Effect of general warm-up plus dynamic stretching on endurance running performance in well-trained male runners

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Abstract

Purpose: The purpose of this study was to compare the acute effects of general warm-up (GWU) and GWU plus dynamic stretching (GWU + DS) on endurance running performance in well-trained male runners. **Method:** The endurance running performances of eight well-trained long-distance male runners were assessed on a treadmill after 2 types of intervention for 5 min after running on the treadmill at a velocity equivalent to 70% maximal oxygen uptake ($\dot{V}O_2max$) in each athlete for 15 min. The interventions were GWU and GWU + DS. In the GWU + DS intervention, dynamic stretching was performed for ten repetitions as quickly as possible for the five muscle groups of the lower extremities. The total duration of the dynamic stretching was 3 min and 45 s. Endurance running performance was assessed at 1 min 15 s after the dynamic stretching. The endurance running performance was evaluated by the time to exhaustion (TTE) during running at a velocity equivalent to 90% $\dot{V}O_2max$ in each athlete. **Results:** The TTE (640.6 ± 220.4 s) after GWU + DS intervention was significantly (d = 1.02, p = .03) shorter than that (760.6 ± 249.1 s) after GWU intervention. **Conclusions:** The results demonstrated that GWU + DS intervention impaired immediate endurance performance of running at a velocity equivalent to 90% $\dot{V}O_2max$ in well-trained male runners compared with GWU intervention. Thus, we are not able to recommend that well-trained runners and their coaches use the protocol for GWU + DS described in this study during actual warm-ups.

Key words: oxygen uptake, heart rate, rate of perceived exertion, running economy

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Stretching is incorporated into warm-up protocols for the prevention of injuries and improvement of performance (Shellock & Prentice, 1985). Stretching techniques include static, ballistic, proprioceptive neuromuscular facilitation and dynamic stretching. Judge et al. (2013) reported that the rates of utilization of dynamic stretching only (41.5%) or a combination of static and dynamic stretching (44.7%) during warm-up by the coaches of endurance athletes were higher than those of the other stretching techniques.

Most endurance athletes and their coaches use dynamic stretching during actual warm-ups, but only three studies (Hayes & Walker, 2007; Yamaguchi, Takizawa & Shibata, 2015; Zourdos et al., 2012) have investigated the acute effects of dynamic stretching on endurance running performance. Two (Hayes & Walker, 2007; Zourdos et al., 2012) of the three previous studies 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 (Hayes & Walker, 2007) used slow-velocity dynamic stretching. The other study (Zourdos et al., 2012) used a small volume of dynamic stretching in only two sets of four repetitions. A systematic review (Yamaguchi & Ishii, 2014) suggested that an optimal protocol for dynamic stretching to acutely improve performance was to perform “as quickly as possible” and “one to two set(s)” of “10-15 repetitions”. Another previous study (Yamaguchi et al.,

2015) demonstrated that dynamic stretching for 10 repetitions as quickly as possible is an optimal protocol for improving performance (Yamaguchi & Ishii, 2014), 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. That study merely revealed that dynamic stretching improved the endurance running performance compared with resting. However, a general warm-up such as submaximal running is commonly performed prior to some stretching as part of the warm-up protocol (Shellock & Prentice, 1985). Such general warm-up improves performance in the long-term - fatiguing effort for ≥ 5 min by elevating baseline oxygen uptake ($\dot{V}O_2$) (Bishop, 2003). It is reasonable to hypothesize that a combination of general warm-up and dynamic stretching might synergistically improve endurance running performance.

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

Methods

Participants

Eight healthy well-trained long-distance male runners (average ± SD: age 19.9 ± 1.1 [18-21] years; height 171.1 ± 6.5 cm; body mass 59.4 ± 4.1 kg; $\dot{V}O_2max$ 4.22 ± .33 $L \cdot min^{-1}$; $\dot{V}O_2max \cdot body\ mass^{-1}$ 71.2 ± 3.3 $ml \cdot kg^{-1} \cdot min^{-1}$) took part in this study. They belonged to university track and field club. All participants were free of injuries in their lower extremities. All experiments were carried out between

February and March. 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 exercises or stretching) 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 the 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

Experiments consisting of 3 testing days interspersed with more than two days of rest were performed. On day 1, each participant visited our laboratory to receive instructions. A test for determining each participant's $\dot{V}O_2$max with maximum incremental exercise utilizing a respiratory gas analyzer (VO2000, S&ME Co. Ltd., Tokyo, Japan) and a treadmill (Nishikawa Iron Co. Ltd., Kyoto, Japan) was conducted with reference to the protocols in a previous study (Yamaguchi et al., 2015). Each participant's relative running velocity equivalent to 70% and 90% $\dot{V}O_2$max with his running and measuring endurance running performance was calculated by measurement data of the test. On day 2 (Figure 1), each participant visited the laboratory and rested. After resting, the mask of the respiratory gas analyzer and a heart rate transmitter (H1, Polar Oy, Kempele, Finland) were fitted and a rate of perceived exertion (RPE) was measured. General warm-up with running on the treadmill at a velocity equivalent to 70% $\dot{V}O_2max$ assessed on day 1 for each participant performed for 15 min. Immediately after general warm-up, RPE was measured. Each participant carried out one of two types of intervention for 5 min: (a) standing rest after general warm-up (GWU), or (b) dynamic stretching after general warm-up (GWU + DS). The intervention on day 2 was determined at random for each participant. RPE was measured about 1 min before the assessment of endurance running performance. The endurance running performance was assessed at a running velocity equivalent to 90% $\dot{V}O_2max$ for each participant. 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 $\dot{V}O_2$ and heart rate from rest to exhaustion were measured. The $\dot{V}O_2$ during assessment of endurance running performance was evaluated as an index of the running economy. RPE was measured again immediately after exhaustion. On day 3, the endurance running performance was assessed again after the opposite intervention from day 2. Data were compared between the GWU intervention and GWU + DS intervention in order to examine the acute effects on endurance running performance, $\dot{V}O_2$, heart rate and RPE. Each participant wore the same T-shirts and shorts, and performed the experiments with 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.

Interventions

In the GWU intervention, each participant performed general warm-up with running for 15 min on the treadmill at a velocity (13.37 ± 1.56 km·hr^{-1}) equivalent to 70% $\dot{V}O_2$max for each participant. The intensity equivalent to 70% $\dot{V}O_2$max was reported to be optimal for improvement of long-term performance (Bishop, 2003). Bishop (2003) also indicated that the duration for ≥10 minutes at the intensity equivalent to 60-80% $\dot{V}O_2$max tended to enhance performance. Previous study reported that the average warm-up duration freely-selected by endurance-trained athletes was 15 minutes and 33 seconds (McIntyne & Kilding, 2015). Based on these previous reports, we determined the intensity and duration of general warm-up. The endurance running performance was assessed at 5 min after the general warm-up. Each participant rested in a standing position for 5 min.

In the GWU + DS intervention, after the same general warm-up with running as the GWU intervention, the participants performed the same order of dynamic stretching of five target muscle groups, i.e., hip extensors and flexors, leg extensors and flexors, and plantar flexors, in upright standing positions following the protocols in the previous study (Yamaguchi et al., 2015). The participants performed one set of 10 repetitions of each stretch synchronized with the tempo of a digital metronome at 30 beats·min^{-1} (.5 Hertz). Each stretch was carried out as quickly and powerfully as possible without bouncing. The total duration of the dynamic stretching was 3 min and 45 ± 9 s. The endurance running performance assessment was started 1 min and 15 s after dynamic stretching. Each participant rested in standing for 1 min and 15 s.

Measurement during endurance running performance

Each participant continued running to exhaustion on the treadmill set at a velocity (16.81 ± .89 km·hr^{-1}) equivalent to his 90% $\dot{V}O_2$max. 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 $\dot{V}O_2$ and heart rate during the experiment were sampled every 10 s with the respiratory gas analyzer (VO2000). The average $\dot{V}O_2$ and heart rate were calculated during rest, running, intervention and assessment of endurance running performance. The $\dot{V}O_2$ and heart rate were also measured at exhaustion. The RPE was measured by using Borg scale at rest, immediately after running, about 1 min before assessment of running performance and at exhaustion. The reliabilities of all data measurements during assessment of endurance running performance were confirmed in the previous study (Yamaguchi et al., 2015).

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*-tests were utilized to examine the differences in time to exhaustion between GWU and GWU + DS intervention. The effect sizes were calculated using Kline's equation (Kling, 2004) (d = mean difference × standard deviation of mean difference^{-1} $\sqrt{2}$ [1 - r(correlation coefficients)]; small d < .50, moderate d = .50-.80, and large d > .80) in consideration of using the paired *t*-test. Repeated measures analysis of variance (interventions ×

times) with post hoc test utilized the Tukey-Kramer test to compare changes in the $\dot{V}O_2$, heart rate and RPE. The effect sizes were calculated as General η^2 (η_g^2; small $\eta_g^2 = .02$, moderate $\eta_g^2 = .13$, and large $\eta_g^2 = .26$) (Bakeman, 2005; Olejnik & Algina, 2003). All variable data were expressed as the average ± standard deviation, and the significance level was set at $p < .05$. The 95% confidence intervals for the differences between interventions was also presented.

Results

The times to exhaustion after GWU + DS intervention were shorter than those after GWU intervention for 6 of 8 participants. The average time to exhaustion after GWU + DS intervention was significantly ($p = .03$) shorter than that after GWU intervention (Figure 2). The difference and 95% confidence interval between interventions were -120 sec and -225.8 sec to -14.2 sec, respectively. The effect size was large (d = 1.02).

The changes in average $\dot{V}O_2$ and heart rate in both interventions showed significant interactions (Table 1; interventions x times: $\dot{V}O_2$ $F_{(4,56)} = 9.77$, $p < .01$; heart rate $F_{(4,56)} = 3.62$, $p = .01$). The effect sizes were large in $\dot{V}O_2$ ($\eta_g^2 = .208$) and small in heart rate ($\eta_g^2 = .058$). As a result of post hoc tests, the average $\dot{V}O_2$ and heart rate during dynamic stretching and rest in GWU + DS intervention were significantly ($p < .01$) greater than those during rest after general warm-up in GWU intervention, although the average $\dot{V}O_2$ and heart rate during rest, running, assessment of endurance running performance and at exhaustion did not show significant differences. The average RPE did not show significant interaction (Table 1; interventions x times: $F_{(3,42)}$ = .16, p = .92). The effect sizes were small (η_g^2 = .007).

Discussion

General warm-up such as running improves performance in long-term - fatiguing effort by elevating baseline $\dot{V}O_2$ (Bishop, 2003). Bishop (2003) suggested that a warm-up of ≥10 minutes at intensity of 70% $\dot{V}O_2$max is likely to be optimal for improving long-term performance. A previous study (Yamaguchi et al., 2015) demonstrated that performing dynamic stretching for 10 repetitions as quickly as possible, followed by resting in a standing position for 1 min and 23 s prolonged the time to exhaustion (+ 18.2%) of well-trained long-distance male runners during running on a treadmill at a velocity equivalent to 90% $\dot{V}O_2$max compared with resting in a sitting position. We thus hypothesized that a combination of general warm-up at the recommended duration at intensity and the same dynamic stretching protocol as in the previous study (Yamaguchi et al., 2015), followed by a rest for the same duration, might synergistically improve endurance running performance in well-trained long-distance male runners. Unfortunately, the result of this study indicated that performing running at an intensity of 70% $\dot{V}O_2$max for 15 min and then dynamic stretching, followed by resting in standing for 1 min and 15 s, shortened the time to exhaustion (-15.8%) during running on a treadmill at a velocity equivalent to 90% $\dot{V}O_2$max compared with performing the same running, followed by resting in standing for 5 min (Figure 2). The effect size was large (d = 1.02). The finding of this study suggests that performing this general warm-up with running at an intensity equivalent to 70% $\dot{V}O_2$max for 15 min and then performing the dynamic stretching protocol during actual warm-up for well-trained long-distance runners would impair their immediate (≤ 1 min and 15 s) endurance running performance at an intensity equivalent to 90% $\dot{V}O_2max$, compared with general warm-up at the same intensity and duration followed by resting for 5 min.

It is reasonable to suppose that the performance impairment of endurance running performance seen was caused by physiological fatigue since the rest duration between dynamic stretching and assessment of endurance running performance was too short in GWU + DS intervention. Bishop (2003) has stated that, while warm-up intensity and duration are important, to improve long-term performance it is probably also necessary that the rest duration be sufficient to allow recovery. In determining rest duration, it is required to elevate baseline $\dot{V}O_2$ while causing minimal fatigue. To our knowledge, no previous studies have investigated the effects of differences in rest duration after warm-up on long-term running performance in well-trained runners. In contrast, Burnley, Doust & Jones (2005) indicated that cycling warm-up at a moderate intensity for 10-12 min followed by rest for 10 min improved cycling performance for 7 min in trained cyclists compared with control conditions, i.e., not cycling. That study (Burnley et al., 2005) also showed that an all-out sprint cycling warm-up at severe intensity for 30 s followed by rest for 10 min tended to impair the cycling performance compared with control conditions, and high $\dot{V}O_2$ and heart rate values remained before assessment of cycling performance compared with cycling warm-up at moderate intensity or control conditions. Bailey, Vanhatalo, Wilkerson, DiMenna & Jones (2009) demonstrated that cycling warm-up at severe intensity for 6 min followed by rest for 9 or 12 min improved cycling performance in recreationally active man, but the same warm-up followed by rest for 3 min impaired their performance, compared with control conditions. That previous study (Bailey et al., 2009) also reported that high $\dot{V}O_2$ and heart rate values remained after a warm-up followed by rest for 9 and 12 min and before assessment of cycling performance compared with control conditions, but the cycling warm-up followed by rest for 3 min caused the highest values of $\dot{V}O_2$ and heart rate at the same time among all conditions. In the results of the present study, the $\dot{V}O_2$ and heart rate before assessment of endurance running performance, that is, during stretching and rest after general warm-up, in GWU + DS intervention were greater than those at rest after general warm-up in GWU intervention (Table 1). The exercise modes were different between this study (running) and the previous studies (cycling). The intensity at general warm-up with running during GWU + DS intervention in this study was lower than those of cycling warm-ups in the previous studies (Bailey et al, 2009; Burnley et al., 2005). The long-term performance, however, was impaired and the $\dot{V}O_2$ and heart rate remained high immediately before the assessment of performance, and the rest duration from intervention to assessment of endurance running performance in this study was relatively short. These results suggested that physiological fatigue was caused by insufficient rest duration, impairing the endurance running performance. Further studies are needed to investigate whether extending the rest duration after general warm-up and dynamic stretching can improve running performance.

This study measured mean $\dot{V}O_2$ during assessment of endurance running performance as an index of running economy. The present results demonstrated that the change in the $\dot{V}O_2$ did not differ between GWU and GWU + DS interventions (Table 1), so running economy evaluated by $\dot{V}O_2$ does not explain why the GWU + DS intervention acutely impaired the endurance running performance compared with GWU intervention. The total running distance of participants in this study calculated by the running velocity at 90% $\dot{V}O_2max$· time to exhaustion was 3232.1 ± 979.8 (2239-5362) m. An athlete's performance at 3,000- 5,000 running events in track and field is determined by running economy evaluated by not only $\dot{V}O_2$ but also the neuromuscular activation (Nummela, et al., 2006) or effective utilization of the stretch-shortening cycle (Midgley, McNaughton & Jones, 2007; Saunders, Pyne, Telford & Hawley, 2004). No previous studies have examined the effects of differences in rest duration after running and dynamic stretching on any determining factors. However, Herda et al. (2013) demonstrated synchronous impairment of explosive performance and a reduction of neuromuscular activation evaluated by electromyography due to fatigue when the volume of dynamic stretching was excessive. It was also reported that an excessive volume of dynamic stretching impaired countermovement jump performance, in an evaluation of the function of the stretch-shortening cycle (Paradisis et al., 2014). The mechanism explaining the results of this study may be clarified by comparing the acute effects of the interventions in this study on countermovement jump height before assessment of endurance running performance. In addition, future studies are needed to investigate the electromyographic activities of related muscle groups in the lower extremities and some other parameters by analysis of movement during assessment of endurance running performance, and to clarify the reason why the GWU + DS intervention in this study acutely impaired the endurance running performance compared with GWU intervention.

As limitations of this study, the endurance running performance was evaluated on a treadmill at a constant velocity. As mentioned above, the total running distance of the participants in this study was

3232.1 ± 979.8 (2239-5362) m. The results of this study may be relevant to 3,000 or 5,000 m events in track and field. However, the running velocity during actual events is not constant. Future studies will be needed to investigate the acute effects of this GWU + DS intervention on actual running times in 3,000 or 5,000 m time trials in well-trained runners. A strength of this study was that it specifically investigated well-trained long-distance runners, but there is concern that the small sample size involved may be a limitation.

Conclusion

The results of this study demonstrated that performing this general warm-up with running at an intensity equivalent to 70% $\dot{V}O_2max$ for 15 min and then performing the dynamic stretching protocol during actual warm-up for well-trained long-distance runners acutely impaired their immediate (≤ 1 min and 15 s) endurance running performance at an intensity equivalent to 90% $\dot{V}O_2max$, compared with general warm-up at the same intensity and duration followed by resting for 5 min.

What does this article add?

This study demonstrated that general warm-up with running at 70% $\dot{V}O_2max$ for 15 min and dynamic stretching impaired immediate endurance running performance at 90% $\dot{V}O_2max$ in well-trained long-distance runners compared with general warm-up at the same intensity and duration followed by resting for 5 min. Thus, we suggest that well-trained runners and their coaches should reconsider the use of general warm-up and dynamic stretching for the warm-ups from our results.

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Table 1.

Comparisons of change in oxygen uptake ($\dot{V}O_2$), heart rate and rate of perceived exertion (RPE) between interventions.

	Vo_2 [L ・ min^{-1}]			Heart rate [b ・ min^{-1}]			RPE		
	GWU	GWU+DS	Difference (95% Cl)	GWU	GWU+DS	Difference (95% Cl)	GWU	GWU+DS	Difference (95% Cl)
Rest	0.32 ± 0.10	0.18 ± 0.09	-0.14 (-0.14 to -0.14)	72.1 ± 8.3	71.6 ± 11.5	-0.5 (-6.0 to 4.9)	6.6 ± 1.0	6.8 ± 1.3	0.1 (-0.2 to 0.4)
General warm-up	2.86 ± 0.20	2.84 ± 0.23	-0.02 (-0.02 to -0.02)	145.9 ± 12.7	146.5 ± 13.3	0.6 (-2.8 to 3.6)	-	-	
Post general warm-up	-	-		-	-		11.3 ± 1.0	11.5 ± 1.4	0.3 (-0.9 to 1.4)
Rest or Stretching and rest	0.81 ± 0.11	1.35 ± 0.18**	0.54 (0.16 to 0.93)	109.2 ± 10.3	120.9 ± 14.5**	11.8 (6.4 to 17.1)	-	-	
Pre performance test	-	-		-	-		9.0 ± 1.4	9.8 ± 1.9	0.8 (-0.2 to 1.7)
Performance test	3.76 ± 0.29	3.66 ± 0.36	-0.10 (-0.40 to 0.19)	178.4 ± 7.5	173.6 ± 11.5	-4.8 (-9.8 to 0.1)	-	-	
Exhaustion	4.09 ± 0.36	3.93 ± 0.40	-0.15 (-0.45 to 0.14)	186.3 ± 9.0	185.4 ± 10.9	-0.9 (-6.2 to 4.4)	17.9 ± 1.2	18.1 ± 1.5	0.3 (-0.5 to 1.0)

GWU: general warm-up intervention, GWU + DS: general warm-up + dynamic stretching intervention, 95% Cl: 95% confidence interval. ** indicates that the measurements in GWU + DS intervention were significantly ($p < .01$) greater than in GWU intervention.

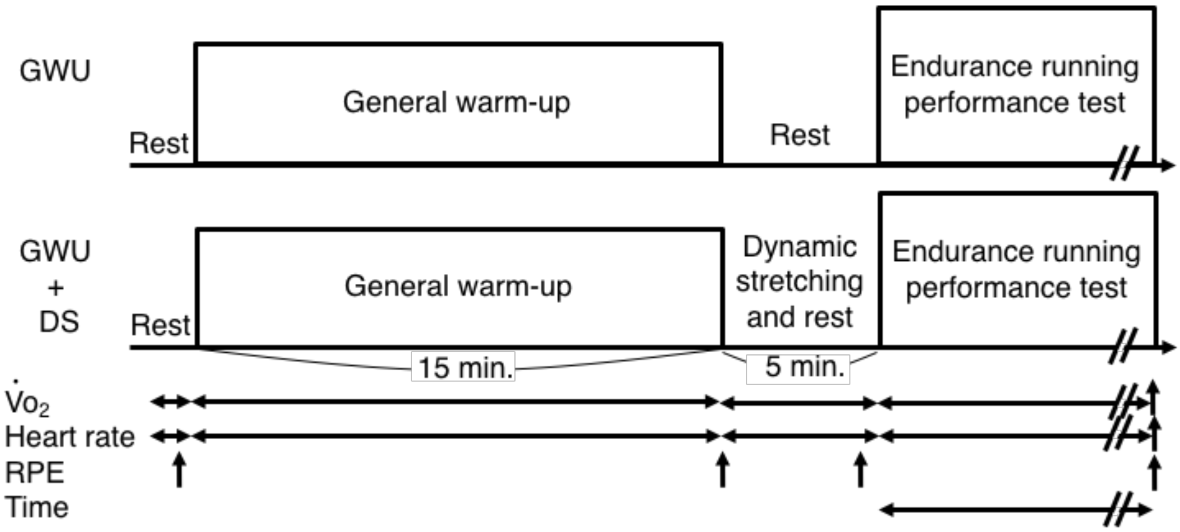

Figure 1. Experimental protocol for days 2 and 3. GWU: general warm-up intervention, GWU +DS: general warm-up + dynamic stretching intervention, $\dot{V}O_2$: oxygen uptake, RPE: rate of perceived exertion.

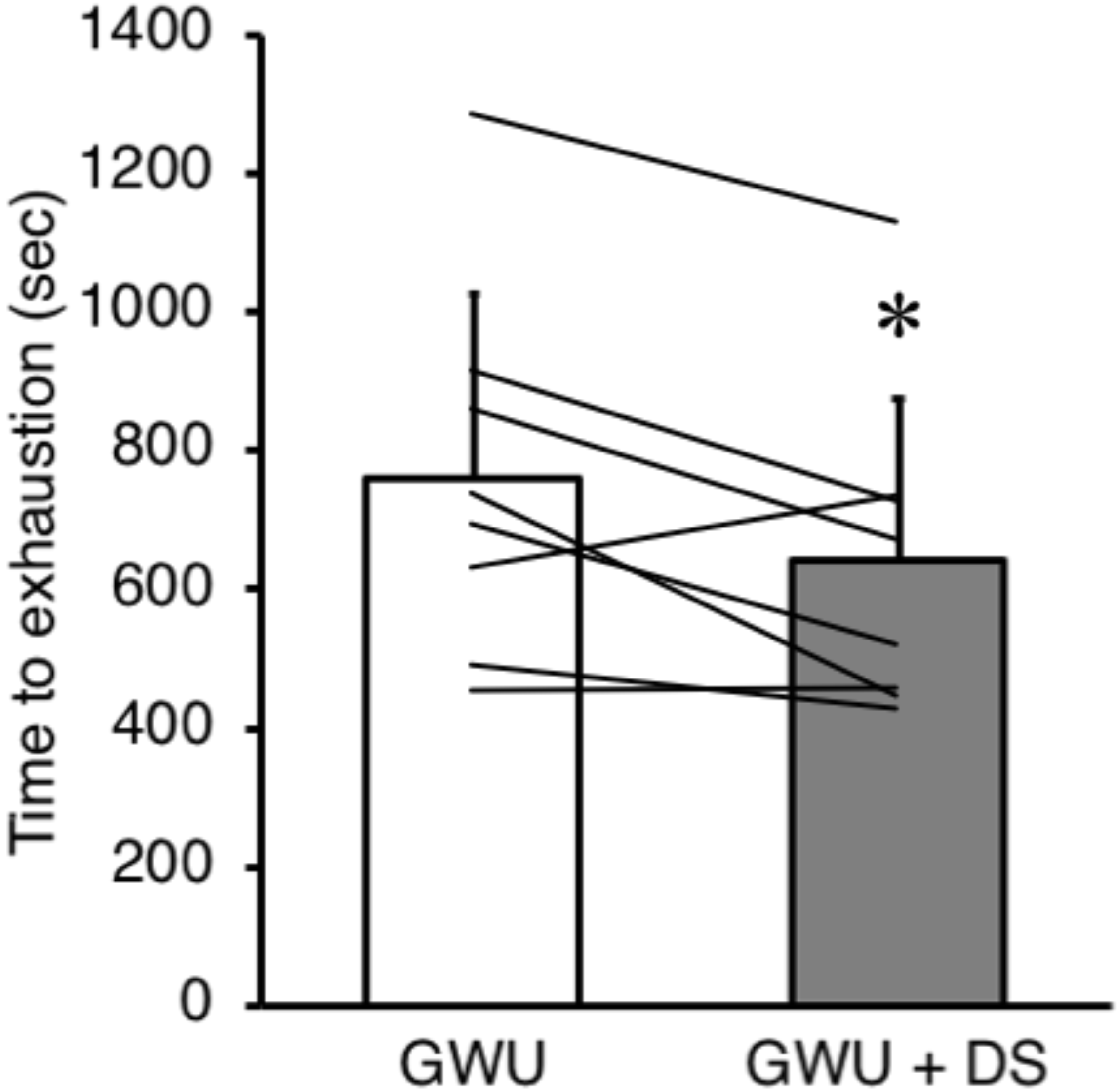

Figure 2. Comparison of running times to exhaustion after both interventions. Each line is the time for an individual athlete. Bars are the average value after each intervention. GWU: general warm-up intervention, GWU + DS: general warm-up + dynamic stretching intervention. * indicates that the time after GWU + DS intervention was significantly (p = .03) shorter than that after GWU intervention.