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Effects of short or long warm-up on intermediate running performance

Running title: Warm up and intermediate running performance

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ABSTRACT

The aim of the study was to compare the effects of a long warm-up (general + specific) and a short warm-up (specific) on intermediate running performance (3-min run). Thirteen experienced endurance-trained athletes (age 23.2 ± 2.3 yr, body mass 79.8 ± 8.2 kg, body height 1.82 ± 0.05 m) conducted two types of warm-ups in a cross-over design with one week in between: a long warm-up (10 min, 80% maximal heart rate, and 8x60 m sprint with increasing intensity and 1 min rest in between) and a short warm-up (8x60 m sprint with increasing intensity and 1 min rest in between). Each warm-up was followed by a 3-min running test on a non-motorized treadmill. Total running distance, running velocity at each 30 s, heart rate, blood lactate concentration, oxygen uptake, and rate of perceived exertion were measured. No significant differences in running performance variables and physiological parameters were found between the two warm-up protocols, except for the rate of perceived exertion and heart rate, which were higher after the long warm-up and after the 3-min running test compared with the short warm-up. It was concluded that a short warm-up is as effective as a long warm-up for intermediate performance. Therefore, athletes can choose for themselves if they want to include a general part in their warm-up routines, even though it would not enhance their running performance more compared with only using a short specific warm-up. However, to increase efficiency of time for training or competition these short specific warm-up should be performed instead of long warm-ups.

Keywords: blood lactate concentration, rate of perceived exertion, heart rate, oxygen uptake

INTRODUCTION

In most sports, a warm-up is performed with the aim to prepare the body for high-level performance and to prevent injuries when performing at that high level (5, 12, 18, 21, 24). In endurance sports, it is normal to have a preparatory exercise period for at least a half hour to an hour with the goal to enhance subsequent competition (15). These warm-ups often start with the general part, like jogging at a slow intensity, followed by a period of static/ dynamic stretching. Subsequently, the specific part, including high-intensity runs (15), is performed before the competition starts.

Many studies have investigated the effects of warm-ups on sports performance by manipulating the content (general–specific), duration, and intensity of warm-ups (5, 12, 19). Bishop (5, 6) and McGowan et al. (18) explain that there are temperature-related and non-temperature-related mechanisms that can improve intermediate performance. Bishop suggests that a warm-up may improve intermediate performance by decreasing the initial oxygen deficit, leaving more of the anaerobic capacity for later in the task (6). Earlier studies have reported a decreased oxygen deficit and/or a greater aerobic contribution when a warm-up preceded the intermediate performance (1, 3, 11, 13, 17). However, when the intensity of the warm-up is too high, it could cause too much fatigue and thereby impair the intermediate performance (7, 14, 27, 30, 31). It is therefore important that a warm-up is of sufficient duration and intensity to elevate baseline VO_2, while causing minimal fatigue (6, 7, 20, 24).

Bishop (6) suggests that a 3 to 5 min warm-up of moderate intensity is enough to significantly improve short-term performance, whereas for intermediate performance a longer warm-up duration is necessary to elevate baseline VO_2. It is often prescribed with a general cardiovascular warm-up of 10-20 minutes, stretching followed by a specific warm-up for the intermediate performance (5). However, it is still not clear if a general warm-up in the start, like jogging for a duration of longer than 10 minutes, would have a more positive effect upon intermediate performances than only conducting a short intensive warm-up. Perhaps, a short intensive warm-up could also elevate baseline VO_2 as much as the long warm-up. If this is the case less time is necessary for a warm-up and warm-up would be more efficient. This could be very handy when time for training is short in today's society.

Van den Tillaar and von Heimburg (29) have shown that only eight sprints (50–60 m) of increasing intensity (60–95% of maximal sprint performance) with 1 –min of rest in between was enough to reach enhanced short-term performance compared with a long typically team-sport warm-up. Furthermore, they found that this warm-up had the same performance enhancement for repeated sprint performance (8*30 m sprint with sprint every 30 s) for soccer players compared with the longer-duration warm-up (28). The repeated sprint performance could be seen as an intermediate performance, because the total duration was 4 min. However, the intermittent character and the intensity of the performance (sprints), and thereby the anaerobic sprints in nature, could perhaps not be explained by an elevated baseline VO_2 but by other processes (decreased stiffness or altering the force–velocity relationship). Furthermore, no oxygen uptake measurements were performed that could clarify if there was an elevated baseline VO_2 that could explain the performance enhancement in the repeated sprint performance. When the intermediate performance is continuous, it may be more important to have an elevated baseline VO_2 at the start of the performance. In addition, it is possible that only eight 60-m sprints, equivalent to 80 s of work, could elevate baseline $VO_{2.}$ However, it may be necessary to include a general part of jogging (low intensity) beforehand.

Therefore, the aim of the present study was to compare the effects of a long warm-up (general + specific) with a short warm-up (only specific part) on an intermediate running performance of 3 min. A 3-min running test was used as an intermediate running performance, because in earlier studies it was found that a short warm-up gives better results in achievements shorter than 3 min, whereas a long warm-up seems to give better results in performances longer than 3 min (7, 9, 16). It was hypothesized that a short warm-up would enhance running performance equally or more in comparison to a long warm-up, because earlier studies on short term performances have shown that the duration of this short warm-up (only specific part) is enough to increase performance (7, 24, 27). The theory is that the increased aerobic metabolism is high enough even after a short warm-up without causing an oxygen depth at the start of the running performance. The anaerobic metabolism is thus saved for the last part of the performance (6). In addition, it is thought that a long warm-up could cause increased pre-competition fatigue and prematurely elevate the anaerobic contribution, instead of saving it for the end of the running performance (6, 24, 31).

METHODS

Experimental approach to the problem

To compare the effects of the two warm-up protocols (long warm-up: general + specific vs. short warm-up: only specific part) on intermediate running performance (3 min run), a counterbalanced cross-over design with repeated measurements was conducted in which the subjects performed both warm-ups with one week in between. The independent variables were the types of warm-up (a short or a long one), and the dependent variables were the total running distance performance, running velocity, oxygen uptake, heart rates every 30 s during the 3-min run, blood lactate concentration, and rate of perceived exertion (RPE).

Subjects

Thirteen experienced endurance-trained athletes (age 23.2 ± 2.3 yr, body mass 79.8 ± 8.2 kg, body height 1.82 ± 0.05 m) participated in the study. The subjects were sport students who had several years of training experience in different sports (cross-country skiing, biathlon, soccer, and long-distance running). The subjects were fully informed about the protocol before the start of the study, and an informed consent was obtained from all subjects prior to testing, with the approval of the local ethics committee and in accordance with the current ethical standards in sports and exercise research. The experiment was conducted in February and March, and the two tests were always conducted on the same day and at the same time of day for each subject, with the same researchers (18). The subjects were instructed to avoid strenuous training 48 hours prior, alcohol consumption at least 12 hours prior, and food consumption 2 hours prior to each test, and they were asked to wear the same shoes for both tests.

Procedures

The running performances were tested on a non-motorized treadmill (Woodway Curve, Woodway Inc, Waukesha, USA). All subjects had experience in running on a motorized treadmill, but only 3 on a non-motorized treadmill. Therefore, one familiarization session was conducted on this treadmill. The familiarization session consisted of a warm-up of at least 10 min at an independently chosen intensity on the non-motorized treadmill. After these 10 min, the subjects performed three maximal sprints on the treadmill to establish their maximal running velocity, which was necessary to know for the warm-up protocol. The highest running velocity was used for calculating the different velocities for the warm-up. After this, a maximal heart rate test was performed. The maximal heart rate test was two times 3 min with 90 s of rest in between. The first 3 min were hard, but not exhaustive, while the second 3 min were exhaustive (2). Heart rate was measured every 5 s with a heart rate belt (Polar RS 400, Polar Electro, OY Kempele, Finland), and the highest heart rate was used to calculate the intensity of the long warm-up.

The test procedure was either the long warm-up, which consisted of a general and a specific part, or the short warm-up, which only consisted of a specific part. Height and weight were determined before each test. Thereafter, the subjects sat on a chair for 10 min to measure heart rate (Polar RS 400, Polar Electro, OY Kempele, Finland). The average heart rate of the last min was used as baseline. In addition, blood lactate concentration (EKF diagnostics, Biosen C – line, Magdeburg, Germany) was tested by taking blood from the index finger immediately after these 10 min of rest. Next, the subjects started with either the long or the short warm-up. The long warm-up consisted of an initial 10 min running on 70% maximal VO_2, equivalent to 80% maximal heart rate (25). This intensity was chosen because Bishop (5) suggested that 10 min running on 70% VO_{2max} is long and intensive enough for increased muscle temperature sufficient for an optimal running performance (27). After the general part, the subjects had 1 min of rest in which blood lactate concentration was measured again together with the RPE on a scale of 1 to 10 (8, 23). The specific part of the warm-up consisted of eight 60-m sprints with a 5% increase of maximal running velocity as found in the familiarization test, starting at 60% and reaching 95% in the final run; the same warm-up protocol as van den Tillaar et al. (28, 29) was used for investigating the effect of this warm-up on sprint and sprint ability. Between each 60 m was 1 min of rest, in which one of seven dynamic flexibility exercises for the shoulder, hip, knee, and ankle joints was conducted, starting with the shoulders and working downwards (for a detailed description of these exercises, see van den Tillaar et al. [28, 29]).

After the last 60-m run, 5 min of active recovery was taken before the start of the 3-min running test. During the warm-up protocol and running test, oxygen uptake was measured in “breath by breath” mode (Oxycon Pro, Erich Jaeger GmbH, Hoechberg, Germany). The oxygen uptake at the end of the general and specific parts of the warm-up and at the end of the running test, together with the lactate and heart rate, was used for further analysis. To get a better understanding of the development of the 3-min running performance, the heart rate and oxygen uptake at 10, 20, and 30 s after the start and every 30 s thereafter were used for further analysis. In addition, the running velocity every 30 s and the total distance covered were used (Figure 1). Time to peak heart rate and time to peak oxygen were also calculated to investigate if the warm-up had an effect on these two variables.

INSERT FIGURE 1 AROUND HERE

Statistical analyses

To investigate the development of the different physiological (oxygen uptake, heart rate, and blood lactate concentration) and perceptual (RPE) variables during the two warm-up protocols, a two-way (warm-up protocol and time of measurement) analysis of variance (ANOVA) with repeated measurements was used. In addition, a 2 (long–short warm-up) x 8 (60-m running velocity) ANOVA was used to investigate if the running velocity increased during the specific warm-up part and if there were differences in performance and performance-related variables between the two warm-up protocols.

To compare the effects of the two warm-up protocols on the 3-min running performance variables (running velocity), a 2 (long vs. short warm-up) x 6 (every 30 s during the running test) ANOVA with repeated measurements was used. For the heart rate and oxygen uptake, a

2 (long vs. short warm-up) x 9 (at start, 10 s, 20 s, 30 s, and every 30 s after during the running test) ANOVA with repeated measurements was used. Post hoc comparisons with Holm–Bonferroni corrections were conducted to locate differences. A one-way ANOVA with repeated measurements was used to compare the total distance covered, time to peak oxygen uptake, and peak heart rate during the 3-min running test. All results are presented as mean ± SD. Where sphericity assumptions were violated, Greenhouse–Geisser adjustments of the *p*-values were reported. The criterion level for significance was set at $p<0.05$. Effect size was evaluated with η^2 (ETA partial squared), where $0.01<\eta2<0.06$ constitutes a small effect, $0.06<\eta2<0.14$ constitutes a medium effect, and $\eta2>0.14$ constitutes a large effect (10). Statistical analysis was performed in SPSS, version 22.0 (SPSS Inc., Chicago, IL, USA).

To test the reliability of the protocol, oxygen uptake, heart rate and running velocity during the test after each warm-up protocol were used to calculate ICC by Crombachs' Alpha. The ICCs of oxygen uptake, heart rate and running velocity were respectively 0.91, 0.92 and 0.91.

RESULTS

The highest running velocity obtained during the familiarization session was 7 m/s (SD = 0.94 m/s) and a peak heart rate of 194±7 beats/min. No significant effect of warm-up (short vs. long) was found at the different times (rest, specific warm-up, and end of the test) for heart rate, oxygen uptake, and lactate concentration ($F\leq2.1$, $p\geq0.17$, $\eta^2\leq0.15$, Table 1). A significant effect was found only for the RPE ($F=6.4$, $p=0.026$, $\eta^2=0.35$, Table 1). Post hoc comparison showed that the RPE after the specific part of the long warm-up was significantly higher than after the short warm-up (Table 1). In addition, a significantly higher heart rate at the end of the running test was found for the long warm-up compared with the short warm-up ($p=0.027$,

Table 1). Furthermore, a trend was found for the heart rate after the warm-up, with a higher heart rate after the long warm-up compared with the short warm-up (p=0.058).

INSERT TABLE 1 AROUND HERE

All variables significantly increased from rest to the end of the test (F≥238, p≤0.001, $\eta^2 \geq 0.95$, Table 1) except for the oxygen uptake after the general part of the long warm-up, which was the same as immediately after the specific part of this warm-up (p=0.18). Each sprint in the specific part was faster than the previous one (F=305, p<0.001, $\eta^2=0.97$). In addition, an effect was also found for warm-up duration (F=4.7, p=0.049, $\eta^2=0.29$). However, post hoc comparison did not show significant differences between the sprint velocities of the specific part of the long and short warm-ups, except for some trends in sprints 2 (p=0.052) and 3 (p=0.079), with a higher sprint velocity after the long warm-up (Figure 2).

INSERT FIGURE 2 AROUND HERE

The total distance covered in 3 min was not significantly different (F=2.7, p=0.12, $\eta^2=0.19$) after the long and short warm-ups (long warm-up: 765±80 m vs. short warm-up: 752±78 m). Furthermore, no differences between the time to maximal oxygen uptake (long warm-up: 153±30 s vs. short warm-up: 149±32 s) and time to peak heart rate (long warm-up: 154±30 s vs. short warm-up: 155±21 s) were found (F≤0.28, p≥0.63, $\eta^2 \geq 0.01$).

When analyzing the development of the oxygen uptake, heart rate, and running velocity during the 3-min running test, a significant increase in all of these variables (F≥24; *p*<0.001; $\eta^2 \geq 0.67$, Figure 3) was observed. No significant effect was found between the two protocols for the heart rate (F=3.3; p=0.093; η^2=0.22), oxygen uptake (F=2.5; p=0.14; η^2=0.17), and running velocity (F=2.8; p=0.12; η^2=0.19). Post hoc comparison showed that the running velocity increased significantly for both warm-ups from 2 to 3 min every 30 s. Oxygen uptake and heart rate for both warm-up protocols showed almost the same development; they increased significantly until 2 min (oxygen uptake) and 2.5 min (heart rate). However, pairwise comparison revealed that the heart rates at the start (p=0.024) and at the end (p=0.027) of the running test were significantly higher for the long warm-up compared with the short warm-up (Figure 3).

INSERT FIGURE 3 AROUND HERE

DISCUSSION

The purpose of the present study was to compare the effects of a long warm-up (general + specific) with a short warm-up (only specific part) on intermediate running performance of 3 min. The main findings were that no significant differences in running performance variables and physiological parameters were found between the two warm-up protocols, except for the RPE and heart rate, which were higher after the long warm-up than the short warm-up.

No significant differences were found in running performance (running velocity, total distance covered) and physiological parameters (heart rate, oxygen uptake, time to maximal heart rate, and oxygen uptake) during the 3-min running test (Table 1) that could be explained by the duration of the warm-up. In both the long and short warm-ups the oxygen uptake and heart rate increased equally. At the end of both warm-ups the heart rate was increased to around 85% of maximal heart rate (Table 1), and an oxygen uptake of around 60% of the maximal oxygen uptake was measured during the running test. No difference was found between the oxygen uptakes after the long warm-up and the short warm-up, indicating that it was possible with only eight 60-m sprints to elevate the baseline $V0_2$ sufficiently enough to enhance performance. No protocol involving only a long general warm-up at 70% VO_{2max} was included, because van den Tillaar et al. (28) already showed that only using a general warm-up caused worse performance compared with a warm-up that includes general and specific parts. In addition, Neiva et al. (21) showed that intermediate performance was less when no warm-up was included compared to a warm-up that swimmers regularly perform. Therefore, these protocols (no warm-up or their regular warm-up) were not included in our study.

Stewart and Sleivert (27) showed that an intensity of 70% VO_{2max} during a warm-up of 15 min enhanced intermediate performance better than at an intensity of 60 or 80% VO_{2max}. They suggested that an intensity of 60% is not high enough to enhance baseline oxygen uptake, whereas an intensity of 80% VO_{2max} causes fatigue. In the present study, the intensity during the general part of 10 min was similar to the study of Stewart and Sleivert (27). However, it was based on the percentage of maximal heart rate, which was at around 80%. When the percentage of oxygen uptake was calculated as the percentage of the maximal oxygen uptake measured during the 3-min running test, the oxygen uptake was only around 61% of the maximal oxygen uptake, which is much lower than in the study of Stewart and Sleivert (27). The difference in percentage can be explained by the treadmill and protocol used. Stewart and Sleivert (27) used a treadmill at 13km/h with 20% grade and a maximal VO_{2max} test that had an incremental increasing speed design. By using an incremental increasing speed design for establishing VO_{2max}, the maximal VO_2 is perhaps not the real VO_{2max} that Beltrami et al. (4) found. In the present study, a non-motorized treadmill was used, which allows to adjust the velocity naturally during a running test. This makes it possible to have an end spurt during the test (22) that could cause a higher oxygen uptake than measured during conventional VO_2max tests. This results in a lower percentage of maximal heart rate during the warm-up.

In the present study, a 3-min running test was used, because in earlier studies it was found that a short warm-up gives better results in achievements shorter than 3 min, whereas a long warm-up seems to give better results in performances longer than 3 min (7, 9, 16,). Ingham et al. (16) showed that only using 2x50 m and a continuous 200-m run at an estimated 800-m race pace gave better 800-m times compared with a 10-min self-paced jog and 6x50 m as warm-up. Our study also indicates that it is not necessary to include a 10-min jog at 70% maximal VO_{2max} to get better running results in a 3-min run.

The RPE immediately after ending the warm-up was higher after the long warm-up (Table 1), and the heart rate was higher at the start and end of the running test (Table 1, Figure 3) compared with the short warm-up, which could indicate that the subjects were more fatigued. These findings were in accordance with the findings of earlier studies (28, 29), which also found that the RPE and heart rate were higher after a long warm-up compared to a shorter one. Measuring core temperature could perhaps give an explanation for these differences, because it is possible that in a long warm-up the subjects get overheated earlier and thereby perceive more exertion (higher RPE) and a higher heart rate (26).

It has already been shown that after the general warm-up the subjects were warmer at the start of the 60-m runs with increasing intensity than without this part (short warm-up), because 60-m runs 2 and 3 during the long warm-up were at a higher velocity than the runs in the short warm-up. This indicates that the temperature- and/or non-temperature-related mechanisms were already working.

A limitation of the present study was that the effect of these warm-ups on intermediate running performance was investigated on experienced endurance-trained athletes but not on elite runners, which could give different results, because elite runners are used to much longer warm-ups for competition. Furthermore, muscle temperature during the protocols should be measured to get a better understanding of what happens during the different warm-ups and to examine if the possible explanations are correct. Thus, future studies should take note of these suggestions. Based upon the findings of the present study it is concluded that athletes can choose for themselves if they want to include a general part in their warm-up routines, even though it would not enhance their running performance more compared with only using a short specific warm-up. However, when time is limited or you want to use your time efficient for training or competition of intermediate performance duration these short specific warm-up should be performed instead of long warm-ups.

PRACTICAL APPLICATIONS

The main aim of the present study was to investigate whether a short specific warm-up would get the same or better results in intermediate running performance as a long (general + specific) warm-up. No significant differences in running performance were found, indicating that the short warm-up is good enough and that more time could therefore be dedicated to other training skills. Therefore, to increase efficiency of time to training or competition these short specific warm-up should be performed instead of long warm-ups, which includes a general part for intermediate running performance. Longitudinal studies should be conducted, in which short warm-ups are consistently implemented, in order to consider the effect on injury occurrence.

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Figure Legends

Figure 1. Protocol for the long and short warm-ups with the different measurements. The short warm-up did not include the general part of the warm-up.

Figure 2. Average running velocity (Mean ± SD) for each 60 m for the long and short warm-ups.

Figure 3. Running velocity, oxygen uptake, and heart rate development (Mean ± SD) during the 3-min running test after conducting each warm-up protocol (short and long).

* indicates a significant difference (p<0.05) between the two warm-up protocols.

→ indicates a significant difference (p<0.05) between this variable and all right of the arrow.

Table 1. Heart rate, lactate concentration, RPE and oxygen uptake (± SD) at different times of the warm-up and at the end of the running performance test with the short and long warm-up.

Parameter	**Long warm-up**				**Short warm-up**		
	Rest	**General part**	**Specific part**	**After test**	**Rest**	**Specific part**	**After test**
Heart rate (beat/min)	70 ± 15	155 ± 6	167 ± 12†	196 ± 6*	71 ± 17	161 ± 10	192 ± 6
RPE (1-10)	-	2.9 ± 0.8	5.0 ± 1.2*	9.2 ± 0.9	-	4.3 ± 0.9	8.8 ± 0.9
Lactate concentration (mmol/L)	1.3 ± 0.3	1.9 ± 0.5	4.7 ± 1.2	11.9 ± 1.8	1.5 ± 0.4	4.8 ± 1.4	12.1 ± 2.2
VO_{2max} (mL/ kg/min)	-	36.4 ± 4.6	33.7 ± 3.5	56.5 ± 4.2	-	34.0 ± 2.5	55.6 ± 3.9

* indicates a significant difference with the short warm-up on a $p < 0.05$ level.

† indicates a trend ($p=0.058$) with the short warm-up.

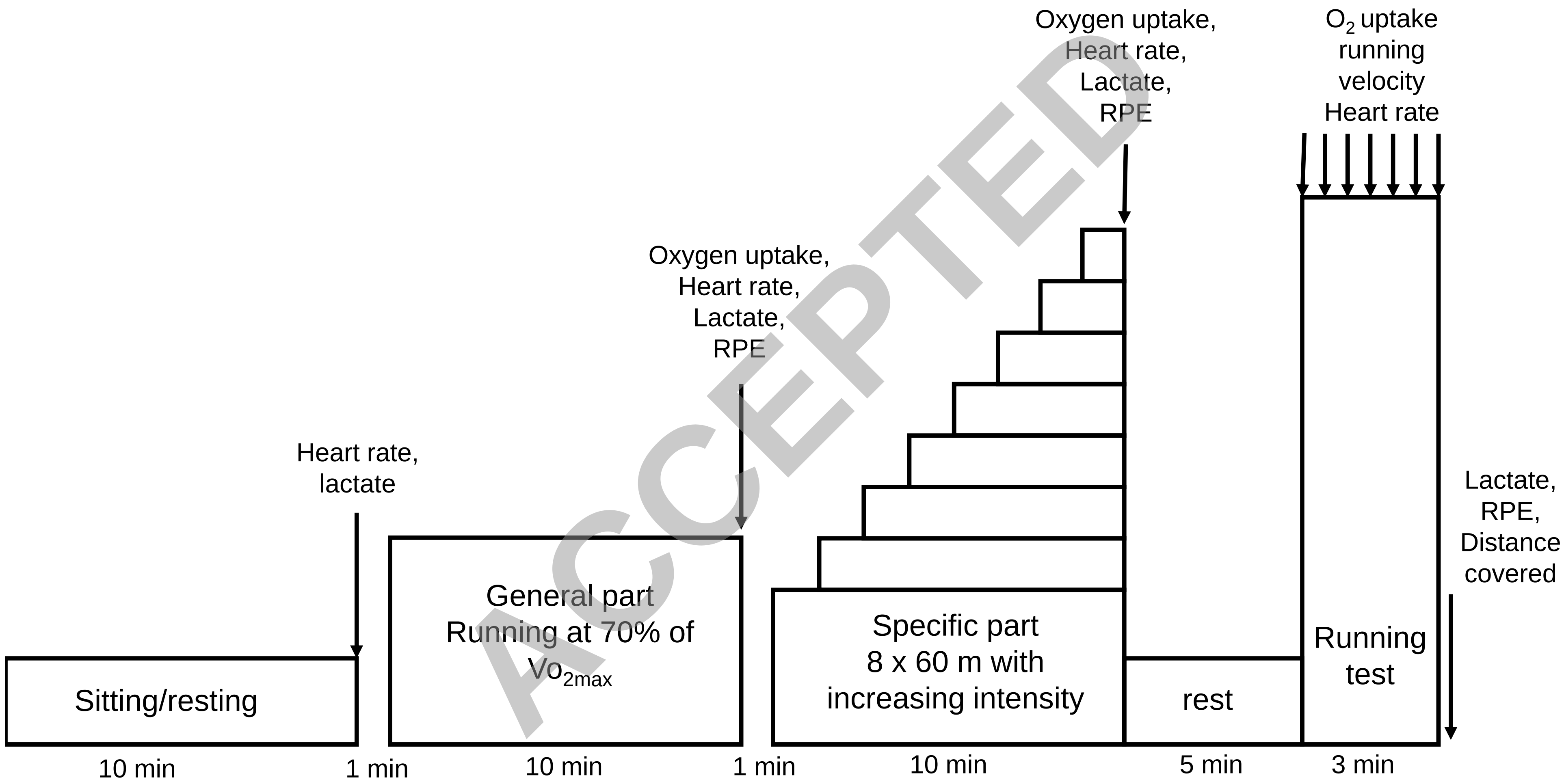
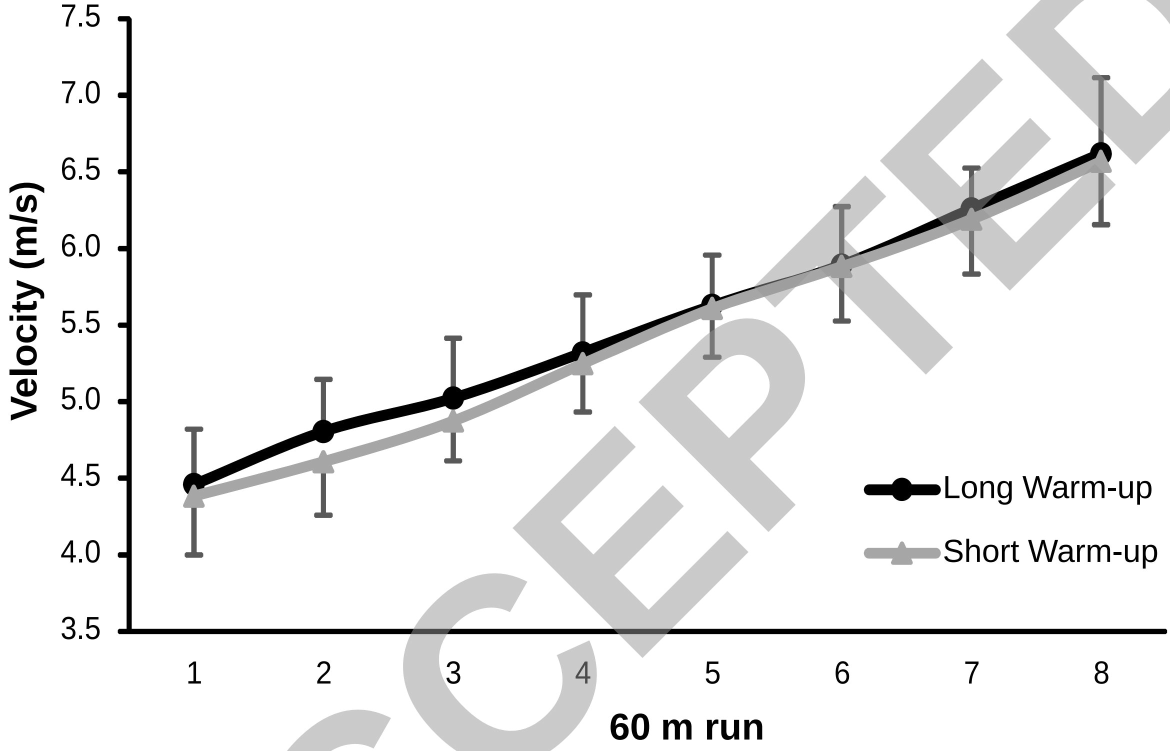

Oxygen uptake,
Heart rate,
Lactate,
RPE
O2 uptake
running
velocity
Heart rate
Oxygen uptake,
Heart rate,
Lactate,
RPE
Heart rate,
lactate
Lactate,
RPE,
Distance
covered
General part
Running at 70% of
Vo2max
Specific part
8 x 60 m with
increasing intensity
Running
test
Sitting/resting
rest
10 min
1 min
10 min
1 min
10 min
5 min
3 min

Figure 2



7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
Velocity (m/s)
1
2
3
4
5
6
7
8
60 m run
Long Warm-up
Short Warm-up

Figure 3

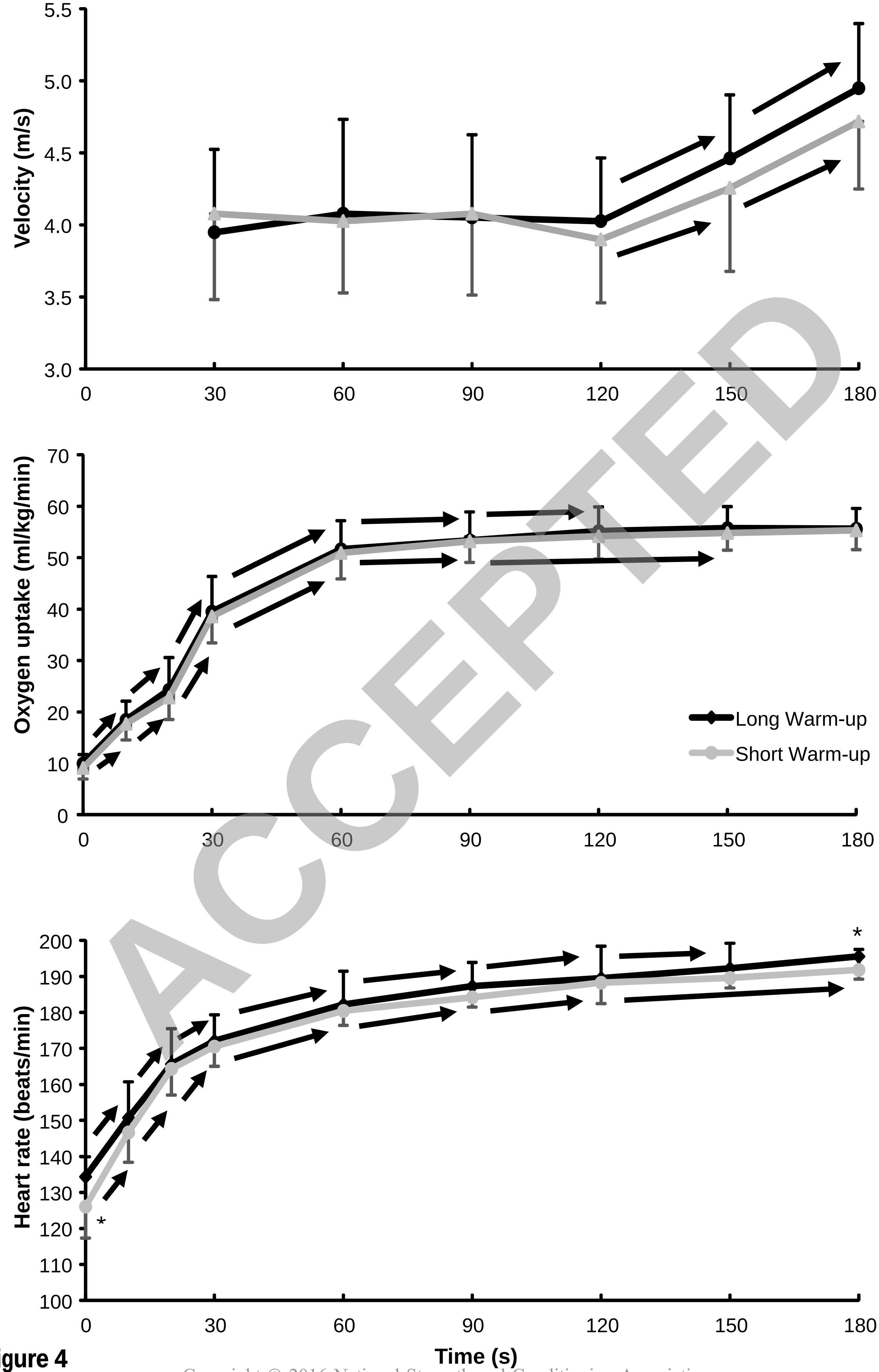

5.5
5.0
4.5
4.0
3.5
3.0
Velocity (m/s)
0 30 60 90 120 150 180
70
60
50
40
30
20
10
0
Oxygen uptake (ml/kg/min)
0 30 60 90 120 150 180
Long Warm-up
Short Warm-up
200
190
180
170
160
150
140
130
120
110
100
Heart rate (beats/min)
*
*
0 30 60 90 120 150 180
Time (s)

Figure 4