

THE EFFECTS OF SHORT-DURATION STATIC STRETCHING OF THE LOWER EXTREMITIES AFTER WARM-UP EXERCISE ON ENDURANCE RUNNING PERFORMANCE

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Abstract

Previous studies have shown that static stretching impairs running economy and endurance running performance. However, these studies have only examined the effects of long-duration static stretching, and the duration of the stretch is generally too long compared to the typical duration in actual practice. Hence, the purpose of this study is to investigate the effects of short-duration (20-second) static stretching of the lower extremities of athletes after a 15-minute warm-up exercise on their endurance running performance. The subjects of this study comprise seven healthy, well-trained middle-distance or long-distance male runners (age: 21.3 ± 2.1 years, height: 170.3 ± 3.1 cm, weight: 60.0 ± 5.5 kg). Each subject ran on the treadmill at 90% VO_2max until exhaustion after one of two warm-up procedures. The two warm-up procedures consist of 15-minute running at 70% VO_2max (Warm-up), and 15-minute running at 70% VO_2max and five static stretches of the lower extremities (Warm-up + static stretching). The running performance was evaluated based on the time to exhaustion. The results show that there are no significant differences in the time to exhaustion between the warm-up treatment (819.3 ± 230.6 s) and the warm-up and static stretching treatment (817.9 ± 213.7 s). The results suggest that endurance running performance is not affected by 20-second static stretches and there may be no need to carry out static stretches before endurance running if the duration is not too long.

Keywords: Running economy, time to exhaustion, VO_2 , muscle temperature

Introduction

Almost all athletes and coaches believe that warm-up exercises will enhance sports performance, and athletes normally include stretching as part of their warm-up procedure. Even though many studies reported that warm-up exercises indeed improve sports performance (Bishop, 2003; Gregson, Batterham, Drust, & Cable, 2002; Gregson, Batterham, Drust, & Cable, 2005; Stewart and Sleivert, 1998; Takizawa and Ishii, 2006a), other studies have also shown that static stretching may inhibit sports performance (Behm & Chaouachi, 2011; Kay & Blazeovich, 2012; Kallerud & Gleeson, 2013; Lowery et al., 2014; Peck, Chomko, Gaz, & Farrell, 2014; Wilson et al., 2010; Yamaguchi & Ishii, 2011).

Recently, a few studies have investigated the effects of static stretching on endurance running performance. Lowery et al. (2014) investigated the effects of stretching on endurance running performance based on a 5-minute treadmill warm-up exercise. The subjects either performed a series of six lower-body stretches for 30 seconds with three repetitions (stretching condition) or sat still for 10 minutes (non-stretching condition) before 1.6 km of uphill running. The results showed that the subjects completed the run earlier in the non-stretching condition compared to the stretching condition (Lowery et al., 2014). Wilson et al. (2010) investigated the effects of static stretching on running economy and endurance performance, whereby the subjects were required to perform 120 seconds of static stretches for each muscle before 60 minutes of treadmill running. They concluded that performing static stretches before endurance running may decrease endurance performance and increase the energy cost of running (Wilson et al., 2010).

However, we perceive that the duration of static stretching in these previous studies (Lowery et al., 2014; Wilson et al., 2010) is longer than usual. According to Duehring, Feldmann, and Ebben (2009), 73% of strength and conditioning coaches prescribe the inclusion of static stretches for less than 20 seconds on each muscle during warm-up exercise. In contrast, the subjects in these studies (Lowery et al., 2014; Wilson et al., 2010) performed static stretching over a longer period, which is four to six times longer than that in actual practice. We believe that the duration of static stretching of 90–120 seconds for each muscle is very long, considering the fact that athletes typically perform static stretches for approximately 20 seconds for each muscle in practice. This may be the reason for the discrepancies in the findings available from the literature. Furthermore, static stretching is usually performed after warm-up exercise, and it is quite common that a warm-up exercise lasts for more than 10 minutes prior to endurance running. According to Mandengue et al. (2005), the warm-up time before endurance running is more than 10 minutes for endurance athletes. For this reason, we perceive that static stretching followed by 5 minutes of running does not reflect an athlete's standard warm-up procedure.

Hence, we rationalized that a more practical and detailed investigation on static stretching and warm-up exercise is needed. Previous studies pertaining to static stretching and warm-up exercise do not reflect the actual athletic scene since the subjects who participated in these studies performed long-duration static stretching. In contrast, other studies are focused on short-duration static stretching of athletes, but with a

number of repetitions. Hence, the purpose of this study is to clarify the effects of short-duration (20-second) static stretching of the lower extremities after a 15-minute warm-up exercise, without repetitions. The endurance running speed (i.e. the intensity) of the athletes was evaluated based on 3000–5000 metre track running event.

Materials and Methods

Subjects

The subjects involved in this study comprise seven healthy, well-trained middle-distance or long-distance male runners (age: 21.3 ± 2.1 years, height: 170.3 ± 3.1 cm, weight: 60.0 ± 5.5 kg, VO_2max : 4.35 ± 0.53 l/min, $\text{VO}_2\text{max}/\text{weight}$: 72.3 ± 3.7 ml/kg/min, 5,000 m season record time: 16 min. 37 sec. 03 ± 54 sec. 24). The subjects were recruited from the Track and Field Club of Hokkaido University. All of the subjects were free from injuries in their lower extremities. The experiments were carried out between the months of February and March (off season period) and therefore, the subjects did not perform any vigorous training. The subjects were advised to avoid intense exercise or training (e.g. running, resistance training or stretching) one day before experiments as well as on each day of experiments. The subjects were also advised to consume similar meals one day before the experiments as well as on each day of experiments. The subjects were informed to finish their meals 2 hours before the experiments. In addition, the subjects were prohibited from drinking alcohol one day before the experiments and they were not allowed to drink caffeine on each day of experiments. The subjects were all briefed regarding the purpose, protocols and risks of the study, and informed consent was obtained from all subjects. This study was approved by the Institutional Ethics Committee of Rakuno Gakuen University.

Experimental Design

In order to determine the validity of our hypothesis, our experiments were divided into three days of testing interspersed with more than two days of rest. The subjects participated in all of the tests, and cross-over design was implemented on the second and third day of testing. On the first day of testing, the subjects visited our laboratory to receive instructions. We conducted the VO_2max test, in which we increased the running velocity of the subjects gradually. We used a respiratory gas analyser and treadmill to measure each subject's relative running velocity and endurance running performance concurrently.

On the second day of the testing, the subjects visited our laboratory again and they were informed to have a rest. We conducted the second day of testing after more than two days following the first day of testing. After resting, we assessed the blood lactate accumulation of the subjects. We used the mask of the respiratory gas analyser and a special probe to measure the vastus lateralis muscle temperature. We attached the probe to the vastus lateralis muscle. We assessed the endurance running performance of the subjects after they have one of the following types of pre-treatment: (a) 15 minutes of

running warm-up exercise at 70% VO₂max intensity, or (b) static stretching of the lower extremities after 15 minutes of running warm-up exercise at 70% VO₂max intensity. It shall be noted that the pre-treatment was determined randomly for each subject. During the assessment, the running velocity of the endurance running performance is equivalent to 90% of the VO₂max assessed on the first day of testing for each subject. The subjects continued to run on the treadmill set at the running velocity until exhaustion. The time to exhaustion was used as the indicator of endurance running performance whereas the vastus lateralis temperature was used as the indicator of muscle temperature. The VO₂ from rest to exhaustion was used as an indicator of running economy, which was measured using the respiratory gas analyser. The blood lactate accumulation was measured immediately after exhaustion.

On the third day of testing, we assessed the endurance running performance of the subjects after the opposite pre-treatment from the second day of testing. We compared the data obtained from the Warm-up and Warm-up + static stretching treatments in order to examine the acute effects of static stretching on endurance running performance and metabolism of the subjects. Both pre-treatments were performed at the same time of the day, taking into account the subjects' circadian rhythm. The temperature of the laboratory was set at 20–24°C throughout the experiments.

Procedure

Gradual increase velocity running test

We conducted the gradual increase velocity running test using a motor-driven treadmill (Nishikawa Iron Co. Ltd., Kyoto, Japan) to determine the VO₂max and relative running velocity at 90% VO₂max for each subject. The subjects continued to run for 4 minutes at each velocity setting with a rest period of 1 minute between velocities. The first running velocity was set at 167 metres per minute (6 minutes per kilometre). The running velocity was then increased gradually as follows: 200 metres per minute (5 minutes per kilometre), 222 metres per minute (4 minutes and 30 seconds per kilometre), 250 metres per minute (4 minutes per kilometre), 273 metres per minute (3 minutes and 40 seconds per kilometre), 300 metres per minute (3 minutes and 20 seconds per kilometre), 333 metres per minute (3 minutes per kilometre), and 364 metres per minute (2 minutes and 45 seconds per kilometre). Either one of the following criteria was used to indicate the completion of the test: (1) the heart rate of the subject exceeds the age-predicted maximum heart rate (220 beats/min), (2) the respiratory quotient (RQ) exceeds 1.1, or (3) the subject is no longer able to run further. We measured the VO₂ every 10 seconds using the mixing chamber method. We used a respiratory gas analyser (VO2000, S&ME Co. Ltd., Tokyo, Japan) throughout the running test. VO₂max was used as the indicator of the peak VO₂. We calculated the running velocity at 90% VO₂max for each subject using the running velocity and VO₂ values obtained from the running test, and we found that the average running velocity at 90% VO₂max is 280.5 ± 25.6 metres per minute (3 minutes and 35.4 ± 19.6 seconds per kilometre).

Pre-treatment

In the Warm-up + static stretching treatment, the subjects were required to perform static stretching which targets five muscle groups (hip extensors and flexors, leg extensors and flexors, and plantar flexors) in the upright position. Figure 1 shows the static stretches adopted in this study: (a) hip joint flexors, (b) hip joint extensors, (c) leg extensors, (d) leg flexors, and (e) plantar flexors. The subjects performed 20 seconds of static stretching for each muscle after running warm-up. It shall be noted that the static stretching routine was performed only once and therefore, there were no repetitions. Prior to each stretch, we instructed the subjects to stretch their muscles until they experienced slight discomfort. The subjects performed each stretch on a particular muscle group followed by the next target muscle group without rest. The total duration of static stretching was 4 minutes and 21 ± 11 seconds. We assessed the endurance running performance of the subjects 5 minutes after static stretching (i.e. 39 seconds after static stretching). In contrast, in the Warm-up treatment, the subjects were required to rest in a standing position for 5 minutes after 15 minutes of running warm-up. We assessed the endurance running performance of the subjects immediately after that.

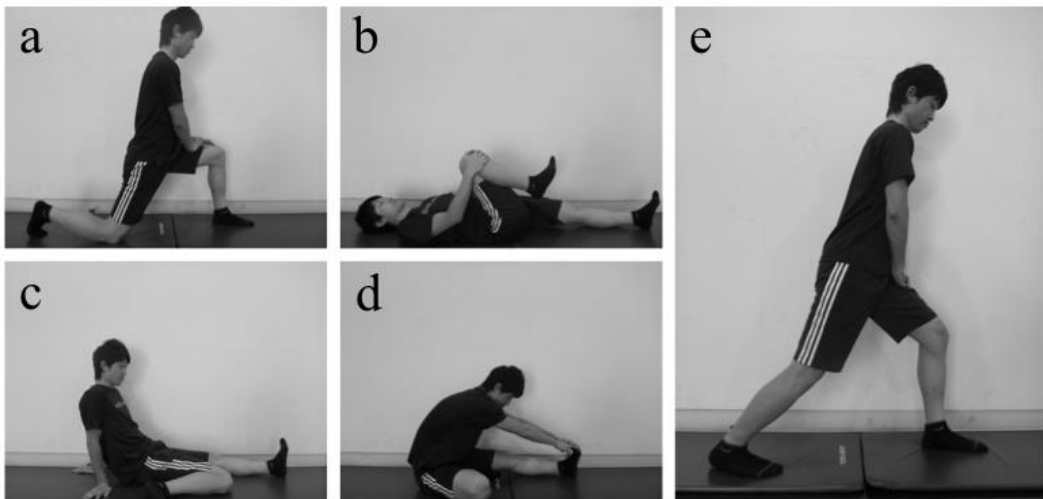


Figure 1: Protocols of static stretching treatment on each target muscle group: (a) hip joint flexors, (b) hip joint extensors, (c) leg extensors, (d) leg flexors, and (e) plantar flexors

Measurements during endurance running performance

Each subject continued to run on the treadmill set at a velocity equivalent to his 90% VO_2max until exhaustion. Either one of the following criteria was used to indicate exhaustion: (1) the subject is no longer able to run further, or (2) the subject is unable to stay in our defined position for more than 10 seconds. The time to exhaustion was used as indicator of endurance running performance. We measured the vastus lateralis muscle temperature of the subjects during pre-treatment and just before running. We also sampled the VO_2 of the subjects while they were at rest, during pre-treatment and while they were running every 10 seconds using the respiratory gas analyser (VO2000). For

both pre-treatments, we calculated the average VO_2 for 1 minute at rest (i.e. 1 minute before treatment) and from the start of running to 1 minute before exhaustion. The VO_2 measured during the run was used as an indicator of running economy. We performed blood sampling in the right earlobe at rest and immediately after running to exhaustion. We measured the blood lactate accumulation using an analyser (Lactate Pro, LT-1710, Arkray, Kyoto, Japan) in order to verify the running intensities and metabolism responses. We measured the vastus lateralis muscle temperature before the warm-up exercise and running test using a surface-type deep body thermometer (Core temp CTM-210, Telmo, Tokyo, Japan).

Statistical Analysis

We used paired t-test to examine the difference in the time to exhaustion between the Warm-up and Warm-up + static stretching treatments. We used repeated measures ANOVA (pre-treatments \times times) to compare the variations in the muscle temperature, VO_2 and blood lactate accumulation. When there were significant differences in the interactions or main effects, we used one-way ANOVA and post hoc test (Tukey-Kramer) or paired t-test to analyse the same time or same conditions. We calculated the effect size using Kline's equation ($d = \text{mean difference}/\text{standard deviation of the mean difference}$; small $d: < 0.50$, moderate $d = 0.50\text{--}0.80$, and large $d = > 0.80$, Kline, 2004), considering that we used the paired t-test. Following this, we calculated the power ($1-\beta$). All of the variable data were expressed in the form of average \pm standard deviation, and the significance level was set at $p \leq 0.05$.

Results

Running time

Figure 2 shows the time to exhaustion of the subjects during the endurance running performance test. It can be observed that there is no significant difference in the time to exhaustion between (Warm-up: 819.3 ± 230.6 s versus Warm-up + static stretching: 817.9 ± 213.7 s). The effect size is found to be very small ($d = 0.01$) and the power is 0.05.

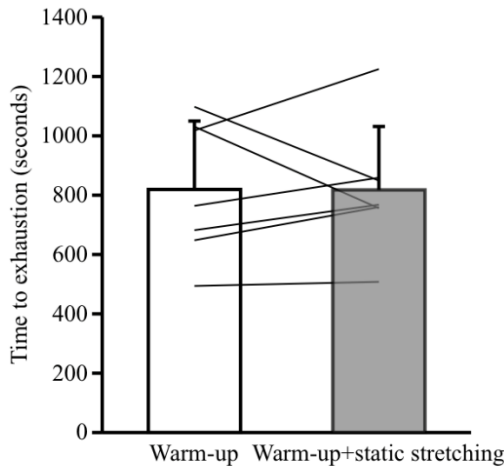


Figure 2: Time to exhaustion of the subjects during endurance running performance test

Muscle temperature

Table 1 shows the vastus lateralis muscle temperature of the subjects during pre warm-up and pre-test. It is found that there are neither interactions nor any main effects of pre-treatment or time. However, there is a significant main effect of time course ($p < 0.01$). The vastus lateralis temperature is higher during pre-test ($p < 0.01$) compared to that during pre warm-up for both conditions (Warm-up and Warm-up + stretching). The effect size is found to be moderate ($d = 0.60$) whereas the power is 0.68.

Table 1: Vastus lateralis temperature of the subjects during pre warm-up and pre-test, and blood lactate accumulation of the subjects during pre warm-up, pre-test and post-test. ‘a’ denotes a significant difference ($p < 0.01$) between pre warm-up and pre-test. ‘b’ denotes a significant difference ($p < 0.01$) between pre warm-up and post-test.

	Vastus lateralis temperature (°C)		Blood lactate accumulation (mmol/l)		
	Pre warm-up	Pre test	Pre warm-up	Pre test	After test
Warm -up	35.0 ± 0.2	37.1 ± 0.5 a	0.94 ± 0.14	0.89 ± 0.41	6.55 ± 2.32 a,b
Warm-up + Static stretching	34.8 ± 0.6	36.7 ± 0.4 a	1.04 ± 0.34	1.00 ± 0.13	6.91 ± 1.91 a,b

Blood lactate accumulation

Table 1 shows the blood lactate accumulation of the subjects during pre warm-up, pre-test and post-test. It is found that there are neither interactions nor main effects of pre-treatment. However, there is a significant main effect of time course ($p < 0.01$). The blood lactate accumulation is higher ($p < 0.01$) during post-test compared to that during pre warm-up and pre-test for both conditions (Warm-up and Warm-up + stretching).

Oxygen uptake

Figure 3 shows the time course of VO_2 for each treatment, and it can be seen that there are no interactions and main effects of pre-treatment. However, there are significant main effects of time course ($p < 0.01$).

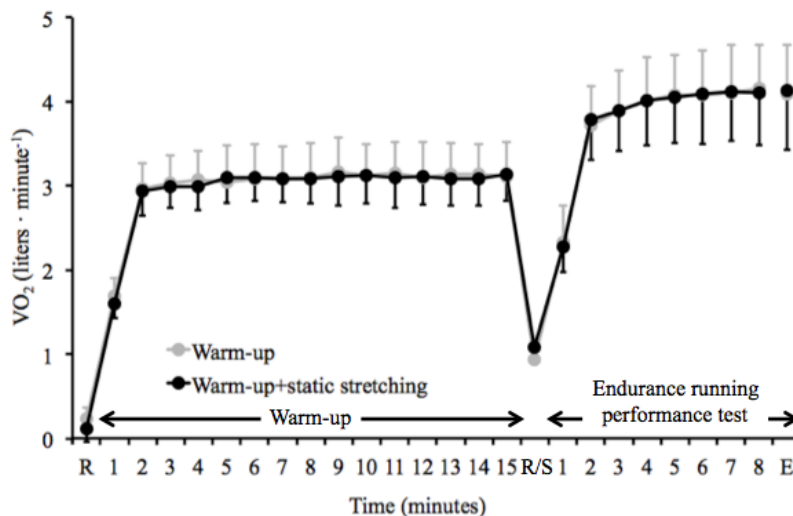


Figure 3: Time course of VO_2 in each treatment. ‘R’, ‘S’ and ‘E’ denotes rest, stretching and exhaustion, respectively.

Discussion

The results of this study show that short-duration (20-second) static stretching of the lower extremities after 15-minute warm-up exercise has no effect on the 90% VO_{2max} of the subjects. The results indicate that static stretching neither improves nor impairs endurance running performance. In addition, there is no difference in the VO_2 between the Warm-up and Warm-up + static stretching treatments during the endurance running performance test and therefore, there is no significant difference in the running economy between the two treatments. The results indicate that endurance running performance is not influenced by the inclusion of 20-second static stretches in the warm-up exercise. To date, a few studies have been carried out regarding warm-up procedures on the submaximal running performance and thus, the results obtained in this study may be invaluable to restructure the warm-up procedures for endurance athletes and coaches.

Furthermore, it is found that short-duration static stretching does not affect endurance running performance, which contradicts the findings of Lowery et al. (2014) and Wilson et al. (2010). The running economy is also not impaired in any way, as evidenced by the insignificant difference in the oxygen uptake between Warm-up and Warm-up + static stretching treatments. We believe that the subjects in this study experienced the same level of exhaustion for both treatments since the blood lactate accumulation after the endurance running performance test is the same. In previous studies (Lowery et al., 2014;

Wilson et al., 2010), the subjects performed static stretching for 90 to 120 seconds for each muscle. However, Duehring et al. (2009) reported that 73% of the strength and conditioning coaches performed static stretching during warm-up exercise for less than 20 seconds on each muscle. We concur that previous studies on running economy and endurance running performance (Lowery et al., 2014; Wilson et al., 2010) are based on long-duration static stretching, which is not the norm in actual practice. Based on the findings in this study and those of Duehring et al. (2009), we perceive that static stretching may not affect the endurance running performance of athletes. Hence, it is not necessary for athletes to avoid static stretching before endurance running, provided that the duration of stretches is short.

Our results reveal that short-duration static stretching will not induce performance-decline mechanisms and for this reason, it should not degrade endurance running performance. Siatras, Mittas, Mameletzi, & Vamvakoudis, (2008) reported the relationship between the duration of static stretching and muscle force and they observed that there was a decrease in muscle force when the duration of static stretching was within 10–20 seconds. However, they did not investigate the relationship between the duration of static stretching and endurance performance. Yamaguchi and Ishii (2011) reviewed a number of studies related to the duration of static stretching and subsequent exercise performance. One of the key findings is that exercise performance decreases in 30.7% of the subjects when the duration of static stretching is less than 30 seconds. However, the exercise performance decreases in a larger number of subjects (57.9 and 64.8%) when the duration of static stretching is 30 seconds and more than 30 seconds, respectively. The variations in exercise performance may be induced by biomechanical changes of the muscle-tendon tissues or physiological changes of neuromuscular functions (Yamaguchi & Ishii, 2011). However, according to Guissard, Duchateau, and Hainaut (1998) and Magnusson, Aagaard, and Nielson (2000), these biomechanical changes and physiological changes are lost upon completion of static stretching over a duration of 45 and 30 seconds, respectively. In addition, even though respiratory and circulation capacity have significant influence on endurance running performance, running economy is also a key factor which needs to be considered (Saunders, Pyne, Telford, & Hawley, 2004). Running economy is influenced by both the biomechanics of the muscle-tendon tissues and physiology of the neuromuscular functions (Nummela et al., 2006; Saunders et al., 2004). In this study, we perceive that 20 seconds of static stretching per muscle at the lower extremities after 15 minutes of warm-up exercise does not induce biomechanical changes of the muscle-tendon tissues or physiological changes of neuromuscular functions. Consequently, there is no difference in the endurance running performance between the Warm-up and Warm-up + static stretching treatments.

Based on the results of this study, we deduce that short-duration static stretching does not induce any physiological effects on endurance running performance. However, it is imperative for one to avoid a drastic drop in muscle temperature after warm-up exercise in order to ensure exercise performance (Faulkner et al., 2013). In addition, it is found that there is no significant difference in the pre-test muscle temperature between Warm-up and Warm-up + static stretching treatments and therefore, we conclude that there is an insignificant difference in the temperature drop between standing rest and static stretching. We have mentioned previously that there is no difference in the running

economy between Warm-up and Warm-up + static stretching treatments since there is no difference in the VO_2 between these treatments during the endurance running performance test. These physiological data support the endurance running performance results in this study.

However, we perceive that the warm-up intensity may have been too low, and this is one of the limitations in this study. It has been reported in a previous study (Takizawa & Ishii, 2006b) that warm-up exercise below the lactate threshold may not be effective for maximal exercise. In this study, we found that the lactate accumulation after warm-up exercise is within a range of 0.89–1.00, which is below the lactate threshold. This indicates that running at 70% $\text{VO}_{2\text{max}}$ is below the lactate threshold intensity for the subjects in this study. Hence, the warm-up exercise may not have any effect on performance enhancement. More vigorous warm-up may induce different effects of static stretching. Another limitation of this study is the size of the sample, which is rather small. It shall be noted that the experiments were carried out under the same conditions, with the exception of pre-treatments. However, the statistical power for the time to exhaustion is very small, which may have resulted in the large standard deviations. This is one of weaknesses in the results of this study.

In summary, short-duration (20-second) static stretching of the lower extremities after 15 minutes of warm-up exercise neither improves nor inhibits running performance of athletes in the 3000–5000 metre track race. According to Duehring et al. (2009), 73% of strength and conditioning coaches recommended static stretching for less than 20 seconds on each muscle during warm-up exercise. Our results reveal that it is not necessary to avoid static stretching before endurance running provided that the duration of the stretches is less than 20 seconds on each muscle. It is also evident from our results that short-duration static stretching does not improve endurance running performance. Moreover, if the athletes perform static stretching over longer durations, they may experience lower running economy and a decline in running performance, as previous studies have shown.

Conclusion

We have investigated the effects of short-duration (20-second) static stretching of the lower extremities on the endurance running performance of athletes involved in the 3000–5000 metre track race. Based on our findings, we conclude that 20 seconds of static stretching on each target muscle group after the warm-up exercise does not reduce endurance running performance. Indeed, a number of previous studies have suggested that if stretches are done over long periods, this will result in a decrease in endurance running performance. Hence, we believe that both athletes and coaches should not be concerned regarding the inclusion of static stretching during warm-up exercise – rather, they should focus more on the duration of stretching.

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