

Higher evening metabolic responses contribute to diurnal variation of self-paced cycling performance

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ABSTRACT: This study examined the effect of time of day (TOD) on physical performance, and physiological and perceptual responses to a 10-km cycling time trial (TT_{10km}). Twelve physically trained subjects (20.3 ± 1.2 years, 74.3 ± 7.4 kg, 179.7 ± 5.5 cm) completed, in a randomized order, a TT_{10km} in the morning and in the evening. Intra-aural temperature (IAT) was measured at rest and following the TT_{10km}. Completion time, power output (PO), rating of perceived exertion (RPE), heart rate (HR), minute ventilation (VE), oxygen uptake (VO₂), carbon dioxide production (VCO₂) and respiratory exchange ratio (RER) were assessed every km during the TT_{10km}. Blood lactate concentration [La] and blood glucose concentration [Glu] were assessed before, during and immediately after the TT_{10km}. Faster completion time ($\Delta = 15.0s$, $p = 0.03$) and higher IAT ($\Delta = 0.33^{\circ}C$, $p = 0.02$ for pre-TT_{10km}) were obtained in the evening compared to the morning with a significant correlation between Δ completion time and Δ IAT at post-TT_{10 km} ($r = -0.83$, $p = 0.04$). VO₂, [La] and [Glu] increased significantly during both test sessions ($p < 0.001$) with higher values in the evening compared to the morning ($p = 0.015$, $p = 0.04$, $p = 0.01$, respectively). However, the remaining parameters were found to be only affected by the TT_{10km} ($p < 0.001$). The TT_{10km} generates a higher VO₂ and higher [La] and [Glu] responses, contributing to a better cycling performance in the evening compared to the morning. The similar magnitude of the TOD effect on completion time and IAT at post-TT_{10km} confirms that core temperature is one of the underlying factors contributing to the diurnal variation in physical performance.

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INTRODUCTION

It is well established that several aspects of human functioning, such as physical performance, are time of day (TOD) dependent [1, 2]. Indeed, the diurnal variation of short-term performance has been widely confirmed by several previous studies with a nadir (minimum) in the morning and a peak (maximum) in the evening [1, 3, 4, 5, 6]. However, conflicting findings have been reported regarding the effect of TOD on long-duration endurance performance [1, 7, 8, 9]. Particularly, some previous investigations have shown better endurance performance in the evening compared to the morning during sub-maximal cycling [10] or maximal [11] running exercise. In contrast, findings from other studies failed to show significant diurnal variation of endurance performance during similar types of exercise [9, 12, 13].

The effect of TOD on cardiorespiratory responses also presented controversial findings during endurance exercises with some reports

identifying a higher maximal oxygen uptake (VO_{2max}) [7, 11] and maximum heart rate (HR_{max}) [7, 14, 15] in the evening hours, while other studies reported no diurnal variation of oxygen uptake (VO₂), heart rate (HR) or minute ventilation (VE) responses to similar endurance efforts [16, 17, 18]. These conflicting findings suggest that the extent of diurnal variation in endurance performance and cardiorespiratory responses remains uncertain.

Although athletes' pacing behaviour is widely recognized as an essential determinant of endurance performance, TOD effects have been examined considerably more during externally paced [1, 6, 7] than self-paced exercises [9, 19]. To the best of the authors' knowledge, only two studies have explored the diurnal variation of endurance performance and cardiorespiratory responses during self-paced cycling exercise [9, 19]. Findings from these studies were also

controversial, with one of them showing faster completion time and higher $\dot{V}O_2$ in the evening compared to the morning during a 1 km cycling time trial (TT) [19], while the second one reported no diurnal variation of the same parameters during a 3 km TT [9].

These discrepancies could be related to methodological and individual issues, such as the small sample sizes, the habitual training time and the participant's chronotype [20] as well as training level [21]. In this line, Roveda et al. [8] revealed that participants reached their higher endurance performance at the same time as their habitual training sessions, which may mask the TOD effect.

All considered, it seems that the effect of TOD on endurance performance and cardiorespiratory function during self-paced exercise is still unclear and requires further studies. Therefore, the aim of the present study was to determine the diurnal variation of cycling performance, as well as cardiorespiratory and perceptual responses to a 10-km cycling time trial (TT_{10km}) in well-trained team sport players. We hypothesized that physical, physiological and perceptual responses to TT_{10km} would be better in the evening than the morning hours.

MATERIALS AND METHODS

Participants

The required sample size was determined a priori, using the software G*Power [22] and procedures suggested by Beck [23]. Values for power and α were set at 0.95 and at 0.05, respectively. Based on the results of Knaier et al. [21] and Brisswalter et al. [24], effect sizes were estimated to be 0.45 (medium effect). To reach the desired power (0.9), data from at least twelve participants were deemed to be sufficient to minimize the risk of incurring a type 2 statistical error. Allowing for an 20% attrition rate, fifteen team sport players were recruited to participate in this study. To avoid possible confounding effect of training at a specific TOD [1, 25], three players, habituated to training only during the morning times, were excluded. The final sample included twelve physically trained subjects (mean \pm standard deviation (SD): 20.3 \pm 1.2 years, 74.3 \pm 7.4 kg, 179.7 \pm 5.5 cm, peak oxygen uptake ($\dot{V}O_{2\text{ peak}}$) 58.3 \pm 7.7 ml \cdot min⁻¹ \cdot kg⁻¹) volunteered to participate in this study. They trained four days per week for an average of three hours per day (90 min in the morning session and 90 min in the evening session). According to Horne and Östberg's chronotype questionnaire [26], all the participants were classified as intermediate type. They were non-smokers, without any risk factor of acute or chronic diseases (i.e., obesity, diabetes, cardiovascular or pulmonary disorders) and did not consume nutritional supplements, alcohol, or drugs during the experimental period and for at least one month before the commencement of the study. Participants signed an informed consent form to participate in the experiment after being informed about the experimental protocol and the potential risks and benefits of the study. The study design was approved by the local Institutional Review Board (approval code N° 0183/2019) and carried out according to the guidelines of the Declaration of Helsinki for human experimentation.

Experimental design

The experimental design was composed of four different sessions interspaced by 72 hours of rest in between. During the first session, participants were instructed and familiarised with the material and methods of the study before signing their informed consent. During the second session, participants performed familiarization with the TT_{10km} to minimize bias and error related to learning effects. This familiarization session was performed between 12:00h and 13:00h in order to prevent adaptation to a particular experimental TOD. During this session, participants adjusted their seat position and chose the cycling braking load with which they achieved the best performance in the TT_{10km}. During the third and the fourth sessions, participants performed, in a randomised design, the TT_{10km} either in the morning (from 07:00h to 08:00h) or in the evening (from 17:00h to 18:00h). Intra-aural temperature (IAT) was assessed before and after the TT_{10km}. Power output (PO), rating of perceived exertion (RPE) and cardiorespiratory parameters (HR, $\dot{V}E$, $\dot{V}O_2$, carbon dioxide production ($\dot{V}CO_2$) and respiratory exchange ratio (RER)) were averaged every covered km during the TT_{10km}. Completion time was also assessed during the TT_{10km}. Blood lactate concentration [La] and glucose concentration [Glu] were assessed before and immediately following the completion of the first and the second 5 km of the TT_{10km}. Environmental temperature and relative humidity of the laboratory were maintained constant at 20 to 21°C and 40 to 45%, respectively. During the experimental sessions, participants maintained their habitual physical activity and were required to avoid intensive efforts for at least 24 hours before each experimental session.

Endurance performance

The TT_{10km} was conducted on a cycle ergometer (Monark 874E, Stockholm, Sweden) after a standardized warm-up at a constant power output of 100 W for 5 minutes. During the two experimental trials (morning and evening), using the same cycle ergometer and the same seat position, participants were instructed to complete the TT_{10km} as fast as possible after the same warm-up and against the same cycling braking load (2.0 \pm 0.2 kg) chosen in the familiarization trial. During TT_{10km}, they were permitted to view elapsed distance, but they were blinded to power output and HR. No verbal encouragement was given during the two experimental trials. All data were averaged for each km before statistical analyses were performed.

Cardiorespiratory variables

The cardiorespiratory parameters were assessed using a gas analyser (K4B2, Cosmed, Italy) connected to the heart rate monitor Polar H10 (Finland). $\dot{V}E$, $\dot{V}O_2$, $\dot{V}CO_2$, RER and HR were recorded and averaged for each covered km during the TT_{10km}.

Blood lactate concentration

[La] was measured at rest, at 5 km and immediately after the TT_{10km}. A 5 μ l sample of whole fresh blood was taken from the fingertip and

analysed for lactate concentration (mmol/l) using a portable analyser (lactate Pro2, Arkray, Shiga, Japan).

Blood glucose concentration

[Glu] was measured at rest, at 5 km and immediately after TT_{10km}. A 5 µl sample of whole fresh blood was taken from the fingertip and analysed for blood glucose concentration (g/l) using a portable analyser (Contour Next, USA).

Intra-aural temperature

Intra-aural temperature (IAT) was measured using a digital infrared thermometer (Braun, ThermoScan 6, France) before and immediately after the TT_{10km}.

Rating of perceived exertion

The RPE scale is a reliable indicator of physical discomfort, has sound psychometric properties, and is strongly correlated with several other physiological measures of exertion [27]. In this study, we used a 10-point scale ranging from 1 (very very light) to 10 (very very

hard). Every 1 km of TT_{10km}, participants were requested to rate their subjective exertion.

Statistical analysis

Statistical analyses were performed using STATISTICA software (Stat-Soft, Paris, France). All data were presented as mean ± standard deviation (SD). Once the assumption of normality was confirmed using the Shapiro-Wilk W test, parametric tests were performed. Two-way repeated measure ANOVA [2 TOD (morning vs. evening) × 10 covered km] was used to compare morning-evening differences for PO, cardiorespiratory parameters (HR, $\dot{V}E$, $\dot{V}O_2$, $\dot{V}CO_2$, RER) and RPE. Moreover, repeated measure ANOVA [2 TOD (morning vs. evening) × 3 covered distance (at 0, 5 and 10 km)] was performed to compare [La] and [Glu] concentration differences. In addition, repeated measure ANOVA [2 conditions (morning vs. evening) × 2 covered km (at 0 and 10 km)] was conducted to compare IAT differences. When significant main or interaction effects were observed, the Bonferroni post-hoc test was conducted. Effect size was calculated as partial eta squared (η_p^2). The paired samples t-test

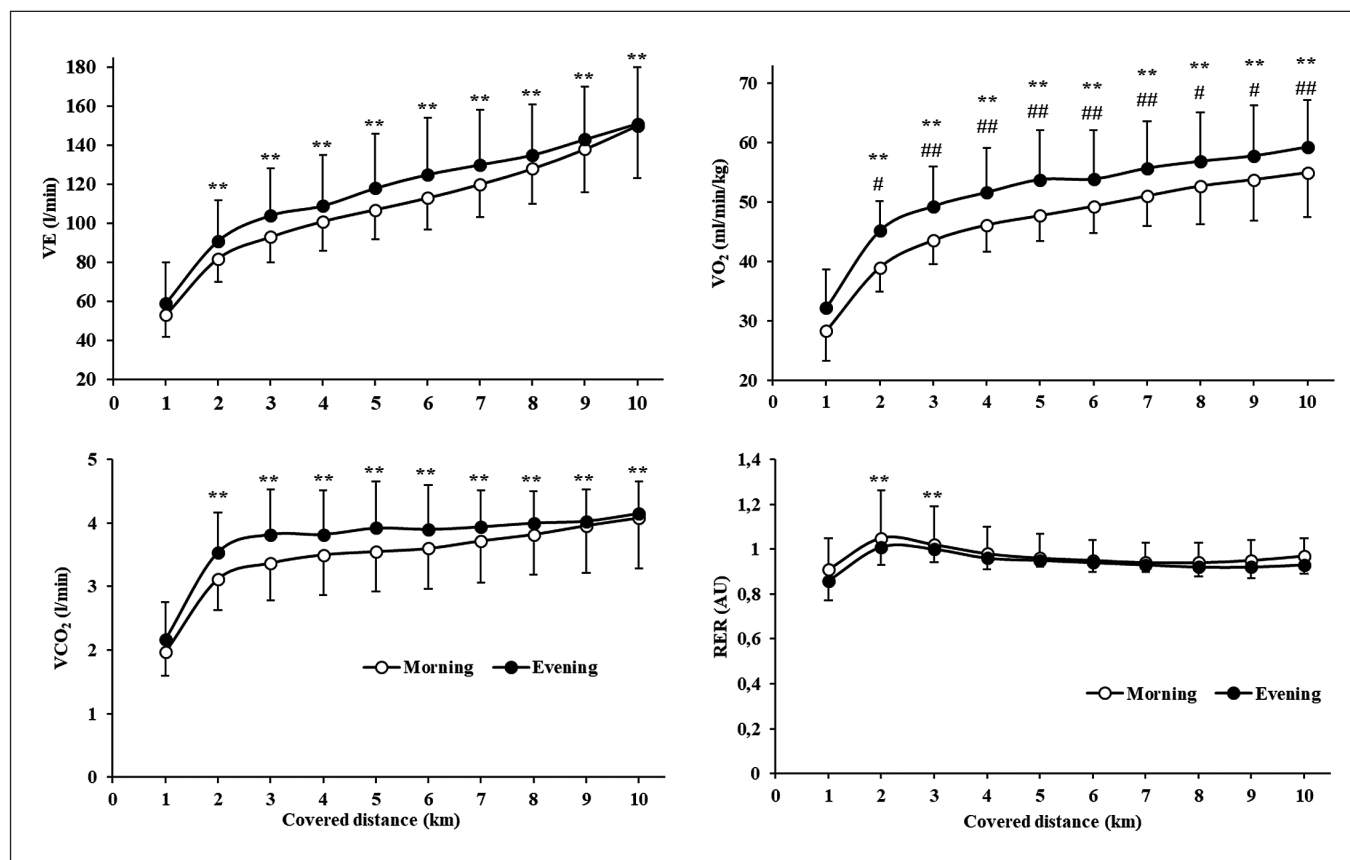


FIG. 1. Mean ± SD (standard deviation) for ventilation minute ($\dot{V}E$), oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$) and respiratory exchange ratio (RER) during the 10 km cycling time trial in the morning and in the evening. # significant effect of time of day (TOD) ($p < 0.05$), ## significant effect of time of day (TOD) ($p < 0.0005$), *Significantly different than 1 km value for the same time of day ($p < 0.05$) and ** significantly different than the 1 km value for the same time of day ($p < 0.001$)

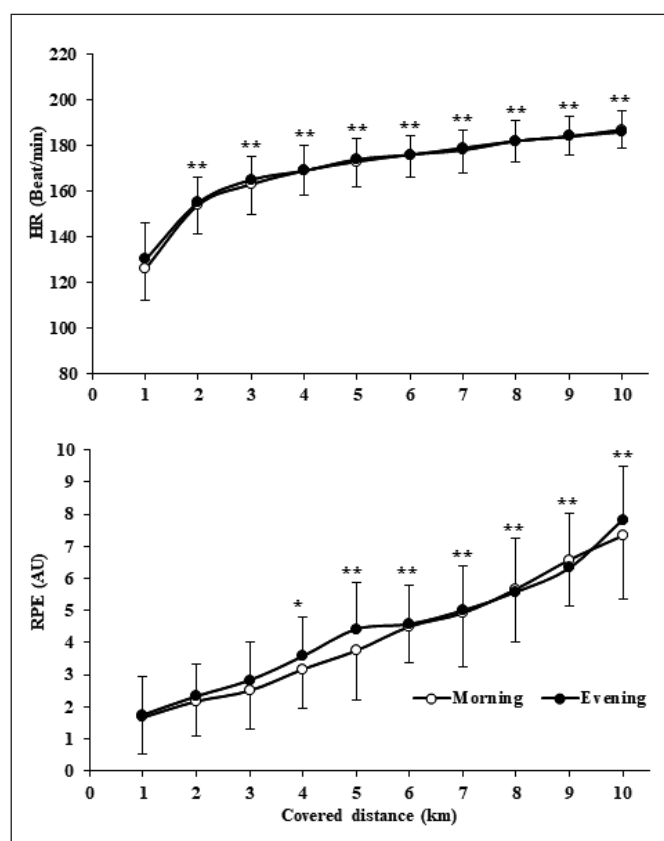


FIG. 2. Mean \pm SD (standard deviation) for heart rate (HR) and rating of perceived exertion (RPE) during the 10 km cycling time trial in the morning and in the evening.

*Significantly different than 1 km value for the same time of day ($p < 0.05$) and ** significantly different than the 1 km value for the same time of day ($p < 0.001$).

was used to determine differences of the completion time of TT_{10km} . The effect size was calculated using Cohen's corrected (d) test [28] and the magnitude of changes using the following criteria: < 0.2 = trivial, $0.2-0.6$ = small, $0.6-1.2$ = moderate, $1.2-2.0$ = large, and 2.0 = very large. Pearson correlation was conducted to examine the relationships between parametric variables. When the STATISTICA output demonstrated significance levels of $p = 0.000$, these were corrected to $p < 0.0005$ [29]. The significance level for all statistical procedures was set at $p < 0.05$.

RESULTS

Endurance performance

The completion time of the TT_{10km} was shorter in the evening compared to the morning [$(804 \pm 89$ s vs. 823 ± 78 s; $t = 2.35$, $p = 0.04$, $d = 0.66$]. Elapsed time was higher in the morning compared to the evening [$F_{(9,99)} = 172.9$, $p < 0.0005$, $\eta_p^2 = 0.92$].

Mean PO values in each 1 km of the TT_{10km} were not different between morning and evening [$F_{(1,11)} = 2.19$, $p = 0.16$].

Cardiorespiratory responses

Mean (\pm SD) values of $\dot{V}E$, $\dot{V}O_2$, $\dot{V}CO_2$ and RER in each 1 km of the TT_{10km} are displayed in Figure 1.

Repeated measure ANOVA revealed a significant main effect of covered km on HR [$F_{(9,99)} = 182.24$, $p < 0.0005$, $\eta_p^2 = 0.94$] (Figure 2), $\dot{V}E$ [$F_{(9,99)} = 125.58$, $p < 0.0005$, $\eta_p^2 = 0.92$], $\dot{V}O_2$ [$F_{(9,99)} = 84.79$, $p < 0.0005$, $\eta_p^2 = 0.89$], $\dot{V}CO_2$ [$F_{(9,99)} = 48.64$, $p < 0.0005$, $\eta_p^2 = 0.82$] and RER [$F_{(9,99)} = 14.03$, $p < 0.0005$, $\eta_p^2 = 0.56$] values. At both TOD, all these cardiorespiratory responses (except RER) increased continuously through the 10th covered km ($p < 0.001$). A significant increase in RER [$F_{(9,99)} = 14.03$, $p = 0.000$, $\eta_p^2 = 0.56$] was only observed at 2 km and 3 km compared to 1 km in both conditions. A significant main effect of TOD was observed only for $\dot{V}O_2$ [$F_{(1,11)} = 8.27$, $p = 0.02$, $\eta_p^2 = 0.43$], with higher $\dot{V}O_2$ values observed in the evening compared to the morning ($0.0005 < p < 0.04$).

Blood lactate concentration

Repeated measure ANOVA showed a significant effect of TT_{10km} [$F_{(2,22)} = 192.01$, $p < 0.0005$, $\eta_p^2 = 0.94$] and TOD [$F_{(1,11)} = 5.75$, $p = 0.04$, $\eta_p^2 = 0.34$] on [La] with a rising level from rest to 5 km and 10 km ($p < 0.0005$) and from 5 km to 10 km ($p < 0.0005$) in both morning and evening conditions (Table 1). Moreover, at 10 km [La] showed higher values in the evening compared to the morning at 10 km, affected by TOD ($p = 0.04$).

Glucose concentration

Repeated measure ANOVA showed a significant effect of TT_{10km} [$F_{(2,22)} = 66.72$, $p < 0.0005$, $\eta_p^2 = 0.86$] and TOD [$F_{(1,11)} = 8.58$, $p = 0.014$, $\eta_p^2 = 0.44$] on [Glu] with a rising level from rest to 5 km ($p = 0.01$ in the morning and $p < 0.0005$ in the evening) and 10 km ($p < 0.0005$) and from 5 km to 10 km ($p < 0.0005$) in both morning and evening conditions (Table 1). Moreover, [Glu] was higher in the evening compared to the morning at 5 km ($p = 0.03$) and 10 km ($p = 0.001$).

Intra-aural temperature

Repeated measure ANOVA revealed a significant main effect of TT_{10km} [$F_{(1,11)} = 33.30$, $p < 0.0005$, $\eta_p^2 = 0.75$] and TOD [$F_{(1,11)} = 7.20$, $p = 0.02$, $\eta_p^2 = 0.40$] on IAT. Compared to the rest values, IAT increased significantly following TT_{10km} in the evening (36.89 ± 0.39 vs. 37.33 ± 0.43 , $p = 0.010$) and in the morning ($36.58 \pm 0.22^\circ\text{C}$ vs. $37.11 \pm 0.34^\circ\text{C}$, $p = 0.002$), with higher pre- TT_{10km} values registered during the evening compared to the morning session ($p = 0.02$, $\Delta = 0.33^\circ\text{C}$). In addition, a high negative correlation was found between Δ completion time (morning to evening) and Δ IAT (morning to evening) at post- TT_{10km} ($r = -0.83$, $p = 0.04$).

Rating of perceived exertion

Mean (\pm SD) RPE scores are presented in Figure 2. In both TOD, RPE scores significantly increased at each successive 1 km of the

$TT_{10\text{km}}$ [$F_{(9,99)} = 65.77$, $p < 0.0005$, $\eta_p^2 = 0.86$], with no significant effect of TOD.

DISCUSSION

The main purpose of the present study was to determine the effect of TOD on physical, physiological and perceptual responses to the $TT_{10\text{km}}$. The primary findings indicated better endurance performance with higher IAT, $\dot{V}O_2$, [La] and [Glu] values during the $TT_{10\text{km}}$ performed in the evening compared to the morning. However, $\dot{V}E$, $\dot{V}CO_2$, RER and RPE values were unchanged between conditions.

The present study reported a significant TOD effect on $TT_{10\text{km}}$ performance with faster completion time in the evening compared to the morning. These findings are in line with previous studies showing a greater endurance performance in the evening during a cycling time trial [10, 14, 19, 30], intermittent running test [7] or self-paced running exercise [8]. However, these findings are in contrast with other studies demonstrating no diurnal variation of endurance performance in response to a self-paced cycling time trial: 4 km [9], 15 min [31], 4×5-min [17], submaximal cycling exercise [12], maximal cycling [32] or running [33] exercises. These discrepancies could be explained by the chronotype of the participants and/or the habitual training time [20, 21, 34]. Indeed, Knaier et al. [21] suggested that participants reached their peak endurance performance at the same time as their habitual training sessions, which may mask the TOD effect. In the same way, a recent study by Roveda et al. [8] indicated that participants' chronotype has the potential to influence the TOD when peak performance is achieved and showed that the morning-type group tends to perform better in the morning while the evening-type group tends to perform better in the evening. These results suggest that recruiting a specific number of morning-type participants may mask the diurnal variation of endurance performance and thereby explain the absence of a TOD effect in some previous studies. The findings of the present study confirm these recent suggestions and showed that, using team sport players of intermediate chronotype and with no specific habitual training time, a significant TOD effect on endurance performance was registered with faster completion time during the $TT_{10\text{km}}$ observed in the evening.

This better physical performance registered during the $TT_{10\text{km}}$ performed from 17:00h to 18:00h was associated with higher IAT at post- $TT_{10\text{km}}$, which suggests the possibility of a causal effect between changes in IAT and fluctuations in endurance performance. Particularly, the results of the present study showed a high negative correlation ($r = -0.76$) between the diurnal fluctuation of completion time and IAT at post- $TT_{10\text{km}}$. This finding may indicate that morning-evening increase in IAT (and consequently core temperature) could explain in part the decreased completion time and thereby the better physical performance recorded in the evening. In line with this speculation and given the similar magnitude of the TOD effect on IAT and physical performance, changes in core temperature have been frequently used to explain the enhanced performance in the late after-

noon and evening [3, 4, 5, 21, 35]. Indeed, it has been previously suggested that the increase in core temperature during the day can serve as a passive muscle warm-up improving the efficiency of the neuromuscular system through (i) increasing nerve conduction velocity, body chemical reaction, muscle vascularization and range of motion and (ii) decreasing muscle viscosity [14, 36, 37, 38, 39]. However, Atkinson et al. [30] stated that diurnal variation of core temperature cannot solely explain the TOD differences in performance and suggested that explaining the underlying physiological mechanism of diurnal variation in physical performance needs further studies measuring a broad range of possible psychophysiological responses accompanying the completion of exercise at different TOD.

In this context, aiming to better understand the underlying mechanism behind the endurance performance fluctuation, the present study also examined the diurnal variation of cardiorespiratory, metabolic ([La] and [Glu]) and perceptual responses to $TT_{10\text{km}}$ performed at two different TOD. $\dot{V}O_2$, [La] and [Glu] were found to be significantly affected by the TOD. The present findings are in accordance with other studies showing a higher [La] and $\dot{V}O_2$ in the evening compared to the morning during a 1000 m cycling time trial [19], endurance exercise above the ventilatory threshold [38, 42] or during the YoYo intermittent recovery test [7, 11]. However, the present results are in contrast with several previous studies that failed to provide evidence for significant diurnal variation of $\dot{V}O_2$ and/or [La] during submaximal [12, 18, 40], maximal [7, 21, 32, 41] or self-paced [9, 19, 35] exercises. These results could be explained by an achieved $\dot{V}O_{2\text{max}}$, [La] and RPE at different TOD by different athletes [21]. Discrepancies between findings suggest that the protocol of the used endurance exercise seems to be also one of the methodological factors influencing the TOD effect when peak psychophysiological responses are achieved. Additionally, the intermediate chronotype in all the recruited subjects in the present study could also explain, in part, the absence of diurnal variation in physiological (HR, $\dot{V}E$, $\dot{V}CO_2$, RER) and perceptual (RPE) responses to the $TT_{10\text{km}}$. Therefore, it is necessary to conduct further TOD studies controlling as many influencing factors as possible (i.e., chronotype, habitual time of training, training level, exercise protocol) and testing at the same time a wide range of psychological (e.g., motivation, psychomotor) and physiological (hormonal profile, inflammatory and muscle damage) responses.

CONCLUSIONS

According to the present findings, the evening session seems to result in better endurance performance, which was accompanied by higher IAT, $\dot{V}O_2$, [La] and [Glu] compared to the morning session. The similar magnitude of TOD effect on IAT, $\dot{V}O_2$, [La], [Glu] and $TT_{10\text{km}}$ completion time and the absence of diurnal variation in the remaining physiological (i.e., HR, $\dot{V}CO_2$, RER, $\dot{V}E$) and perceptual (RPE) parameters confirm that core temperature, oxygen consumption and metabolic responses are important underlying factors contributing to the diurnal variation in endurance cycling performance.

It is recommended for athletes, coaches and sport scientists to consider self-paced endurance performance as time-of-day dependent. Importantly, endurance performance during the 10 km cycling time trial exercise should be scheduled in the evening to achieve better performance. However, the TOD of the competition should also be considered when scheduling the training programme to benefit from specific adaptations at this TOD. Indeed, a previous report indicated that adaptations to training are greater at the TOD at which training is regularly performed than at other times [1]. Finally, to guarantee comparable results in future TOD-based investigations, it is recommended to recruit participants with an intermediate chronotype when assessing metabolic responses (i.e., oxygen uptake, and blood glucose and lactate levels) to physical exercise.

Limitations

In the present study, a small sample size of participants with inter-

mediate chronotype was included in the experimental procedure. Moreover, endurance performance was measured only at two times of day. More studies are required to investigate the effect of different times of day on endurance using different test times and different participants' chronotypes.

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REFERENCES

- Chtourou H, Souissi N. The effect of training at a specific time of day: a review. *J Strength Cond Res.* 2012; 26(7):1984–2005.
- Grgic J, Lazinica B, Garofolini A, Schoenfeld BJ, Saner NJ, Mikulic P. The effects of time of day-specific resistance training on adaptations in skeletal muscle hypertrophy and muscle strength: A systematic review and meta-analysis. *Chronobiol Int.* 2019;36:4, 449–460.
- Ammar A, Chtourou H, Hammouda O, et al. Acute and delayed responses of C-reactive protein, malondialdehyde and antioxidant markers after resistance training session in elite weightlifters: Effect of time of day. *Chronobiol Int.* 2015;32(9):1211–1222.
- Ammar A, Chtourou H, Hammouda O, et al. Relationship between biomarkers of muscle damage and redox status in response to a weightlifting training session: effect of time-of-day. *Physiol Int.* 2016;103(2):243–261.
- Ammar A, Chtourou H, Souissi N. Effect of Time-of-Day on Biochemical Markers in Response to Physical Exercise. *J Strength Cond Res.* 2017; 31(1):272–282. doi:10.1519/JSC.0000000000001481
- Hammouda O, Chtourou H, Chahed H, Ferchichi S, Kallel C, Miled A, Chamari K, Souissi N. Diurnal variations of plasma homocysteine, total antioxidant status and biological markers of muscle injury during repeated sprint: effect on performance and muscle fatigue: A pilot study. *Chronobiol Int.* 2011;28:958–967
- Aloui K, Abdelmalek S, Chtourou H, Wong DP, Boussetta N, Souissi N. Effects of time-of-day on oxidative stress, cardiovascular parameters, biochemical markers, and hormonal response following level-1 Yo-Yo intermittent recovery test. *Physiol Int.* 2017; 104(1):77–90.
- Roveda E, Mulè A, Galasso L, et al. Effect of chronotype on motor skills specific to soccer in adolescent players *Chronobiol Int.* 2020;1–12.
- Zadow E, Kitic C, Wu S, Abbiss C, Peiffer J, Fell J. Effects of Time of Day on Pacing in a 4-km Time Trial in Trained Cyclists. *Int J Sports Physiol Perform.* 2020;1–5. doi: 10.1123/ijspp.2019-0952
- Callard D, Davenne D, Gauthier A, Lagarde D, Van Hoecke J. Circadian rhythms in human muscular efficiency: continuous physical exercise versus continuous rest. A crossover study. *Chronobiol Int.* 2000;17(5):693–704.
- Hammouda O, Chtourou H, Chaouachi A, Chahed H, Bellimem H, Chamari K, Souissi N. Time of day effect on biochemical responses to soccer-specific endurance in elite Tunisian football players. *J Sports Sci.* 2013;31(9):963–71.
- Edwards BJ, Edwards W, Waterhouse J, Atkinson G, Reilly T. Can cycling performance in an early morning, laboratory-based cycle time-trial be improved by morning exercise the day before? *Int J Sports Med.* 2005; 26(8):651–656.
- Reilly T, Atkinson G, Edwards B, Waterhouse J, Farrelly K, Fairhurst E. Diurnal variation in temperature, mental and physical performance, and tasks specifically related to football (soccer). *Chronobiol Int.* 2007; 24(3):507–519.
- Atkinson G, Coldwells A, Reilly T, Waterhouse J. A comparison of circadian rhythms in work performance between physically active and inactive subjects. *Ergonomics.* 1993;36(1–3):273–281.
- Reilly T, Garrett R. Effects of time of day on self-paced performances of prolonged exercise. *J Sports Med Phys Fitness.* 1995;35(2):99–102.
- Amaro-Gahete FJ, Jurado-Fasoli L, Triviño AR, et al. Diurnal Variation of Maximal Fat-Oxidation Rate in Trained Male Athletes. *Int J Sports Physiol Perform.* 2019;14(8):1140–1146.
- Bessot N, Moussay S, Gauthier A, Larue J, Sesboüe B, Davenne D. Effect of pedal rate on diurnal variations in cardiorespiratory variables. *Chronobiol Int.* 2006;23(4):877–887.
- Morris C, Atkinson G, Drust B, Marrin K, Gregson W. Human core temperature responses during exercise and subsequent recovery: an important interaction between diurnal variation and measurement site. *Chronobiol Int.* 2009; 26(3):560–575.
- Fernandes AL, Lopes-Silva JP, Bertuzzi R, Casarini DE, Arita DY, Bishop DJ, Lima-Silva AE. Effect of time of day on performance, hormonal and metabolic response during a 1000-M cycling time trial. *PLoS One.* 2014;9(10):e109954.
- Hill DW, Chtourou H. The effect of time of day and chronotype on the relationships between mood state and performance in a Wingate test. *Chronobiol Int.* 2020; 37(11):1599–1610.
- Knaier R, Infanger D, Niemeyer M, Cajochen C, Schmidt-Trucksäss A. In Athletes, the Diurnal Variations in Maximum Oxygen Uptake Are More Than Twice as Large as the Day-to-Day Variations. *Front Physiol.* 2019. doi:10.3389/fphys.2019.00219
- Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power

- analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007; 39(2):175–91.
23. Beck TW. The importance of a priori sample size estimation in strength and conditioning research. *J Strength Cond Res*. 2013; 27(8):2323–37.
 24. Brisswalter J, Bieuzen F, Giacomoni M, Tricot V, Falgairette G. Morning-to-evening differences in oxygen uptake kinetics in short-duration cycling exercise. *Chronobiol Int*. 2007; 24(3):495–506.
 25. Chtourou H, Ammar A, Nikolaidis PT, Abdel Karim O, Souissi N, Chamari K & Chaouachi A. Post-resistance training detraining: time-of-day effects on training and testing outcomes. *Biol. Rhythm Res*. 2015;897–907.
 26. Dosseville F, Laborde S, Lericollais R. Validation of a chronotype questionnaire including an amplitude dimension. *Chronobiol Int*. 2013;30(5):639–648.
 27. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14(5):377–381.
 28. Cohen J. *Statistical power analysis for the behavioral sciences* (2nd ed). Psychology Press (New York, USA). 1988.
 29. Kinnear PR, Gray CD. *SPSS/PC+ made simple*, Lawrence Erlbaum Associates. 1995.
 30. Atkinson G, Holder A, Robertson C, Gant N, Drust B, Reilly T, Waterhouse J. Effects of melatonin on the thermoregulatory responses to intermittent exercise. *J Pineal Res*. 2005;39(4):353–359.
 31. Dalton B, McNaughton L, Davoren B. Circadian rhythms have no effect on cycling performance. *Int J Sports Med*. 1997;18(7):538–542.
 32. Deschenes MR, Sharma JV, Brittingham KT, Casa DJ, Armstrong LE, Maresh CM. Chronobiological effects on exercise performance and selected physiological responses. *Eur J Appl Physiol Occup Physiol*. 1998; 77(3):249–256.
 33. Souissi M, Chtourou H, Zrane A, Cheikh RB, Dogui M, Tabka Z, Souissi N. Effect of time-of-day of aerobic maximal exercise on the sleep quality of trained subjects. *Biol Rhythm Res*. 2012; 43(3):323–330.
 34. Rae DE, Stephenson KJ, Roden LC. Factors to consider when assessing diurnal variation in sports performance: the influence of chronotype and habitual training time-of-day. *Eur J Appl Physiol*. 2015; 115(6):1339–1349.
 35. Ammar A, Chtourou H, Turki M, et al. Acute and delayed responses of steroidal hormones, blood lactate and biomarkers of muscle damage after a resistance training session: time-of-day effects. *J Sports Med Phys Fitness*. 2018; 58(7–8):980–989.
 36. Joch W, Uckert S. Il riscaldamento ed i suoi effetti. *Scuola Dello Sport Italie*. 2001; 20(51), 49–54.
 37. Mohr M, Krstrup P, Nybo L, Nielsen JJ, Bangsbo J. Muscle temperature and sprint performance during soccer matches--beneficial effect of re-warm-up at half-time. *Scand J Med Sci Sports*. 2004; 14(3):156–162.
 38. Racinais S, Connes P, Bishop D, Blonc S, Hue O. Morning versus evening power output and repeated-sprint ability. *Chronobiol Int*. 2005;22(6):1029–1039.
 39. Souissi N, Driss T, Chamari K, Vandewalle H, Davenne D, Gam A, Filliard JR, Jousselin E. Diurnal variation in Wingate test performances: influence of active warm-up. *Chronobiol Int*. 2012b;27(3):640–652.
 40. Tsuji B, Honda Y, Kondo N, Nishiyasu T. Diurnal variation in the control of ventilation in response to rising body temperature during exercise in the heat. *Am J Physiol Regul Integr Comp Physiol*. 2016;311(2):R401–R409.
 41. Rowland T, Unnithan V, Barker P, Lindley M, Roche D, Garrard M. Time-of-day effect on cardiac responses to progressive exercise. *Chronobiol Int*. 2011;28(7):611–616.
 42. Hill DW, Leiferman JA, Lynch NA, Dangelmaier BS, Burt SE. Temporal specificity in adaptations to high-intensity exercise training. *Med Sci Sports Exerc*. 1998;30(3):450–455.