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Conscious distance monitoring and perceived exertion in light-deprived cycling time trial

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ABSTRACT

The monitoring of distance is crucial to calculate the metabolic requirement and the ratings of perceived exertion (RPE) for a given exercise bout. Visual cues provide valuable information for distance estimation, navigation and orientation. The present study investigated if light deprivation may affect the conscious monitoring of distance, RPE and associative thoughts to exercise (ATE) during a 20-km cycling time trial ($TT_{20\ km}$). Eleven male, endurance cyclists performed two $TT_{20\ km}$ in illuminated-control and light-deprived laboratory. They were asked to self-report RPE and ATE when they perceived they had completed each 2 km. *Results:* The light deprivation resulted in elongated perceived distance at each actual 2 km, rather than in illuminated-control trial ($P < 0.05$). Although there was no difference in RPE when it was plotted as a function of the perceived distance, RPE was lowered in light-deprived environment when it was plotted as a function of the actual distance ($P < 0.05$). Additionally, ATE was lowered during $TT_{20\ km}$ in light deprivation ($P < 0.01$); however, pacing and performance were unaffected in light-deprived environment. *Conclusion:* Results suggest that pacing and performance were regulated through a system which was unaffected in light-deprived environment, despite the altered conscious distance monitoring and perceptive responses.

1. Introduction

According to the original pacing algorithm model, two aspects are crucial for the pacing regulation during exercise [1]. First, the monitoring of distance is important to set the algorithm of pacing, as the brain cannot calculate the metabolic requirement for the remaining period of exercise if the time that has passed or the distance that has been covered is unknown [1,2]. This model assumes that the brain uses a subconscious, scalar internal clock to monitor the passage of time, thereby enabling the individual to consciously judge the remainder exercise bout. Importantly, time and distance have been interpreted interchangeably in this model [1,3], although this relationship may be asymmetric in real world situations [4].

The second important aspect for the pacing algorithm is the conscious awareness of fatigue sensation, as the ratings of perceived exertion (RPE) would be incorporated in the brain's pacing algorithm [1]. Although the interpretation of the RPE's role in pacing regulation has differed slightly between studies [5,6], it has been proposed that RPE increases in a scalar fashion during exercise, reaching maximal values only at the exercise endpoint [7]. The scalar internal time clock would monitor the time during exercise to set a pacing algorithm according to the RPE's increase, thus matching maximal RPE scores with the exercise endpoint [1]. Hence, a robust pacing algorithm would be set due to both conscious and subconscious mechanisms; the pacing set at the first trial would be refined during successive trials due to a greater reliance on the conscious perceived distance and RPE [8–10].

Although several studies have evidenced the effectiveness of the pacing algorithm model, since the deception of distance elapsed or the manipulation of visual and auditory inputs affected neither pacing nor performance [11–13], a setup depriving ambient lighting may challenge this model and provide some insightful information to this topic. It has been well documented that the intensity of light may alter the activity in reticular formation, thereby modifying the cortical arousal and perception of time [14,15]. Therefore, the light deprivation could elongate the conscious perception of distance during exercise, presumably due to the down-regulated cortical activity triggered by a reduced brainstem reticular formation [16]. As a result of the elongated conscious perceived distance there may be a distortion of the actual distance-RPE ratio [17,18], thus challenging the effectiveness of a pacing algorithm [1].

In contrast to the original internal clock model, which based most of the pacing responses on subconscious factors [1,19], recent models have suggested that pacing is either consciously regulated (exclusively) according to the individual's RPE [20], or guided by an affordance-based control [21]. In this regards, variations in pacing may result from the conscious desire to maintain the exercise intensity while tolerating sensations of fatigue [20], or from the actions when perceiving available possibilities in the environment [21]. Thus, a setup depriving ambient lighting may further provide insights into these pacing models [20–22], as it could alter the conscious distance monitoring and RPE, as well as the perception of affordances.

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Regardless of the pacing model, effects of light deprivation may be particularly interesting to individuals attending nighttime cycling training and competitions. The RPE is a practical tool for training purposes [23], so that the rate of increase in RPE is usually used as an anchor for pacing strategy in different exercise modes [3,5]. Therefore, a likely impairment of the individual's conscious distance monitoring through an elongated time perception in light-deprived setup may result in distortion of the actual distance-RPE ratio, thereby limiting the use of RPE during nighttime cycling.

Additionally, a recent study showed that light-deprived setup speeded-up the RPE during a time-to-exhaustion exercise, due to an increased perception of body sensations in the darkness [24]. It was suggested that the increased emotional disturbance in light deprivation may have mediated reinvestments in the conscious control of movement, by increasing the focus on internal body sensations during exercise [24–26]. Given the relationship between focus on body sensations and RPE [1,27], the increased associative thoughts to exercise (ATE) in the darkness probably affected the rate of increase in RPE. However, if a light-deprived setup would also increase ATE and momentary RPE [24,27] in a self-paced cycling time trial still needs verification, as this light deprivation study used a controlled-pace exercise. A previous study [12] had investigated the darkness effects on pacing strategy and performance during a self-paced cycling time trial, however no measure of the conscious distance monitoring was addressed.

Therefore, the present study investigated if the conscious monitoring of distance and RPE would be altered when performing a cycling time trial in a light-deprived environment. We hypothesized that individuals would report elongated conscious distance, with a greater ATE and RPE when cycling in the light-deprived setup. As a result, we expected that pacing and performance were changed.

2. Materials and methods

2.1. Participants

Eleven male, experienced endurance cyclists (34.9 ± 5.1 years, 178.9 ± 5.3 cm, 76.3 ± 8.8 kg, VO_{2PEAK} of 56.2 ± 8.0 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ and W_{PEAK} of 366.5 ± 26.1 W), familiarized with 20-km cycling time trials ($TT_{20\ km}$), but unaccustomed to cycling in the dark environments, volunteered to take part in this study. They were informed about the experimental procedures, risks, and benefits before providing their written informed consent. This study, which conformed to the Declaration of Helsinki, was approved by our institutional Research Ethics Committee.

2.2. Design

During the first visit, cyclists completed a Physical Activity Readiness Questionnaire (PAR-Q), and were familiarized with procedures, equipment and scales. During the second visit cyclists performed a familiarization with the $TT_{20\ km}$, and during visits 3 and 4 they performed the $TT_{20\ km}$ in illuminated and light-deprived setups. Sessions 2, 3 and 4 were conducted after a washout interval between 3 and 7 days, and sessions 3 and 4 were performed in a counterbalanced order, after random allocation of participants. The cyclists were asked to refrain from consuming alcohol and caffeine during the 24 h before the procedures, and to avoid intense exercise for the 48 h before the procedures. All the $TT_{20\ km}$ were performed in a laboratory environment (~ 20 °C), at the same time of the day, on a bicycle (Giant®, USA) coupled with a cycle-simulator (CompuTrainer™ RacerMate® 8000, USA) calibrated before each test, according to manufacturer's instructions.

2.3. Familiarization with the $TT_{20\ km}$

Cyclists were accommodated on the bicycle and performed a standard 7-min warm-up, which consisted of a 5-min self-paced exercise (gear and cadence freely adjusted) and a 2-min controlled-pace exercise (fixed gear, power output at 100 W and cadence at 80 rpm). At the end of the warm-up period, when they were still cycling at 80 rpm, they began the $TT_{20\ km}$. Feedback of time and distance was available on the computer's monitor. Cyclists were instructed to pace themselves throughout the exercise bout, in order to finish the trial within the shortest possible time. Moreover, they were asked to self-report their RPE and ATE every 2 km. The familiarization session were conducted in a conventional laboratory illuminated with artificial light (≈ 225 lx and 10^{01} W/m^2).

2.4. Illuminated-control and light-deprived setups

The brightness was manipulated in order to set a complete darkness in the light-deprived condition, in contrast to the illuminated-control condition. The laboratory's door and windows were sealed with a thick black plastic, and the lights of the electronic devices were covered with black fabric to block any light sources. In addition, a 1.1 m area was used to separate the participant from the electronic devices and experimenter, and this area was further isolated with black thick curtains. We obtained a dark environment with ≈ 2 lx and 0^{01} W/m^2 when the room's lights were switched off in the light-deprived condition. In contrast, the laboratory's lights were switched on in the illuminated-control condition, creating a setup with normal, constant light intensity of ≈ 225 lx and 10^{01} W/m^2 [28]. Although the brightness of ≈ 2 lx and 0^{01} W/m^2, the overall perception was of complete darkness in the testing room in the light-deprived setup, in contrast to a typical laboratory environment in the control setup. Importantly, we used a testing room with a ≈ 2 lx and 0^{01} W/m^2 brightness in order to potentiate the effects of light deprivation, agreeing with previous studies [12,24].

After being accommodated on the bicycle, a 2-min habituation period was performed with the room's lights switched on in the control, and with lights switched off in the light deprivation. Then, cyclists warmed-up for 7 min, as performed in the familiarization session, and then they immediately started the $TT_{20\ km}$. Before the trials, cyclists were encouraged to complete the $TT_{20\ km}$ as fast as possible in both the environments, but no verbal encouragement was provided during the trials. No recommendation to maintain the pacing strategy used in the familiarization $TT_{20\ km}$ was given, so that they were free to pace themselves throughout the trials. No distance feedback, time cues or information about performance was provided in these conditions, but the participants knew that all trials would finish at the actual 20th km. Cyclists were asked to report RPE and ATE when they had perceived they completed each 2 km (every self-perceived 2 km). A flashlight was used for a few seconds to illuminate the scales at each measurement, in the light-deprived condition.

2.5. Pacing and monitoring of perceived distance

The $TT_{20\ km}$ performance was interpreted as the time to complete the 20 km. The pacing strategy was analyzed in terms of relative distance, thus the mean power output at every 2 km was plotted as a function of the real distance. Furthermore, to monitor how cyclists perceived the cycling distance, the actual distance was plotted as a function of the perceived distance. In addition, the error of the conscious perceived distance was calculated as a percentage of the perceived distance that deviated from the real distance. For example, a cyclist perceiving 2 km, but actually covering 1.95 km would have shown an error of − 5%.

2.6. Ratings of perceived exertion

Cyclists rated their overall effort sensation through the 6–20 Borg's scale, considering breathlessness, cardiopulmonary work and body temperature as signals [29]. Then, RPE was plotted as a function of the actual distance. In accordance with study by Parry and Micklewright [18], we further normalized the real distance completed per each RPE measure, thus the actual distance-RPE index was calculated by dividing the actual distance covered between two self-reported RPEs, by the RPE self-reported at the second moment. Thereafter this index was plotted as a function of the perceived distance. In addition, the rate of increase in RPE (RPE_{SLOPE}) was also calculated.

2.7. Associative thoughts to exercise

The cyclists were instructed to rate their thoughts according to internal (sensations derived from the body) and external cues (unrelated body sensations). Internal cues were muscular discomfort, tiredness, respiration, etc., while external cues were thoughts on daily tasks, personal projects, environment, etc. Thus, they were fully aware about the distinction between associative and dissociative thoughts, however only ATE was reported. A 10 cm bipolar Likert scale that scores 0 to 4 as dissociative thoughts to exercise, and 6 to 10 as ATE (5 scores a shift from dissociative to ATE) was used every self-perceived 2 km. Evidences of ATE scale's validity have been reported elsewhere [26].

Important, during pilot study we observed that some participants disengaged from the time trial when the endpoint was determined as the perceived 20th km, due to a much-elongated perceived distance. Thus, given the clear linear pattern of the dependent variables plotted as a function of the perceived distance (RPE, ATE and error of the conscious perceived distance) a linear regression equation predicted the values for these variables at missing points, where the actual distance did not match the perceived distance.

2.8. Statistics

Data were presented as mean and standard deviation (± SD). The data distribution was initially verified through Shapiro-Wilk test to ensure Gaussian distribution. The time to complete the $TT_{20\ km}$ between illuminated-control and light-deprived condition was compared through a paired t-Student test. A mixed model, repeated measure design was used to compare pacing, error of predicted distance, RPE and ATE between control and light-deprived condition. Thus, a number of two-way mixed models were performed, having distance and conditions as fixed factors and subjects as random factor. Bonferroni correction for multiple comparisons was applied always when significant F values were observed. Statistical analysis were carried out with SPSS software (version 19.0), having the significance set at 5% ($P < 0.05$). Important, all significant results reached a power of analysis ≥ 0.98. We further calculated effect size, expressed as Cohen's d and interpreted as small (< 0.2), moderate (> 0.2 and < 0.8) and large (> 0.8).

3. Results

3.1. Pacing and performance

The power output during the $TT_{20\ km}$ showed no difference between conditions ($P > 0.05$) so that no difference was observed in the time to complete the $TT_{20\ km}$. Thus, cyclists completed the $TT_{20\ km}$ within 33.3 min (± 1.6) and 33.9 min (± 1.8) in illuminated-control and light-deprived condition, respectively ($P > 0.05$). Furthermore, there was no condition-by-distance interaction effect in power output ($P > 0.05$), however we observed a distance main effect ($P = 0.04$; F = 2.33, $d = 0.67$, power = 1.0) as cyclists adopted a decreasing pacing strategy during the $TT_{20\ km}$ (Fig. 1).

3.2. Actual distance as a function of the perceived distance

A distance main effect ($P < 0.01$; F = 51.34, $d = 3.2$, power = 1.0), but not a condition main effect ($P > 0.05$), was observed for the actual distance plotted against the perceived distance. Furthermore, a condition-by-distance interaction effect ($P < 0.05$; F = 2.14, $d = 0.66$, power = 0.99) was observed, thus the light deprivation increased the actual distance covered at each perceived 2-km (Fig. 2). In contrast, although neither distance-by-condition interaction effect ($P > 0.05$) nor distance main effect ($P > 0.05$) occurred in the error of conscious distance monitoring, cyclists showed a greater error of conscious distance monitoring when they cycled in light deprivation, as a condi-

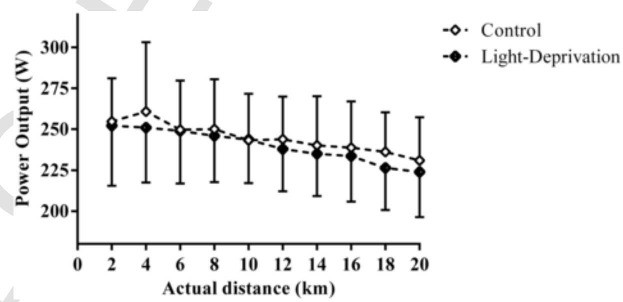

Fig. 1. Pacing strategy as indicated by the power output distribution during 20-km cycling time trial. Empty symbols indicate illuminated-control condition and filled symbols indicate light-deprived condition. A distance main effect ($P = 0.04$; F = 2.33, $d = 0.67$, power = 1.0) was observed.

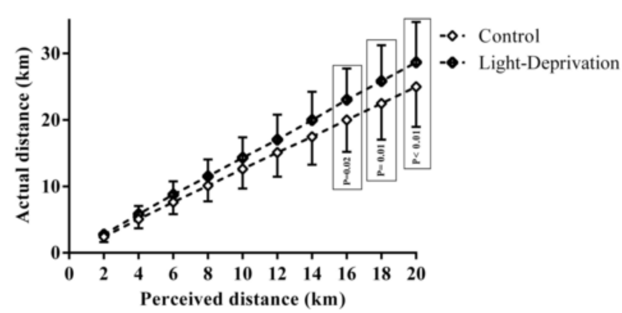

Fig. 2. Actual cycling distance as a function of the perceived distance. Empty symbols indicate illuminated-control condition and filled symbols indicate light-deprived condition. A distance main effect ($P < 0.01$; F = 51.34, $d = 3.2$, power = 1.0), but not a condition main effect ($P > 0.05$) was observed. As indicated in the scatterplot, there was a condition-by-distance interaction effect ($P < 0.05$; F = 2.14, $d = 0.66$, power = 0.99) as cyclists covered greater actual distances at each perceived 2-km distance, in light deprivation.

tion main effect ($P < 0.01$; $F = 36.15$, $d = 2.68$, power = 1.0) was detected (Fig. 3).

3.3. RPE and ATE responses

Neither condition main effect ($P > 0.05$), nor condition-by-distance interaction effect ($P > 0.05$) was observed in RPE as a function of the perceived distance. Accordingly, the RPE slope was not different between illuminated-control (0.37 ± 0.08 a.u.·km^{-1}) and light-deprived setup (0.40 ± 0.13 a.u.·km^{-1}). However, there was a distance main effect ($P < 0.01$; $F = 58.08$, $d = 3.4$, power = 1.0) so that RPE increased progressively during the $TT_{20\ km}$ regardless of the brightness (Fig. 4).

The distance/RPE index showed a condition ($P < 0.01$; $F = 36.96$, $d = 2.72$, power = 1.0) and distance main effect ($P < 0.01$; $F = 68.35$, $d = 3.69$, power = 1.0). Additionally, a condition-by-distance interaction effect ($P < 0.05$; $F = 6.76$, $d = 1.16$, power = 1.0) was observed, thereby indicating that cyclists had ridden greater distances between each two RPE scores in the light-deprived $TT_{20\ km}$ (Fig. 5).

Regarding the ATE, neither distance main effect ($P > 0.05$) nor distance-by-condition interaction effect ($P > 0.05$) was observed, however the light-deprived environment induced cyclists to report a lower ATE (a condition main effect) during the $TT_{20\ km}$ ($P < 0.01$; $F = 12.24$, $d = 1.56$, power = 1.0) (Fig. 6).

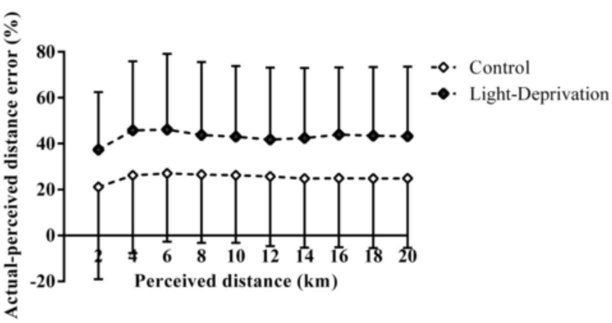

Fig. 3. Error of the conscious distance monitoring as a function of the perceived distance. Empty symbols indicate illuminated-control condition and filled symbols indicate light-deprived condition. There was a condition main effect ($P < 0.01$; $F = 36.15$, $d = 2.68$, power = 1.0), but neither a distance main effect ($P > 0.05$), nor a distance-by-condition interaction effect ($P > 0.05$) was observed.

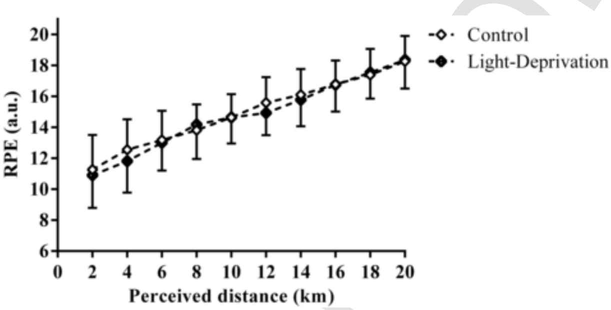

Fig. 4. Ratings of perceived exertion (RPE) responses as a function of the perceived distance. Empty symbols indicate illuminated-control condition and filled symbols indicate light-deprived condition. Neither condition main effect ($P > 0.05$) nor condition-by-distance interaction effect ($P > 0.05$) was observed in RPE. There was a distance main effect when RPE was plotted against the perceived distance ($P < 0.01$; $F = 58.08$, $d = 3.4$, power = 1.0).

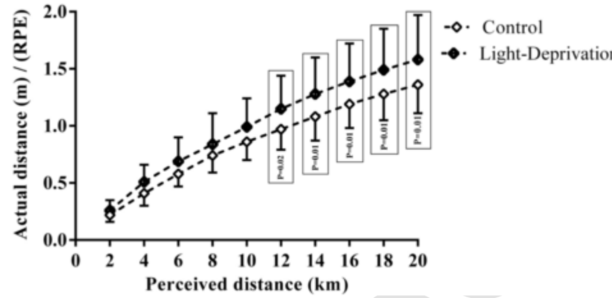

Fig. 5. Distance/RPE index as a function of the perceived distance. Empty symbols indicate illuminated-control condition and filled symbols indicate light-deprived condition. There was a condition main effect ($P < 0.01$; $F = 36.96$, $d = 2.72$, power = 1.0) and a distance main effect ($P < 0.01$; $F = 68.35$, $d = 3.69$, power = 1.0). As indicated in the scatterplot, there was a condition-by-distance interaction effect ($P < 0.05$; $F = 6.76$, $d = 1.16$, power = 1.0).

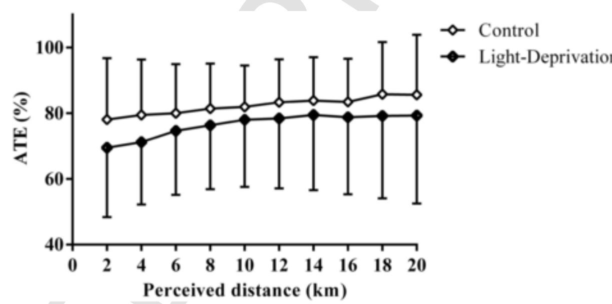

Fig. 6. Associative thoughts to exercise (ATE) as a function of the perceived distance. Empty symbols indicate illuminated-control condition and filled symbols indicate light-deprived condition. There was a condition main effect ($P < 0.01$; $F = 12.24$, $d = 1.56$, power = 1.0), but neither distance main effect ($P > 0.05$) nor distance-by-condition interaction effect ($P > 0.05$) was observed.

4. Discussion

The main findings of this study were: 1) the elongated perceived distance in the light-deprived environment, as cyclists completed greater distances at each self-reported 2 km (Fig. 2); 2) and the lowered RPE in light deprivation, as indicated by the higher real distance covered between RPE scores. In addition, a lowered ATE occurred together with a lowered RPE-actual distance ratio (Figs. 5 and 6). Despite the elongated conscious distance monitoring and lower RPE and ATE, pacing and performance were unaffected by light deprivation.

The optic flow provides valuable information for navigation and orientation, so that the lack of optic flow leads individuals to undershoot the real distance covered [30,31]. The fact that individuals cycled on a stationary ergometer with no landmarks to estimate the distance covered, as it should occur in a “real illuminated-world situation”, may explain the error of estimated distance in both illuminated-control and light-deprived setups. However, this error was even greater in the darkness, as cyclists elongated their perception of distance and increased the real distance covered at each perceived 2 km. This result suggests that the visual sensory inputs in the illuminated laboratory refined the conscious monitoring of distance during the stationary $TT_{20\ km}$, perhaps as a result of the increased brainstem reticular formation and cortical activity in this condition [14–16].

Somehow, the slowed-down internal clock observed in our light-deprived environment may be further associated with a decreased alertness. A previous study had shown an acute alerting response, probably due to an increased cortical activity and suppressed plasma melatonin when individuals were exposed to a 23–3190 lx illuminance, after being exposed to a long-term ≈ 3 lx darkness [32]. Thus, assuming the opposite effect when exposing individuals to the darkness (≈ 2 lx), after exposing them to a lighting environment (≈ 225 lx), the impaired conscious distance monitoring during light-deprived $TT_{20\ km}$ may have been a result of a possible lowered alertness. However, what remains to be verified is that this also occurs after a short-term darkness exposition as that used in the present study (≈ 35 min).

Results of the present study are partially in accordance with the original internal clock model, as a robust pacing algorithm was set to both the illuminated-control and light-deprived conditions, regardless of the disturbed conscious distance monitoring and RPE. Similar findings were provided by a recent study [18] manipulating optic flow during exercise. In that study there was a significant increase in the actual distance-RPE ratio when individuals ran watching an optic flow video footage calibrated 25% slower than the true speed, but pacing and performance were unchanged. Together, these studies showed that a robust pacing strategy was set to a particular exercise bout (a 5-km running time trial and a 20-km cycling time trial), despite the disrupted RPE and conscious distance monitoring through different manipulations, suggesting that an internal clock may have operated at a subconscious, rather than a conscious level [1].

Our results could further address information to recent pacing models [20,21]. According to an effort-based decision-making theory, RPE is a conscious perception of internal (i.e. physiological) and external (i.e. environment) factors, so that individuals would consciously change their pace to compensate for a negative/positive RPE [20]. Results of the present study challenged such a suggestion, as the manipulation of ambient lighting distorted the conscious pacing regulation and RPE, without affecting the actual pacing. Accordingly, our results further challenged an affordance-based control. This model assumes that changes in pacing would reflect possibilities perceived in the environment for a given individual capability to exercise [21]. Variations in environment stimuli such as visual input should influence both perception and action, thus affecting pacing [21]. A previous study observed such an effect [17], but others did not [12,18]. Nevertheless, rather than refuting some pacing models to elect a particular one, our results together with several others [8–10,12,17,18] may indicate the presence of a complex interplay between conscious-subconscious brain [1] and interoceptive-exteroceptive factors [21,33], which leads to different levels of awareness during regulation of pacing [22].

Studies have proposed that pacing strategy and performance would be consistent with a RPE-template [3,7,11,34], as pacing would be regulated to match the actual RPE with that RPE “expected and acceptable” for a given exercise bout [7]. The fact that RPE is an output of different features such as prior experience, knowledge of the exercise bout endpoint and physiological alterations in peripheral organs has been used to support this notion [19,35,36]. However, pacing and performance were unchanged when depriving ambient lighting, even though the greater actual distance-RPE ratio. It is improbable that our light-deprived setup has changed these features, as the same experienced cyclists performed the illuminated and light-deprived $TT_{20\ km}$ in a counterbalanced order, under identical conditions; the exception was the presence/absence of light. Thus, although a RPE-template may predict pacing and performance in most real world situations [37], this was disrupted in our experimental light-deprived setup. Studies are required to verify how the RPE-template would work in real, nighttime cycling races.

The mismatch between RPE and actual distance in light deprivation may be explained with different ways. First, the increased actual distance-RPE ratio may have been due to the elongated perceived distance in the darkness [14,15]. As the rate of increase in RPE is thought to be set according to the exercise endpoint [3,5], the elongated conscious perceived distance may have increased the actual distance-RPE ratio. Second, these results could further indicate that RPE is a cognitive process highly affected by changes in other psychological variables [19]. The RPE is generated in a quantal unit manner, as we have only one perception of reality at any time point (a single dominant stream of conscious thought) [1,19]. Because the darkness increases anxiety and fear [38], the light deprivation may have led cyclists to intensify these competitive emotions when compared to the illuminated-control environment, therefore lowering the quantal unit of RPE. Unfortunately, we have not measured anxiety and fear, so that other studies are required to investigate this hypothesis yet.

The ATE is another psychological variable that could have affected RPE in the darkness. In contrast to a previous study [24], we observed that light deprivation decreased the body sensations as measured by ATE scale, perhaps resulting in a lowered quantal unit of RPE because RPE is affected by the percentage of ATE [1,27]. It is not clear why the darkness led to different ATE responses in these studies, but the different participants' training status is possibly a factor to be considered. It has been suggested that athletes may subconsciously shift from associative to dissociative thoughts to exercise as a mean to deal with unpleasant sensations during exercise [39]. Therefore, perhaps the cyclists of the present study subconsciously lowered the ATE in the darkness, as a mean to deal with unpleasant sensations such as anxiety and fear (in contrast to the untrained participants of the previous study). Furthermore, light deprivation may have led to an overcompensation of inputs from different sensorial systems, for example, the auditory system. Cyclists may have been distracted from internal body sensations toward external cues in the light-deprived $TT_{20\ km}$ (such as the noise of the bicycle's wheel attached to the cycle-simulator), rather than in the illuminated-control $TT_{20\ km}$.

Results of the present study are appealing from a practical standpoint. The RPE has been used as a marker of intensity and homeostatic disruption during exercises performed at different setups; the RPE is interpreted as a psychophysiological integrator that could predict exercise capacity, training status, and changes in pacing strategy [23]. However, the greater actual distance-RPE ratio in the light-deprived $TT_{20\ km}$ may suggest caution when using RPE to reflect intensity and pacing during exercise in nighttime environments, such as nocturnal cycling or mountain biking training and competitions. Instead, pacing (variation in power output) and performance (time to complete the $TT_{20\ km}$) were unaffected by light deprivation, thereby suggesting that these variables may be worth for this purpose.

Furthermore, cyclists used an even pacing strategy (with a slight decreasing power output) without end spurt, agreeing with the single study that investigated the effects of light deprivation in pacing and performance [12]. The absence of end spurt may be a result of the blinded time and distance feedback during both trials, which would have led cyclists to consciously choose a more conservative pacing strategy. In fact, as reported elsewhere [40], the uncertainty of the trial endpoint may have led cyclists to adopt a lower metabolic intensity [13] during the $TT_{20\ km}$ with blinded feedback, leading to a mean power output lower than that reported during $TT_{20\ km}$ with accurate/inaccurate feedback [11].

Limitations of the present study should be pointed out. First, although our results could be attractive for practical approaches with nighttime cycling, they may not be directly applied to all real, nighttime cycling situations, as we have used an experimental approach with total darkness. We have used a room with ≈ 2 lx and 0^{01} W/m^2

in the experimental setup in order to potentiate the effects of light deprivation. Hence, future studies are required to confirm these results in real, nighttime situations with different brightness. Additionally, to control the experimental setup we have used a stationary cycle ergometer in a light-deprived laboratory, perhaps creating a symmetric time-distance relationship. Previous study showed that mental representations of duration (time) might not be symmetrically dependent on displacement (distance) [4]. We acknowledge that this may be the case in situations when landmarks are available to monitor the displacement; however this may not be the case when no landmarks are available, as in a controlled-laboratory or in a real world, low brightness nighttime cycling. Lastly, we analyzed pacing strategy by averaging the power output over each 2 km. Despite using a methodology similar to others [17,41], we acknowledge that averaging the data may have lowered the sensitivity to detect small differences in pacing. Studies analyzing high-frequency power output data may better elucidate moment-to-moment variations in pacing.

In summary, the present study showed that cyclists elongated the conscious monitoring of the actual distance covered when they cycled in an experimental light-deprived setup. In addition, this elongated perceived distance occurred together with a greater actual distance-RPE ratio and lower ATE, but neither pacing nor performance were impaired in this condition. These results suggest that pacing and performance were equally regulated in illuminated-control and light-deprived setup, regardless of the disturbed conscious distance monitoring and perceptive responses in the darkness.

Conflict of interest

The authors declare no competing interests.

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