rest
Pretreatment for 5 minutes
Endurance running performance test
Lactate
Vo2
Time

Figure 1

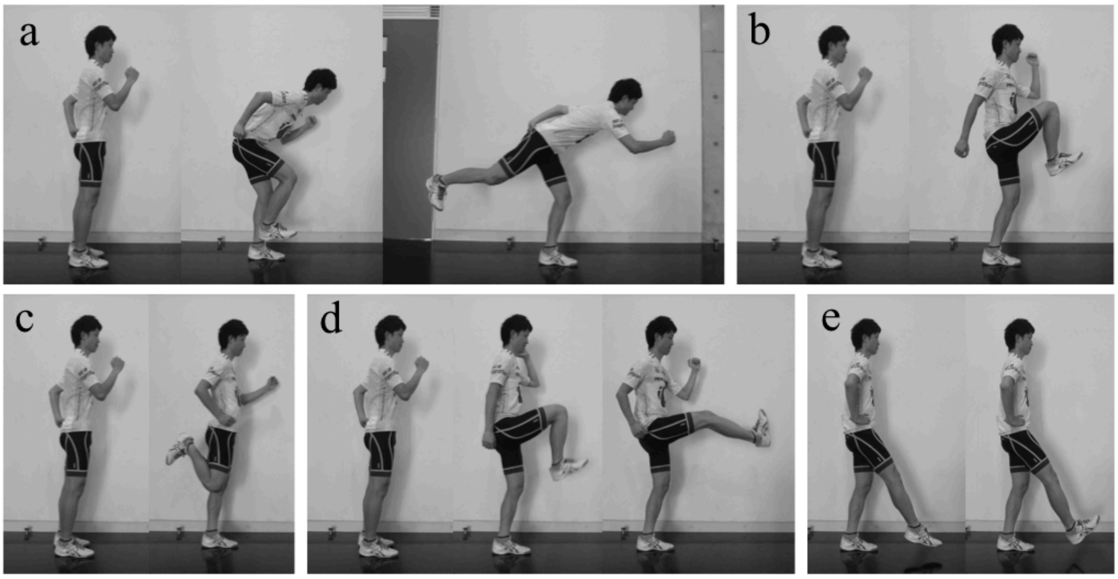

Figure 2

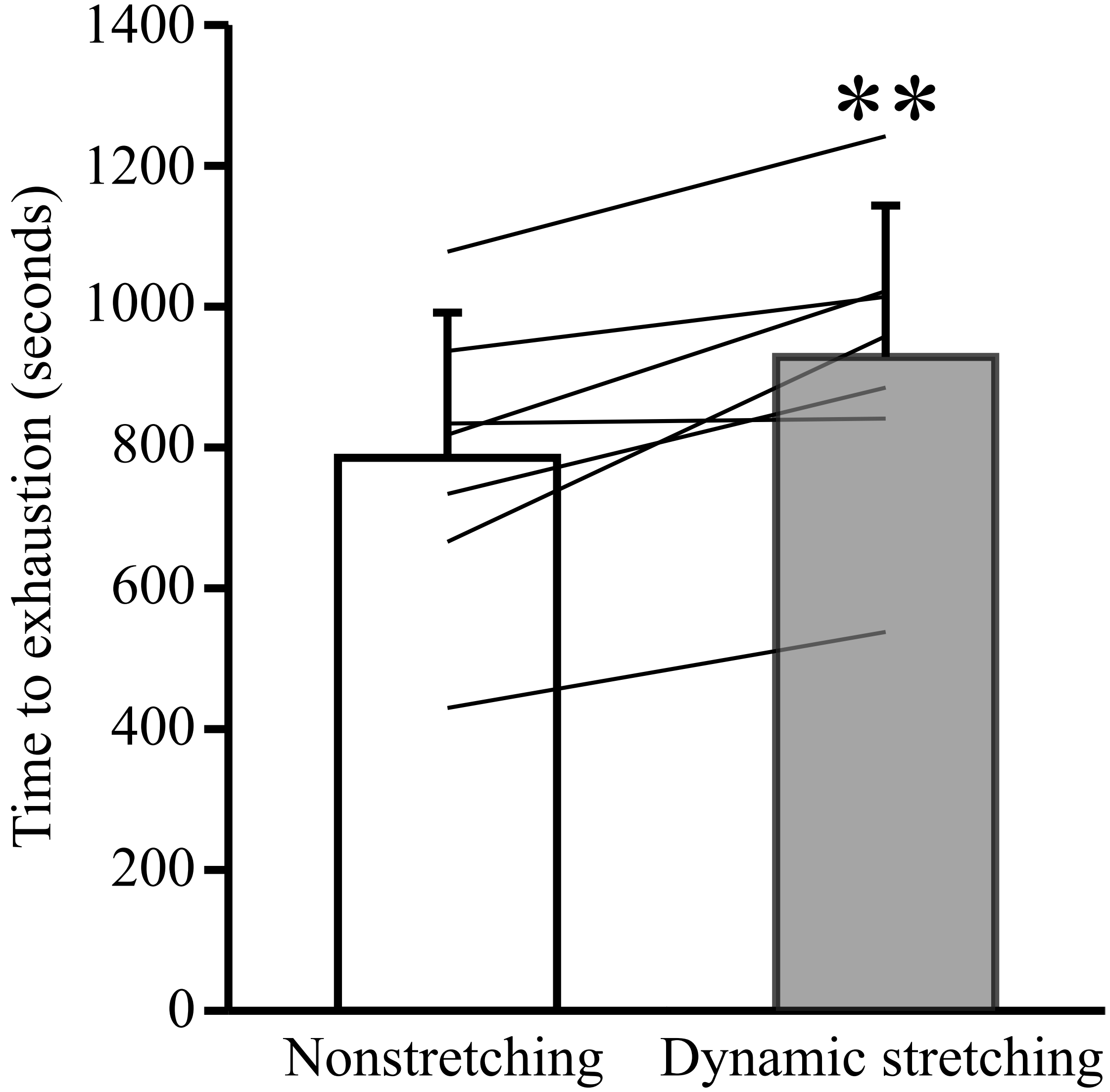
1400
1200
1000
800
600
400
200
0
Time to exhaustion (seconds)
**
Nonstretching
Dynamic stretching

Figure 3

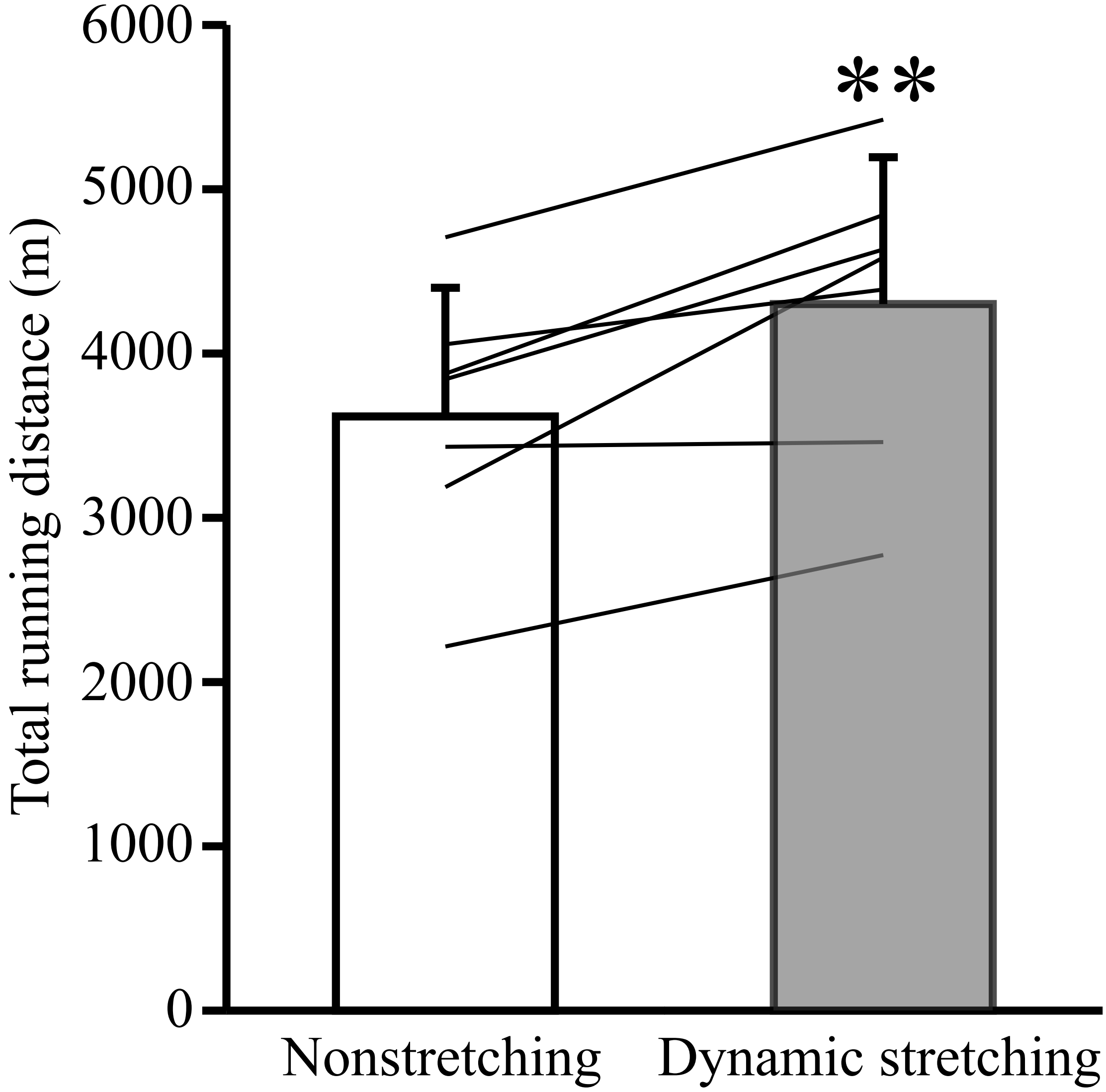
6000
5000
4000
3000
2000
1000
0
Total running distance (m)
**
Nonstretching
Dynamic stretching

Figure 4

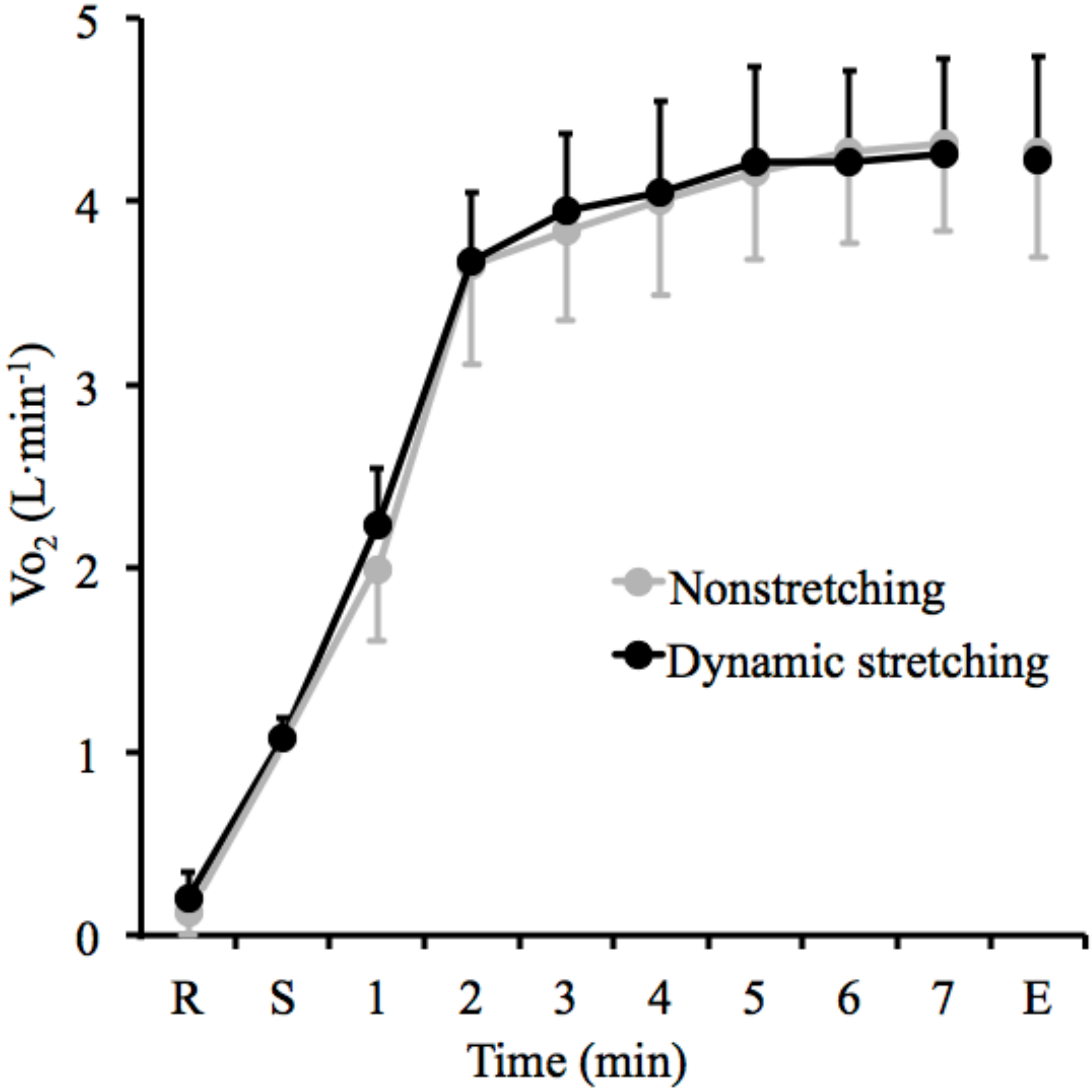
5
4
3
2
1
0
Vo2 (L·min-1)
Nonstretching
Dynamic stretching
R
S
1
2
3
4
5
6
7
E
Time (min)

Figure 5

Table 1 Comparisons of change in oxygen uptake ($\dot{V}o_2$), blood lactate accumulations and heart rate between both pretreatments. The changes in all measurements following the pretreatments showed no significant interactions.

		Rest	**Exhaustion**
$\dot{V}o_2$ (liters·minute^{-1})	**Non-stretching**	**0.12 ± 0.12**	**4.27 ± 0.57**
	Dynamic stretching	**0.21 ± 0.14**	**4.23 ± 0.56**
Lactate (millimoles·liter^{-1})	**Non-stretching**	**1.04 ± 0.33**	**6.11 ± 1.59**
	Dynamic stretching	**1.07 ± 0.18**	**6.67 ± 1.79**
Heart rate (beats·minute^{-1})	**Non-stretching**	**71.3 ± 5.4**	**185.4 ± 9.7**
	Dynamic stretching	**73.3 ± 7.3**	**185.6 ± 6.2**