Accepted Manuscript

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Author: Henrique P. Neiva Mário C. Marques Tiago M. Barbosa Mikel Izquierdo João L. Viana Daniel A. Marinho

PII: S1440-2440(16)30059-7
DOI: http://dx.doi.org/doi:10.1016/j.jsams.2016.04.012
Reference: JSAMS 1324

To appear in: *Journal of Science and Medicine in Sport*

Received date: 4-6-2015
Revised date: 8-4-2016
Accepted date: 30-4-2016

Please cite this article as: Neiva HP, Marques MC, Barbosa TM, Izquierdo M, Viana JL, Marinho DA, Effects of 10<ce:hsp sp=0̈.25/̈>min vs. 20<ce:hsp sp=0̈.25/̈>min passive rest after warm-up on 100<ce:hsp sp=0̈.25/̈>m freestyle time-trial performance: a randomized crossover study, *Journal of Science and Medicine in Sport* (2016), http://dx.doi.org/10.1016/j.jsams.2016.04.012

Effects of 10 min vs. 20 min passive rest after warm-up on 100 m freestyle time-trial performance: a randomized crossover study

Henrique P. Neiva [1, 2], Mário C. Marques [1, 2], Tiago M. Barbosa [2, 3], Mikel Izquierdo[4], João L. Viana [2, 5], Daniel A. Marinho [1, 2]

[1] University of Beira Interior, Department of Sport Sciences, Covilhã, Portugal

[2] Research Center in Sport Sciences, Health Sciences and Human Development, CIDESD, Portugal

[3] National Institute of Education, Nanyang Technological University, Singapore

[4] Department of Health Sciences, Public University of Navarre, Navarre, Spain.

[5] University Institute of Maia, ISMAI, Maia, Portugal

Original Investigation

Corresponding Author and address:

Mikel Izquierdo, PhD

Department of Health Sciences

Public University of Navarra (Navarra) SPAIN

Campus of Tudela
Av. de Tarazona s/n. 31500 Tudela (Navarra) SPAIN
Tel + 34 948 417876
mikel.izquierdo@gmail.com

Manuscript Word count: 2981

Abstract word count: 209

Number of Tables: 2

Number of Figures: 1

Abstract

Objectives: The aim of this study was to compare the effect of 10min vs. 20min passive rest post warm-up on performance in a 100 m freestyle time-trial.

Design: Randomized crossover.

Methods: Eleven competitive male swimmers performed two experimental trials on different days, consisting of 100 m freestyle time-trials following 10min or 20min passive rest after a standard 1,200 m warm-up. Performance (time-trial), biomechanical (stroke length, stroke frequency, stroke index, propelling efficiency), physiological (blood lactate concentrations, heart rate, core and tympanic temperature), and psychophysiological (perceived effort) variables were assessed during both trials.

Results: Time-trial performance was faster after 10min as opposed to 20min passive rest (58.41±1.99s vs. 59.06±1.86, p<0.01). This was supported by strong effect sizes (d=0.99) and the qualitative indication of "likely" positive effects. Heart rate before the time-trial was also higher after 10 min passive rest (89±12bpm vs. 82±13bpm; p<0.01). Furthermore, net core temperature and oxygen uptake values before the time-trial were substantially lower after 20min passive rest.

Conclusions: These data suggest that the 10min post warm-up passive rest enhances 100 m freestyle performance when compared to a 20min period. An improvement that appears to be mediated by the combined effects of a shorter post warm-up period on core temperature, heart rate and oxygen uptake.

Keywords: Sports Performance; Pre-exercise; Swimming; Heart Rate; Temperature.

Introduction

Warming-up before training or competition has become one of the most interesting topics for coaches, swimmers and researchers in the last few years.[1-3] Studies have described physiological adaptations to warm-up that theoretically support a positive effect of warm-up on subsequent performance; these effects are mostly linked to an increase in body temperature.[4,5] For instance, warm-up causes faster oxygen dissociation from hemoglobin, acceleration of metabolic reactions and nerve conduction rate, and reduced muscle and joint resistance.[4] Besides the effects on body temperature, priming physical activities might also exert additional effects that benefit performance, such as elevated baseline oxygen uptake (VO_2) and increased amplitude of the primary VO_2 response to subsequent exercise.[6]

In swimming, it was only recently that evidence of the positive effects of warm-up on performance has started to emerge. Studies found that swimmers were 1.5% faster in the 100m freestyle[7] and were able to apply 11.5% more propelling force during a 30s all-out freestyle when warm-up was perfomed.[8] However, only a few studies have focused on the warm-up structure.[1,2,9] The duration of the rest interval separating the warm-up from the main high intensity task appears to be critical for subsequent performance. It might seem obvious that one should aim to maintain the increased metabolic rate achieved during warm-up,[10] but in competition, a period of time is also needed to accomplish all official requirements before the race. Zochowski et al.[9] reported that 200m time-trial swim performance was 1.38% faster after 10min passive rest compared to 45min. Using a longer rest period, West et al.[2] verified that 200m time-trial swim performance times were 1.48% faster after a 20min passive rest compared to 45min. Higher core temperature (Tcore)[2] and higher heart rate at the beginning of the race, which potentially increased baseline oxygen consumption,[9] were the main mechanisms associated with the improved performance following shorter passive rest intervals. A main limitation of these studies is the longer duration of the rest period used, i.e. 45 min, which might even be too long to simulate a real competition. In addition, both studies focused on 200m time-trial performance and did not measure VO_2 or biomechanical responses.

To the best of our knowledge, studies to date have only focused on the effects of different post warm-up intervals in the 200m race, assessing few physiological parameters and disregarding hypothetical biomechanical responses. Moreover, other racing distances might demand different passive rest periods. For instance, the 100m freestyle involves a different use of metabolic pathways, with a lower aerobic contribution than the 200m and perhaps less dependence on higher pre-trial VO_2.[29] In addition, the majority of studies investigating the effects of warm-up on swimming performance have used a standard 10min interval, but their findings can only be fully understood if one knows how different recovery periods could influence the results. Therefore, the aim of the present study was to compare the effects of two different post warm-up intervals (10 and 20min rest) on 100m freestyle performance. Performance, biomechanical, physiological and psychophysiological responses were investigated. It was hypothesized that the shorter passive rest period would result in better swimming performance.

Methods

Eleven competitive male swimmers (age 17.4±1.8years; height 176.4±5.7cm; body mass 65.7±9.4kg) took part in this study. Swimmers were eligible for the study if they had competed at the national level for the previous 6 years. In the current season, the swimmers trained with 36390±5960m per week during 6 to 9 training sessions/week; the average personal best time in the 100m freestyle was 57.92 ± 2.05s (534.4±56.8 FINA 2015 scoring points). After university ethics committee approval, ensuring compliance with the Helsinki declaration, participants were informed about the study procedures, and written informed consent and/or assent forms were obtained.

The study followed a repeated measures design. Each participant completed 2 time-trials of 100m freestyle, in randomized order, separated by 48hr. Swimmers were asked to wear the swimsuits they normally wore during competitions. All the experiments were conducted two months after the beginning of the season, at the same time of day (8:00–13:00 AM) in a 50m indoor swimming pool with water temperature of 27.6±0.1ºC, air temperature of 27.9±0.1ºC and 60.7±0.2% humidity. The swimmers were familiarized with the warm-up procedures 48hr before the experiments and they were reminded to maintain the same training, recovery and diet routines, including abstaining from caffeine, during the 48hr prior to testing.

After arriving at the pool, the swimmers remained seated for 5min for the assessment baseline heart rate (Vantage NV; Polar, Lempele, Finland), tympanic temperature (Braun Thermoscan IRT 4520, Germany), Tcore (CorTemp, HQ Inc, Palmetto, FL) blood lactate concentration ($[La^-]$; Accutrend Lactate® Roche, Germany) and VO_2 (Kb4^2, Cosmed, Rome, Italy). After that, the swimmers performed a standard warm-up for a total volume of 1,200m (Table1), designed based on research[7,9,10] with the help of an experienced national swimming coach.

With the main set, the aim was to increase VO_2 to optimize the subsequent time-trial performance. It was structured based on the assumptions that i) critical velocity could be faster than lactate threshold and maximal lactate steady state, causing a progressive increase in VO_2 and $[La^-]$;[11] and ii) the rest period should be sufficient to maintain $[La^-]$ levels lower than 5 $mmol \cdot l^{-1}$, as recommended for warm-up procedures.[13] The critical velocity was calculated from the slope of the regression line between distance swam and time, combining the 50m and the 400m best times.[11] The range of critical velocity, between 98 to 102%, corresponded to 85±2% and 88±2% of the 100m race-pace, respectively. Heart rate, VO_2 and rating of perceived exertion[12] (RPE) were monitored during warm-up to ensure the same intensity between the two trials. Once swimmers finished warming-up, they were asked to remain seated for 10 or 20min before performing the 100m time-trial.

-Please insert Table1.

Each swimmer was instructed to step onto the starting block and then take off after official verbal command and the starting signal. Trial times were clocked by a timing system (OMEGA S.A. Switzerland), using as backup a stopwatch held by a swimming coach and a video camera (Casio Exilim Ex-F1, *f*=30 Hz) placed at 15m, perpendicular to lane 7. That same procedures and devices were also used to assess the 15m time. Stroke frequency (SF), stroke length (SL) and stroke index (SI) were determined according to the procedures reported earlier by Neiva et al.[7] The propelling efficiency (η_ρ) was also estimated[14]:

$$\eta_p = [(0.9 \cdot v)/(2\pi \cdot SF \cdot l)] \cdot 2/\pi$$

where v is the swimming velocity ($m\ s^{-1}$), SF is the stroke frequency (Hz) and *l* is the arm length (m). The *l* is computed trigonometrically by measuring arm length and considering average elbow angles during insweep of the arm pull, as reported by Zamparo et al.[14] At the range of swim velocities demonstrated in these swimmers, internal mechanical work is rather low and can be neglected[13] and η_p becomes similar to Froude efficiency. For a more detailed discussion, see Zamparo et al.[14]

Capillary blood samples for [La^-] assessment were collected from the fingertip after the warm-up protocol (1min), immediately before the trial, after the trial (3 and 6min after to obtain the highest value) and 15min after the trial. Heart rate was also assessed over the warm-up period and during recovery following the time-trial. Additionally, the RPE was recorded during and after the warm-up, and after each trial.

Tympanic temperatures were measured before the warm-up, after the warm-up (1min), immediately before and after the trial and 15min post-trial. Tcore was assessed by a temperature sensor that was ingested the night before (10hr before the test).[15] This pill transmitted a radio signal to an external sensor (CorTemp Data Recorder, HQ Inc., Palmetto, FL), which subsequently converted the signal into digital format. The net values of Tcore ($Tcore_{net}$) were selected to compare data and reduce error resulting from pill position.

VO_2 was measured with a backward extrapolation technique immediately after trial.[16] The first 2s of measurement after detection were not considered due to the device's adaptation to the sudden change of respiratory cycles and to oxygen uptake.[17] The peak oxygen uptake (VO_2peak) was considered to be the mean value of the following 6s.[17] Additionally, VO_2 was continually monitored during the post warm-up time period and after the 100m freestyle.

Standard statistical procedures were selected for the calculation of means, standard deviations (SD) and confidence limits. The normality of all distributions was verified by the Shapiro-Wilks test, and parametric statistical analysis was adopted. To compare data between two trials, Student's paired t-tests were used, followed by Cohen's d effect size for repeated measures ($p \leq 0.05$). The effect size was calculated using G-Power 3.1.3 for Windows (University of Kiel, Germany) and 0.2 was deemed small, 0.5 medium, and 0.8 large. An Excel spreadsheet for crossovers was used to calculate the smallest worthwhile effects and to determine the likelihood that the true effect was substantially harmful, trivial, or beneficial (positive, trivial or negative for non-performance variables).[18] The threshold value for the smallest worthwhile change was set at 0.8% for performance, whereas the other variables were set at 0.2 (Cohen's smallest effect size).[18] Suggested default probabilities for declaring an effect clinically beneficial were <0.5% (most unlikely to harm) and >25% (possible benefit).[19] The effect was deemed unclear if it was possibly beneficial (>25%) with an unacceptable risk of harm (>0.5%). Where clear interpretation could be made, chances of benefit or harm were assessed as follows: <0.5%, most unlikely, almost certainly not; 0.5-5%, very unlikely; 5-25%, unlikely, probably not; 25-75%, possibly; 75-95%, likely, probably; 95-99.5%, very likely; and >99.5%, most likely, almost certainly.[19]

Results

Performance was improved moderately in the 10min compared to the 20min rest condition (Table 2), resulting from a large effect on the first 50m lap and a moderate effect on the second 50m lap. The swimmers categorised their effort as being between very hard and exhaustive in both trials (p=0.18;

d=0.55; mean difference 1.0%; 90% confidence limits ±2.9; clinical inferences unclear). Regarding the biomechanical analysis (Table 2), the swimmers showed higher SF after 10min passive rest during the first 50m lap, with small effect sizes seen in the second 50m. Despite the unclear implications of SL and η_p in the first 50m, there were clear decreases in SI, SL and η_p during the second 50m lap.

-Please insert Table2.

Figure 1 depicts the physiological responses to the different conditions. Baseline measures of Tcore (1A) were similar between conditions (p=0.27; d=0.46; 0.8%; ±1.2; unclear). The highest Tcore values were recorded after warm-up (10min 37.67±0.48ºC; 20min 37.76±0.57ºC). There was a small additional decrease in Tcore in the 20min compared to the 10min passive rest (p=0.78; d=0.11; -0.1%; ±0.9; possibly negative), corroborated by pre-trial $Tcore_{net}$ differences (p=0.31; d=0.32; -55.3%; ±19.1; possibly negative). Those differences in $Tcore_{net}$ (1B) were increased after the trial (p=0.16; d=0.59; -66.2%; ±12.0; likely negative). The 15min of recovery were not sufficient to return to baseline values (37.46±0.33ºC; 37.36±0.39ºC). The tympanic temperature (1C) recorded no clear differences between conditions until the end of trial, when medium differences were found (p=0.06; d=0.49; -1.4%; ±1.5; likely negative), and after recovery (p=0.06; d=0.70; -0.9%; ±0.8; likely negative).

Baseline measures of [La$^-$] (1D) were low and similar between conditions (p=0.16; d=0.46; 8.1%; ±9.7; likely trivial). [La$^-$] responded in the same way to warm-up (p=0.20; d=0.44; 5.5%; ±8.8; most likely trivial). [La$^-$] attained the highest values after trial, but no clear differences were observed (11.91 ± 3.82 mmol·l^{-1} vs. 11.32 ± 3.71 mmol·l^{-1}; p=0.36; d=0.29; -4.9%; ±12.2; unclear), and this was maintained during recovery (p=0.18, d=0.43; -10.9%; ±13.6; possibly negative).

There was a small difference in baseline heart rate (1E) between the two protocols (p=0.13; d=0.49;-3.3%; ±3.6; possibly negative) but similar VO_2 (1F) (p=0.78; d=0.11; -0.4%; ±2.3; very likely trivial). The response to warm-up was identical between conditions for both heart rate (p=0.73, d=0.40; -0.8%;

±3.6%; likely trivial) and VO_2 (p=0.82, d=0.09; 4.0%; ±21.7; unclear). This data corroborates the similarity between the warm-up intensities and procedures, as evidenced by the perceived effort after warm-up (10.00±1.48 vs. 9.55±1.63; p=0.45; d=0.25; 6.7%; ±14.8; unclear). However, pre-trial values showed lower heart rates in the 20min condition (89±12bpm vs. 82±13bpm; p<0.01; d=1.07; -7.8%; ±4.0%; very likely negative). This may somehow reflect the near statistically significant difference between VO_2 pre-trial, but with a high effect size ($8.58±1.67 ml·kg^{-1}min^{-1}$ vs. $7.54±2.45 ml·kg^{-1}min^{-1}$; p=0.07; d=0.81; -14.1%; ±10.5; likely negative). After the trial, no clear differences were seen in VO_2peak ($55.23±7.03 ml·kg^{-1}min^{-1}$ vs. $53.67 ± 9.46 ml·kg^{-1}min^{-1}$; p=0.39; d=0.35; -3.4%; ±5.9; possibly negative), while lower heart rates were found in the 20min passive rest condition (173±6bpm vs. 165±11bpm; p=0.10; d=0.75; -4.7%; ±4.5; likely negative). A greater additional decrease in heart rates for the 20min condition was found during recovery (p=0.004; d=1.11; -9.0%; ±4.3; very likely negative).

-Please insert Figure1.

Discussion

The aim of this study was to compare the effects of 10min or 20min post warm-up passive rest on 100m freestyle performance in competitive swimmers. The main finding was a “likely” positive effect on swimming performance when the shorter passive rest period was used (1.12% faster time-trial performance with 10min vs. 20min). This supported the hypothesis that a shorter time-lag between the warm-up and the race benefits time-trial performance. The physiological response may partially explain this finding. Although acute adaptations in body temperature did not seem enough to justify the difference in performance, the combined effects of the shorter post warm-up interval on Tcore, heart rate, and VO_2 appeared to be associated with the faster performance observed.

Active warm-up in swimming seems to improve performance after rest periods of 10min[9] and 20min.[2] However, it remains to be seen which duration is the most effective for optimizing performance and which type of rest (active or passive) should be used.[20] It has been suggested that increases in muscle and core temperature caused by priming exercises are the major factors influencing performance.[4] At least for land-based activity, an increase in the athlete's temperature results in lower time required to achieve peak tension and relaxation,[21] reduced viscous resistance of the muscles and joints,[22] increased muscle blood flow,[23] improved efficiency of muscle glycolysis and high-energy phosphate degradation,[24] and increased nerve conduction rate.[5] Therefore, we implemented a recommended warm-up volume,[14] including a near race-pace velocity set[14] (approximately 90% of the 100m race-pace velocity), that resulted in increased VO_2 and body temperature.

In the present study, as expected, Tcore increased during the warm-up, eventually reaching its maximum value, and then started to drop, decreasing up until the beginning of the time-trial. Before the race, the 20min rest interval had a very "likely" negative effect on $Tcore_{net}$ values. Therefore, the lower $Tcore_{net}$ in the 20min condition could have influenced the swimmers' performance, as a decrease in performance could be related to muscle and core temperature decline after exercitation.[25] Despite not being significant, tympanic temperature recorded a trend towards higher values in the 10min condition, supporting the $Tcore_{net}$ data. West et al.[2] noted that 45min was an excessive rest period for the Tcore, explaining its negative effect on 200m freestyle performance. In this study, the abovementioned effects on Tcore cannot by themselves explain the 1.12% performance improvement; the pre-trial heart rate and VO_2 data can provide complementary support, as the 10min of extra rest in the 20min condition lowered these variables by ~8% and ~14%, respectively. Thus, the strong effect verified in these two variables could influence the race, notably during the first few meters.

After verifying a higher heart rate before the 200m trial in the 10min rest compared with the 45min rest, Zochowski et al.[9] hypothesized that the swimmers started the trial at a high baseline VO_2. The authors did not measure the VO_2, but our data confirmed their speculation for both heart rate and VO_2. Before their study, warm-up was already believed to increase VO_2 and oxygen kinetics.[6] Yet, our study was the first to provide evidence of such. Higher baseline VO_2 might have influenced the energy provision from anaerobic sources in the first part of the race by increasing the aerobic contribution and preserving the high-energy subtracts for later use in the task.[26] This might explain the ~0.7% faster times in the second lap in the 10min condition compared to the 20min condition.

The better performance seen in the first 50m lap after a 10min post warm-up period could be the result of higher SF. The swimmers were able to reach higher SF due to an effect on motor neuron excitability that remained after the shorter post warm-up rest.[27] Also, it could point to a post-activation potentiation effect that should happen by the 8th min of recovery,[28] enabling an optimized SF. Thus, increased SF for the same efficiency (monitored by the SI and η_p) resulted in a faster 50m lap.

The different post warm-up periods were not enough to cause differences in the [La^-] after the trial. Some authors may suggest that a shorter rest induces increased lactate production due to glycolytic stimulation over the trial. However, the increased VO_2 at the beginning of the trial could have stimulated the aerobic contribution, which has been shown to reach approximately 50% of the energy expenditure in a 100m maximal bout.[29] Moreover, this could hinder the glycolytic pathway. Although we failed to observe differences in [La^-], VO_2peak and RPE, the increased heart rate seen after the trial might suggest a higher spike in such variables at the beginning of the trial. An increased primary response would increase the oxidative metabolic contribution early in the exercise and increase anaerobic metabolism in the final meters.[26] This could augment the heart rate response such that the swimmers can easily recover their homeostasis.

Although muscle temperature could be an important complementary variable with which to better understand our findings, we should not disregard Tcore as having a great influence on performance.[4] Recent findings about passive post warm-up heating strategies showed that some exercitation was also needed for better performance.[10,30] Accordingly, our results suggested that temperature alone could not be responsible for the performance optimization. Therefore, researchers should consider analysing the in-water swimming sets so that the abovementioned effects can be extended. The lower values of VO_2 before the race in both trials lead us to speculate that some physiological adaptation mechanism may occur to change the motor unit recruitment patterns, thus optimizing the immediate VO_2 response during trial. We should also be aware of possible differences in the physiological measurements between time-trials compared to competition. For instance, heart rates could be higher during pre-race build-up due to increased anxiety from the competition itself. Nevertheless, we aimed to ensure that the swimmers performed the two maximal trials in the same conditions.

Conclusion

The swimmers were faster in the 100m freestyle following 10min vs. 20min post warm-up passive rest. Despite the expected influence of body temperature in this improvement, our data suggests that temperature is not the only influencing factor. Heart rate and VO_2 seem to be positively influenced by the shorter rest, notably influencing the first meters of the race. This may increase the aerobic contribution to this initial phase of the race, stimulating different metabolic energy pathways and resulting in improved performance. Further research should focus on the passive or active methods of rest for maintaining the benefits of warm-up (i.e. elevated temperature, heart rate and VO_2) during the time frame between warm-up and the swimming race.

Practical implications

-The beneficial effects of in-pool warm-up may decrease over time and influence the subsequent swimming race. It is suggested to conduct the warm-up close to the race to benefit from all of its positive effects.

-The time-lag between warm-up and race should be long enough to allow a post potentiation effect, but not so long that oxygen consumption, heart rate and core temperature effects disappear.

-Coaches should develop methods to maintain the swimmers' warm-up temperature (e.g. passive warm-up) and perhaps some light activities to maintain heart rate and VO_2 above resting values before the swimming race.

Acknowledgements

The authors would like to acknowledge the help of the swimmers who participated in the current study, and also that of the Varzim Lazer EEM in making available the swimming-pool facilities. This work was supported by a grant from the Science and Technology Foundation (SFRH/BD/74950/2010) and by University of Beira Interior and Santander Totta bank (UBI/FCSH/Santander/2010).

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Figure Legends

Figure 1. Physiological variables responses throughout the procedures: core temperature (A), net values of core temperature (B), tympanic temperature (C), blood lactate concentrations ([La^-]; D), heart rate (E), Oxygen uptake (VO_2; F). * Indicates difference between the two conditions assessed ($p < 0.01$). Data presented as mean ± SD (n=11).

Table 1 – Standard warm-up (WU) protocol.

WU	Task description
300m	100m usual breathing, 100m breathing in the 5th stroke, 100m usual breathing
4x100m @ 1:50	2x (25m kick - 25m increased stroke length)
8x50m @ 1:00	98% - 102% of critical velocity (or 85-90% of 100m pace)
100m	Easy swim

Table 2 – Mean ± SD values of the 100 and 50m lap times, stroke frequency (SF), stroke length (SL), stroke index (SI), and propelling efficiency (η_p) with 10min and 20min post warm-up passive rest. Effect sizes (d), p-values, and inferences for percent change of means are presented (n=11).

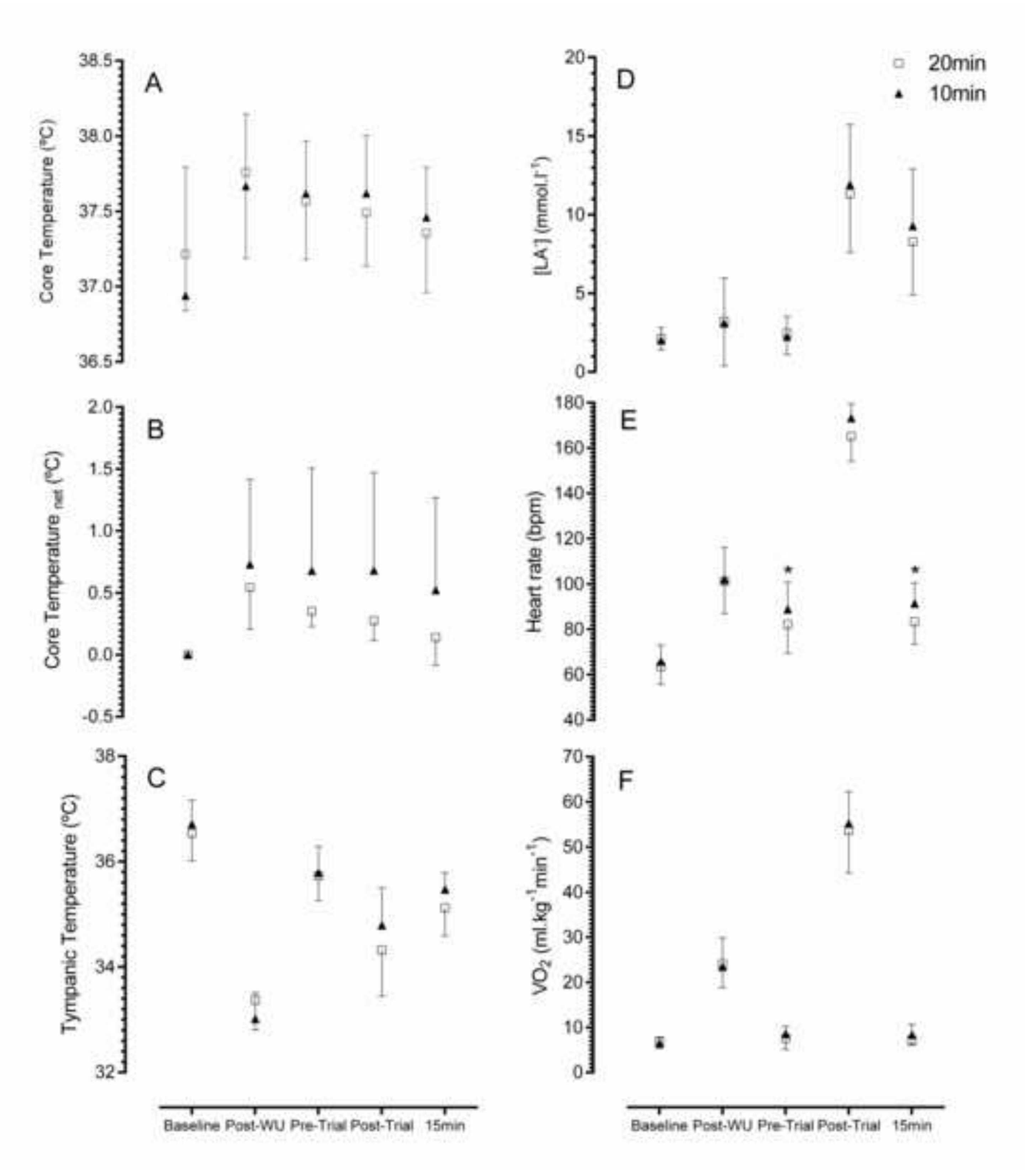
			20-min vs. 10-min				
	10min	20min	d	p-value	Mean % change; ± 90%CL*	%Chance **	Qualitative inference
100m time-trial [s]	58.41 ± 1.99	59.06 ± 1.86	0.99	<0.01	1.1 ± 0.6	80/20/0	Likely harmful
1st 50m [s]	27.72 ± 0.92	28.15 ± 0.73	1.13	<0.01	1.6 ± 0.8	95/5/0	Very Likely harmful
2nd 50m [s]	30.69 ± 1.27	30.91 ± 1.30	0.58	0.08	0.7 ± 0.7	41/59/0	Possibly harmful
1st 15m [s]	7.13 ± 0.33	7.26 ± 0.19	0.51	0.14	1.8 ± 1.9	81/17/2	Likely harmful
1st 50m SF [Hz]	0.87 ± 0.07	0.85 ± 0.06	0.66	0.05	-3.2 ± 2.6	0/16/84	Likely -ive
2nd 50m SF [Hz]	0.73 ± 0.04	0.74 ± 0.04	0.23	0.47	0.6 ± 1.7	38/57/5	Unclear
1st 50m SL [m]	2.03 ± 0.17	2.07 ± 0.17	0.40	0.26	1.9 ± 2.7	49/49/2	Unclear
2nd 50m SL [m]	2.19 ± 0.14	2.16 ± 0.17	0.39	0.24	-1.3 ± 1.9	1/52/46	Possibly -ive
1st 50m SI $[m^2c^{-1}s^{-1}]$	3.60 ± 0.37	3.61 ± 0.35	0.06	0.86	0.3 ± 2.7	11/83/6	Likely trivial
2nd 50m SI $[m^2c^{-1}s^{-1}]$	3.51 ± 0.32	3.44 ± 0.38	0.49	0.14	-2.0 ± 2.2	0/42/57	Possibly -ive
1st 50m η_p [%]	33.88 2.45	34.55 2.34	0.41	0.20	2.0 ± 2.7	61/37/2	Unclear
2nd 50 η_p [%]	36.55 1.91	36.10 2.37	0.36	0.26	-1.3 ± 1.9	2/44/54	Possibly -ive

90% CL = 90% confidence limits. +ive, -ive = positive and negative changes, respectively.

* where a positive % change equates to an increase in 20min condition

** presented as harmful/trivial/beneficial for performance (time) and positive/trivial/negative for other variables

Figure 1


A
Core Temperature (°C)
38.5
38.0
37.5
37.0
36.5
B
Core Temperature net (°C)
2.0
1.5
1.0
0.5
0.0
-0.5
C
Tympanic Temperature (°C)
38
36
34
32
D
[LA-] (mmol.l-1)
20
15
10
5
0
□ 20min
▲ 10min
E
Heart rate (bpm)
180
160
140
120
100
80
60
40
*
*
F
VO2 (ml.kg-1min-1)
70
60
50
40
30
20
10
0
Baseline
Post-WU
Pre-Trial
Post-Trial
15min
Baseline
Post-WU
Pre-Trial
Post-Trial
15min