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

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**ABSTRACT**

BACKGROUND: The purpose of this study was to compare the acute effects of dynamic stretching and running on relative high-intensity endurance running performance in well-trained male runners.

METHODS: The endurance running performances of 16 well-trained long-distance male runners were assessed on a treadmill at about 5 minutes after 2 types of intervention. The interventions were a) running intervention and b) dynamic stretching intervention. In the running intervention, each participant ran on the treadmill at a velocity equivalent to his 70% maximal oxygen uptake ($\dot{V}O_2max$) in each participant for 15 minutes. In the dynamic stretching intervention, dynamic stretching was performed for 10 repetitions as quickly as possible for the 5 muscle groups of the lower extremities for 3 minutes and 40 ± 9 seconds. Endurance running performance was evaluated by time to exhaustion during running at a velocity equivalent to 90% $\dot{V}O_2max$ in each participant.

RESULTS: The time to exhaustion (870.7 ± 237.6 seconds) after dynamic stretching intervention was significantly (d = 0.75, $p = 0.01$) prolonged compared with that (745.4 ± 225.1 seconds) after running intervention.

CONCLUSIONS: The results demonstrated that the dynamic stretching intervention improved the endurance performance of running at a velocity equivalent to 90% $\dot{V}O_2max$ in well-trained male runners. Our findings suggested that performing dynamic stretching was effective for improving performance compared with performing only running during the warm-up.

Key words: warm-up, long distance runner, running economy

## Introduction

Stretching exercises are incorporated into warm-up protocols for prevention of injuries and improvement of performance.[1] Stretching techniques include static, ballistic, proprioceptive neuromuscular facilitation and dynamic stretching. Judge et al.[2] reported that the rates of utilization of dynamic stretching only (41.5%) or a combination of static stretching and dynamic stretching (44.7%) during warm-up by coaches of endurance athletes were higher than those of the other stretching techniques.

Most endurance athletes as well as their coaches use dynamic stretching during actual warm-ups, and three studies[3,4,5] investigated the acute effect of dynamic stretching on endurance running performance in well-trained runners. Two[3,4] of the three previous studies investigated that the acute effect of dynamic stretching on the endurance running performance did not reveal any positive or negative effects on performance. The protocols for dynamic stretching in these two studies might not be suitable for improving performance since one study[3] used slow-velocity dynamic stretching and the other study[4] used a small volume of dynamic stretching. In contrast, another previous study[5] demonstrated that dynamic stretching for 10 repetitions as quickly as possible is an optimal protocol for improving performance,[6] acutely prolonging the time to exhaustion (+18.2%) during running on a treadmill at a velocity equivalent to 90% of maximal oxygen uptake ($\dot{V}O_2max$) compared with resting in a sitting position. However, that study[5] merely revealed that the dynamic stretching improved the endurance running performance compared with resting. Commonly, an active warm-up such as running is incorporated into general warm-up protocol.[15] Such running improves performance in the long-term - fatiguing effort for ≥ 5 minutes by elevating baseline oxygen uptake ($\dot{V}O_2$).[7] However, there seems to be little agreement as to whether running warm-ups improve long-term performance in well-trained runners.[7,8,9] If dynamic stretching alone might improve endurance running performance compared with running, the preconception that running should be included in the general warm-up protocol could be revised. It was thus necessary to examine whether dynamic stretching improves the endurance running performance compared with a running. A recent review[10] suggested that preconditioning-induced post-activation potentiation (PAP) for warm-up might improve endurance performance, compared with running. Dynamic stretching might produce PAP.[11] We hypothesized that dynamic stretching improves endurance running performance, compared with running.

The purpose of this study was to compare the acute effects of dynamic stretching and running incorporated during the general warm-up protocol on endurance running performance in well-trained long-distance runners.

## Materials and methods

### Participants

Sixteen healthy well-trained long-distance male runners (average ± SD: age 20.9 ± 2.1 years [19-25 years]; height 171.6 ± 3.6 cm; body mass 61.4 ± 5.7 kg; $\dot{V}O_2max$ 4.40 ± 0.43 $L \cdot min^{-1}$; $\dot{V}O_2max \cdot body\ mass^{-1}$ 71.9 ± 6.1 $ml \cdot kg^{-1} \cdot min^{-1}$) took part in this study. They belonged to the track and field club of Hokkaido University. All participants were free of injuries in their lower extremities. All experiments were carried out between February and April. Since the period was off-season, the participants did not perform any vigorous training. We cautioned each participant to avoid performing intense exercises or training (e.g., running, resistance or flexibility) on the day of each experiment and the previous day. Moreover, we instructed each participant to ingest similar meals and drinks on the day of each experiment and on the previous day, and to finish any meal on the experimental day two hours before experiment. In addition, we warned each participant to avoid drinking alcohol on the previous day and caffeine on the experimental day. All participants were informed of the protocols, purposes, and risks of the present study, and informed consent was obtained from all participants. The study was approved by the ethics committee of Rakuno Gakuen University.

**Experimental design**

To determine the validity of our hypothesis, experiments consisting of 3 testing days interspersed with more than 2 days of rest were performed. On day 1, each participant visited our laboratory to receive instructions. A test of determining $\dot{V}O_2max$ with maximum incremental exercise utilizing a respiratory gas analyzer ($\dot{V}$O2000, S&ME Co. Ltd., Tokyo, Japan) and two types of treadmills was conducted in order to determine each participant's relative running velocity while his running intervention and measuring endurance running performance. On day 2 (Fig. 1), each participant visited the laboratory and rested. After resting, the mask of the respiratory gas analyzer was fitted. Endurance running performance was assessed at about 5 minutes after one of two types of intervention: (a) running intervention performing running for 15 minutes at a velocity equivalent to 70% $\dot{V}O_2max$ assessed on day 1 for each participant, or (b) dynamic stretching intervention, performing dynamic stretching of the lower extremities. The intervention on day 2 was determined at random for each participant. The running velocity during the assessment of endurance running performance was equivalent to 90% $\dot{V}O_2max$. Each participant continued running to exhaustion on the treadmill set at the running velocity. The time to exhaustion was assessed as an index of the endurance running performance. The $\dot{V}O_2$ from rest to exhaustion was measured using the respiratory gas analyzer. The $\dot{V}O_2$ during assessment of endurance running performance was evaluated as an index of the running economy. On day 3, the endurance running performance was assessed again after the opposite intervention from day 2. Data were compared between the running intervention and dynamic stretching intervention in order to examine the acute effects on endurance running performance, metabolism and fatigue. Each participant wore the same shirts and shorts, and performed the experiments of both interventions at the same time of day in consideration of circadian rhythm. The temperature of the laboratory was set to 20-24ºC throughout all experiments.

**Maximum incremental exercise test**

The maximum incremental exercise tests were performed using two types of motor-driven treadmill (Nishikawa Iron Co. Ltd., Kyoto, Japan, n=7 or Minato Medical Science Co, Ltd, Osaka, Japan, n=9; Each participant used the same treadmill) to determine the $\dot{V}O_2max$ and the relative running velocity equivalent to 70% and 90% $\dot{V}O_2max$ for each participant in reference to the protocols in previous studies.[5] Each participant continued to run for four minutes at each velocity with rest a period of one minute between velocities. The initial running velocity was 10 $km \cdot h^{-1}$. The running velocity was then increased as follows: 12 $km \cdot h^{-1}$, 13.3 $km \cdot h^{-1}$, 15 $km \cdot h^{-1}$, 16.4 $km \cdot h^{-1}$, 18 $km \cdot h^{-1}$, 20 $km \cdot h^{-1}$ and 21.8 $km \cdot h^{-1}$. The criterion of finishing the test was 1) when the heart rate exceeded the predicted maximal heart rate of each participant (220 $beats \cdot minutes^{-1}$ - age), 2) when the respiratory quotient (RQ) exceeded 1.1, or 3) when the participant could not continue to run. All participants finished by meeting criterion 3). $\dot{V}O_2$ was measured every ten seconds by the mixing chamber method utilizing a respiratory gas analyzer ($\dot{V}O2000$) throughout the running test. The maximum $\dot{V}O_2$ value for ten seconds in the maximum increment exercise test was assessed as $\dot{V}O_2max$. The running velocities at 70% and 90% $\dot{V}O_2max$ for each participant were calculated from the relationships between the running velocities and the

$\dot{V}O_2$ obtained by the maximum increment exercise test. The reliability of $\dot{V}O_2max$ and the relative running velocities were confirmed in a previous study.[5]

**Interventions**

In the running intervention, each participant performed running for 15 minutes on the treadmill at a velocity (13.27 ± 1.93 $km \cdot h^{-1}$) equivalent to 70% $\dot{V}O_2max$ for each participant. The intensity equivalent to 70% $\dot{V}O_2max$ was reported to be optimal for improvement of long-term performance.[7]

In the dynamic stretching intervention (Table 1), the participants performed the same order of 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 the previous studies.[5] The participants performed 10 repetitions of each stretch synchronized with the tempo of a digital metronome at 30 $beats \cdot minute^{-1}$ (0.5 Hertz). Prior to performing each stretch, we explained to the participants 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 the participant's target muscle groups were stretched as quickly as possible. 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 intervention was 3 minutes and 40 ± 9 seconds.

The endurance running performance was assessed at about 5 minutes after each intervention. Each participant rested in a standing position for about 5 minutes to prepare the measurement of endurance running performance.

**Measurement during endurance running performance**

Each participant continued running to exhaustion on the treadmill set at a velocity (17.31 ± 2.08 km·h$^{-1}$) equivalent to his 90% $\dot{V}O_2max$. The criterion of exhaustion was when each participant could not continue to run. The continuous time of running to exhaustion was assessed as an index of endurance running performance. The $\dot{V}O_2$ during experiment was sampled every 10 seconds with the respiratory gas analyzer ($\dot{V}$O2000). The average $\dot{V}O_2$ during rest, intervention, rest after intervention and assessment of endurance running performance were determined. The $\dot{V}O_2$ was also measured at exhaustion. The average $\dot{V}O_2$ during assessment of endurance running performance was taken as an index of running economy. The reliabilities of all measurement data during assessing endurance running performance were confirmed in the previous study.[5]

**Statistical analyses**

All data were normally distributed and homogeneity of variance was confirmed by using Chi-squared tests for goodness of fit and Bartlett's tests, respectively. Paired t-test was utilized to examine the differences in time to exhaustion between the running intervention and the dynamic stretching intervention. The effect size was calculated using Kline's equation[12] (d = mean difference·standard deviation of mean difference$^{-1}$ √2[1-r(correlation coefficients)]; 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 (interventions x time) with post hoc test was utilized Tukey-Kramer test to compare changes in the $\dot{V}O_2$. The effect size was calculated as General $\eta^2$ ($\eta_g^2$; small $\eta_g^2 = 0.02$, moderate $\eta_g^2 = 0.13$, and large $\eta_g^2 = 0.26$). [13,14] All variable data were expressed as the average ± standard deviation, and the significance level was set at $p < 0.05$.

## Results

The time to exhaustion after dynamic stretching intervention was greater than that after the running intervention for twelve of 16 participants. The average time to exhaustion after dynamic stretching intervention was significantly ($p$ = 0.01) greater than that after running intervention (Fig. 2). The effect size was moderate (d = 0.75).

Regarding $\dot{V}O_2$, the data from 14 participants were used since sweat from 2 participants entered the tube of the gas analyzer, preventing measurement (Fig. 3). The changes in average $\dot{V}O_2$ after both interventions showed a significant interaction (interventions x phases: $F = 82.08$, $p < 0.01$). The effect size was large ($\eta_g^2 = 0.64$). As a result of post hoc tests, the average $\dot{V}O_2$ during and at rest after dynamic stretching intervention were significantly ($p < 0.01$) lower than those in running intervention. During rest and assessment of endurance running performance, and at exhaustion, average $\dot{V}O_2$ did not show any significant differences.

## Discussion

This study compared the acute effects of dynamic stretching for 10 repetitions as quickly as possible and running on endurance running performance at a velocity equivalent to 90% $\dot{V}O_2max$ in well-trained long-distance runners. The results clarified that dynamic stretching acutely prolonged the time to exhaustion (Fig. 2; + 16.8%) compared with the running at a velocity equivalent to 70% $\dot{V}O_2max$ for 15 minutes. The effect size was d = 0.75 and indicated moderate power. A few recent studies[8,9] have indicated that running during warm-up does not improve the long-term performance of well-trained runners.

Takizawa et al.[9] indicated that three types of running intervention – at velocities equivalent to 60%, 70%, and 80% $\dot{V}O_2max$ for 15 minutes – did not significantly affect the times to exhaustion during running at the same intensity, as in this study, compared with resting in a sitting position. Zourdos et al.[8] also reported that running intervention for 6 minutes split into 2-minute intervals at velocities equivalent to 45%, 55% and 60% $\dot{V}O_2max$ and walking at 3.2 $km \cdot h^{-1}$for 2 minutes did not significantly alter performance, compared with resting in a sitting position. There seems to be little agreement as to whether running improves the long-term performance of well-trained runners.[7] Therefore, the present result that dynamic stretching was superior to running affords some new perspectives and an opportunity to reconsider the warm-up protocols of well-trained runners.

We should consider the reasons why dynamic stretching acutely improved the endurance running performance compared with running. Bishop[7] stated that, while it is important to elevate $\dot{V}O_2$ by a warm-up prior to a task, to improve long-term performance, the participant must sufficiently recover from fatigue after the warm-up. The average $\dot{V}O_2$ during dynamic stretching was lower than that during running. In addition, the average $\dot{V}O_2$ at rest after dynamic stretching was also lower than that at rest after running (Fig. 3), but higher than that at rest before dynamic stretching. Thus, dynamic stretching might have allowed quicker recovery from fatigue after the warm-up than running. To the best of our knowledge, no previous studies have investigated the effect of recovery after warm-up on long-term performance in well-trained runners. In contrast, several previous studies[15,16] have indicated that long-term cycling performances improved in the case of lower $\dot{V}O_2$ after warm-up. Bailey et al.[16] demonstrated that a cycling warm-up at severe intensity for 6 minutes followed by rest for 9 or 12 minutes improved cycling performance in recreationally active males, but the same warm-up followed by rest for 3 minutes impaired their performance, compared with control conditions. The same study also reported that

$\dot{V}O_2$ values remained high after a warm-up followed by rest for 9 or 12 minutes and before assessment of cycling performance compared with control conditions, but the cycling warm-up followed by rest for 3 minutes resulted in the highest value of $\dot{V}O_2$ at the same time among all conditions. From the standpoint of recovery from fatigue after intervention, the dynamic stretching in this study might be more suitable than running for improving endurance running performance.

As the second reason, dynamic stretching might cause PAP and might have improved endurance running performance compared with the running warm-up. A recent review[10] reported that PAP caused by preconditioning muscle action might improve endurance performance. Silva et al.[17] revealed that a 5-repetition maximum leg press warm-up before cycling improved endurance performance in a 20-km cycling time trial compared with a cycling-only warm-up. It was also suggested that dynamic stretching might produce PAP.[11] In the present study, PAP caused by dynamic stretching might have improved endurance running performance compared with running. Further studies are needed to reveal whether dynamic stretching produces PAP and how the PAP affects endurance running performance.

This study measured $\dot{V}O_2$ as an index of running economy to consider why endurance running performance was acutely changed. The present results demonstrated that the change in $\dot{V}O_2$ during assessment of endurance running performance did not differ between running and dynamic stretching (Fig. 3), so running economy evaluated by $\dot{V}O_2$ does not explain why dynamic stretching acutely improved the endurance running performance compared with running. The total running distance of participants in this study calculated by the running velocity at 90% $\dot{V}O_2max$· time to exhaustion was 3,853.3 ±1128.7 (1,704-5,424) m. An athlete's endurance running performance at 3,000- 5,000-m running events in track and field is determined by running economy evaluated by not only $\dot{V}O_2$, but also effective utilization of the stretch-shortening cycle.[18,19] It was reported that dynamic stretching improved countermovement or drop jump performance, in evaluations of the stretch-shortening cycle.[6,11,20] The mechanism behind the results of this study may be clarified by comparing the acute effects of the interventions in this study on countermovement or drop jump height before assessment of endurance running performance. In addition, a recent study examined the acute effects of dynamic stretching on submaximal running mechanics.[21] Pappas et al.[21] revealed that dynamic stretching for 40 repetitions – not the same protocol as this study – increased the vertical ground reaction force, flight time, step length and vertical displacement of the center of mass, and decreased the step rate during running on a treadmill at a velocity = 4.44 $m \cdot sec^{-1}$, about 16.0 $km \cdot h^{-1}$ (the % of $\dot{V}O_2max$ or equivalent for each participant was not reported), that is to say, dynamic stretching had positive effects on submaximal running mechanics. Future studies are needed to investigate running mechanics and the other physiological parameters during assessment of endurance running performance and to clarify the reason why the dynamic stretching protocol used in this study acutely improved the endurance running performance at an exercise intensity of 90% $\dot{V}O_2max$.

As the limitations of this study, the endurance running performance was evaluated on the treadmill at a constant velocity. As mentioned above, the total running distance of the participants in this study was 3,853.3 ±1128.7 (1,704-5,424) m. The results of this study may be relevant to 3,000 or 5,000 m event in track and field. However, the running velocity during actual events is not constant. Future researches will be needed to investigate the acute effect of this dynamic stretching protocol on actual running time in 3,000 or 5,000 m time trials in well-trained runners. Moreover, the general warm-up protocol incorporates both running and some stretching exercises. We might go on to investigate the acute effects of dynamic stretching after running on endurance running performance.

## Conclusions

The purpose of this study was to compare the acute effects of dynamic stretching and running incorporated during the general warm-up protocol on endurance running performance in well-trained long-distance runners. The result demonstrated that dynamic stretching for 10 repetitions as quickly as possible acutely improved endurance running performance at an exercise intensity equivalent to 90% $\dot{V}O_2max$ in well-trained male runners compared with running at intensity equivalent to 70% $\dot{V}O_2max$ for 15 min. This result suggests that this dynamic stretching routine if used during actual warm-ups for well-trained runners might improve their race times in 3,000-5,000-m track and field events than the running. Thus, we recommended that well-trained runners and their coaches use the dynamic stretching protocol described in this study.

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## NOTES

*Conflicts of interest.*— None of the authors decalre competing finacial intersts.

*Funding.*— This study was supported by JSPS KAKENHI Grant number JP24700655 and JP26750273.

*Authors' contributions.*— TY carried out design, data collection, statistical analysis, manuscript preparation; KT, KS, NT, MS and MY conceived of the study, participated in coordination, and helped to edit the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

*Acknowledgements.*— This study was supported by JSPS KAKENHI Grant number JP24700655 and JP26750273.

## TABLES

Table I.— Protocols of the dynamic stretching intervention on each target muscle group.

| Muscle groups | protocols |
|---|---|
| Hip extensors | The participant leaned forward and raised his foot from the floor with his hip and knee joint lightly flexed. Then, the participant contracted his hip joint extensors and extended his hip joint so that his leg was extended to posterior aspect of his body |
| Hip flexors | The participant contracted his hip joint flexors with his knee joint flexed and then flexed his hip joint so that his thigh came up to his chest |
| Leg extensors | The participant contracted his hamstrings and flexed his knee joint so that his heel kicked his buttock |
| Leg flexors | The participant 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 participant contracted his quadriceps with the height of his thigh maintained and then extended his knee joint so that his leg extended to the anterior aspect of his body |
| Plantar flexors | The participant raised foot from the floor and fully extended the knee joint. Then, the participant contracted his dorsiflexors and dorsiflexed his ankle joint so that his toe was raised |

**TITLES OF FIGURES**

Figure 1.— Experimental protocol for day 2 and 3.

Figure 2.— Comparison of running time to exhaustion after alternate interventions. * indicates that the time after dynamic stretching was significantly ($p = 0.01$) longer than that after running.

Figure 3.— Comparison of changes in average oxygen uptake ($\dot{V}O_2$) during each phase after alternate interventions. ** indicates that the $\dot{V}O_2$ during dynamic stretching was significantly ($p < 0.01$) lower than that during running.

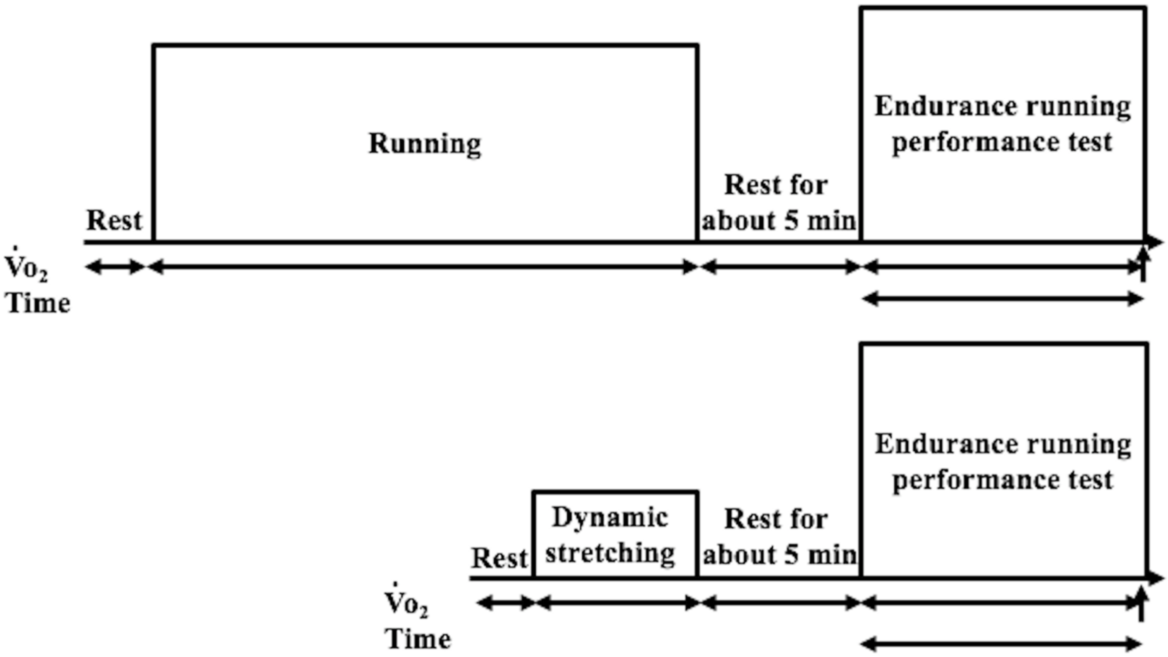
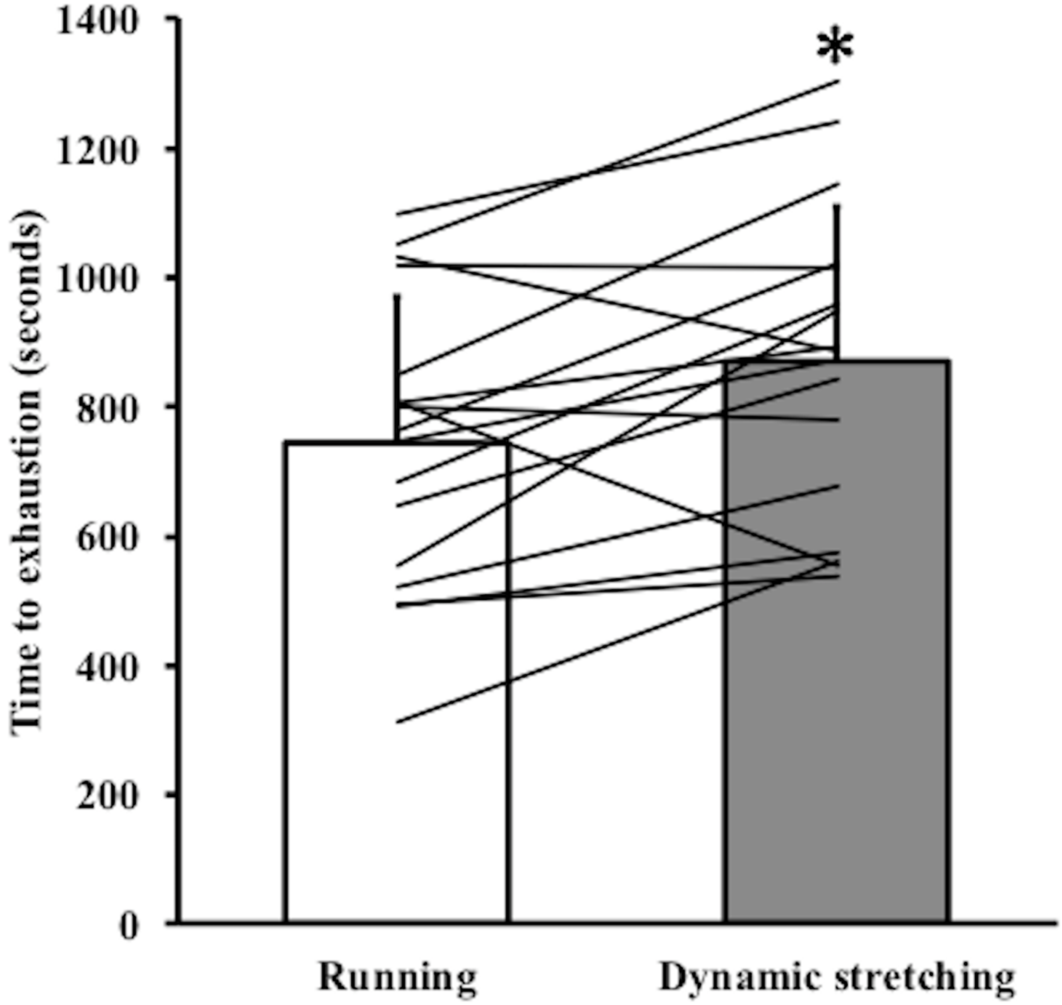
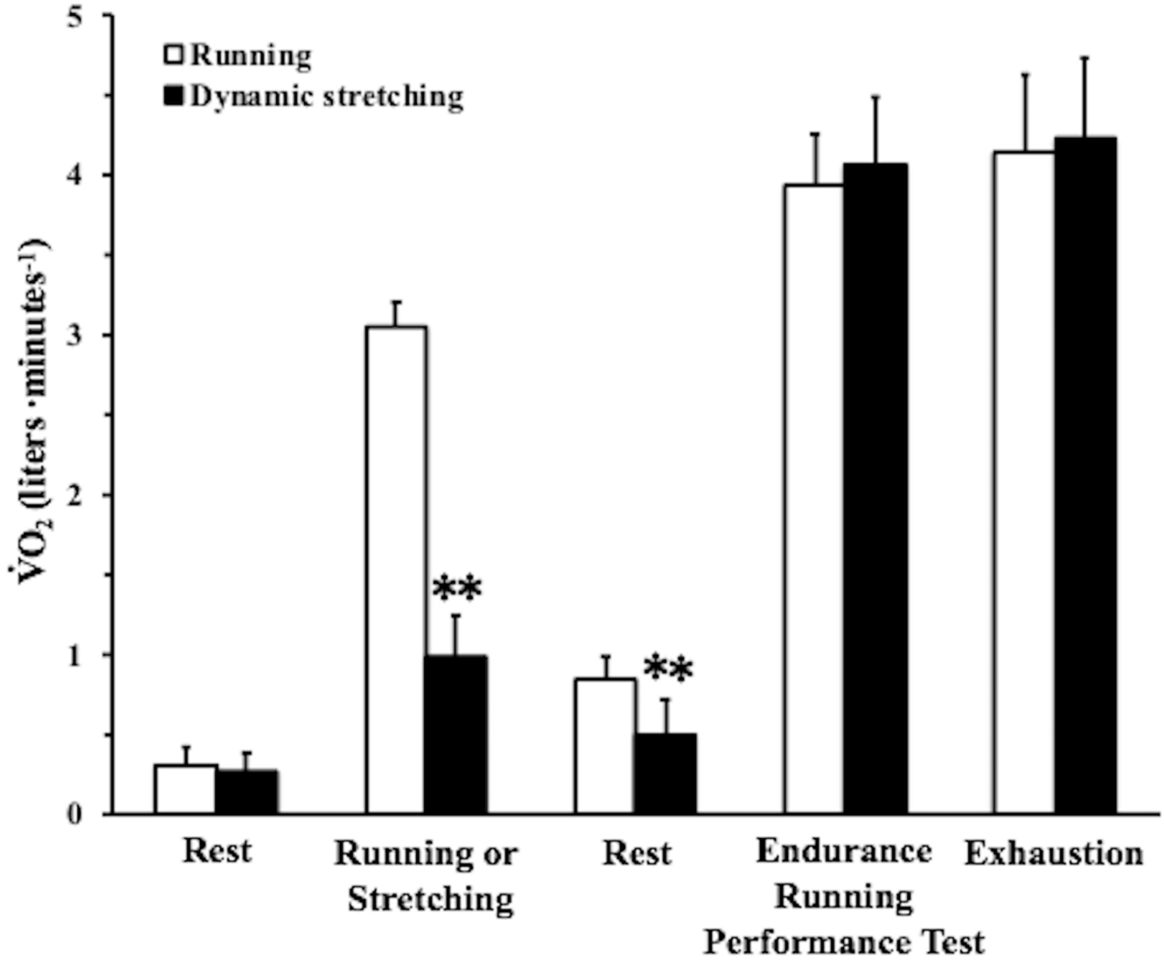

Running
Endurance running performance test
Rest
Rest for about 5 min
$\dot{V}o_2$
Time
Endurance running performance test
Dynamic stretching
Rest
Rest for about 5 min
$\dot{V}o_2$
Time

Figure 1



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


Figure 2



5
4
3
2
1
0
Running
Dynamic stretching
$\dot{V}O_2$ (liters ·minutes⁻¹)
**
**
Rest
Running or Stretching
Rest
Endurance Running Performance Test
Exhaustion


Figure 3