Neuromuscular Activity during Cycling Performance

Subjects: Physiology
Submitted by: Olivier Hue
(This entry belongs to Entry Collection "Metabolic Disorders and Sport")

Definition

To determine the relationships between limiting factors and neuromuscular activity during a self-paced 20-km cycling time trial and evaluate the effect of environmental conditions on fatigue indices.

Methods: Ten endurance-trained and heat-acclimated athletes performed in three conditions (ambient temperature, relative humidity): HUMID (30 °C, 90%), DRY (35 °C, 46%) and NEUTRAL (22 °C, 55%). Voluntary muscular contractions and electromagnetic stimulations were recorded before and after the time trials to assess fatigue. The data on performance, temperature, heat storage, electromyogram, heart rate and rating of perceived exertion data were analyzed. Results: Performance was impaired in DRY and HUMID compared with NEUTRAL environment (p < 0.05). The force developed by the vastus lateral muscle during stimulation of the femoral nerve remained unchanged across conditions. The percentage of integrated electromyogram activity, normalized by the value attained during the pre-trial maximal voluntary contraction, decreased significantly throughout the trial only in HUMID condition (p < 0.01). Neuromuscular activity in peripheral skeletal muscle started to fall from the 11th km in HUMID and the 15th km in DRY condition, although core temperature did not reach critical values. Conclusions: These alterations suggest that afferences from core/skin temperature regulate the central neural motor drive, reducing the active muscle recruited during prolonged exercise in the heat in order to prevent the system from hyperthermia.

1. Introduction

We examined the first hypothesis—that is, that with the failure in homeostasis above a critical core temperature, peripheral factors are the main factors to explain exhaustion—and tested whether or not “central fatigue” causes impaired aerobic performance in hot/humid conditions. It has been demonstrated that it is not ambient temperature, but rather vapor pressure that determines self-paced performance [1]. Tucker et al. indeed showed that power output during self-paced exercise in the heat was lower, whereas heart rate, rating of perceived exertion (RPE) and core temperature were similar to those observed in cool conditions [2]. We demonstrated earlier that tropical climate impaired aerobic performance in ecological conditions. We thus found it interesting to evaluate whether hot/humid conditions would be more stressful than hot/dry conditions on physiological functions [3][4], as compared with a control condition.

Our studies tried to evaluate the impact of the tropical climate on aerobic performance. Thus, we conducted an experiment where we could compare hot/dry to hot/humid conditions. As the dry heat has been well documented [2], we used the same protocol to highlight the more significant impact of hot/humid conditions on aerobic performance. To do so, we conducted a study on acclimated athletes performing a self-paced cycling time trial over 20 km in three laboratory conditions (neutral, hot/dry and hot/humid). The previous studies cited emphasized the detrimental consequences of the tropical climate in outdoor conditions, showing that the athletes did not reach critical Trec even when they took part in a competition (half ironman and 27 km running trail).

We hypothesized that free-intensity cycling exercise in a tropical climate would be influenced by tropical specificities (i.e., the impossibility of reducing core temperature through evaporation and high fluid loss), but that performance would be reduced as a way to prevent a critical core temperature from being reached.
2. Analysis on Results

Performance

The times for the 20-km time trial were 44.6 ± 2.5, 43.9 ± 1.7 and 40.7 ± 1.8 min in HUMID, DRY and NEUTRAL, respectively. Repeated measures ANOVA revealed a significant main effect of Condition (\(p = 0.014, \eta^2 = 0.65\)) on the times and they were significantly greater in HUMID (\(p = 0.019\)) and DRY (\(p = 0.009\)) than in NEUTRAL. Mean speed expressed in km·h\(^{-1}\) was 28.5 ± 4.2, 28.5 ± 3.5 and 30.0 ± 4.8 in HUMID, DRY and NEUTRAL, respectively (\(p = 0.021\)). In the three conditions, the speed in the last 10% interval was significantly higher than that in the previous intervals (Figure 1).

![Figure 1](image1.png)

**Figure 1.** Speed during the 20-km tests in the three conditions HUMID (black), DRY (gray) and NEUTRAL (white). * Significantly greater than in the previous intervals in the three conditions.

Repeated measures ANOVA revealed a significant main effect of Period (\(p = 0.029, \eta^2 = 0.58\)) on RPE. RPE was significantly greater in HUMID compared with DRY (\(p = 0.025\)) and NEUTRAL (\(p = 0.006\)) (Figure 2).

![Figure 2](image2.png)

**Figure 2.** Rating of perceived exertion during the three conditions HUMID (black), DRY (gray) and NEUTRAL (white). * Significantly different from neutral (\(p \leq 0.05\)).
The maximal voluntary contractions of the quadriceps were affected by exercise, showing the same amplitude in the three conditions \( (p = 0.002, \eta_p^2 = 0.66) \) (Figure 3). No statistically significant effect of Condition or effect of Condition × Period was found for the force developed by the vastus lateralis muscle during the magnetic stimulations (Figure 3).

![Figure 3](image)

**Figure 3.** Force developed during maximal voluntary contractions (upper figure) and during magnetic stimulations (lower figure) from the quadriceps pre-trial (gray) and post-trial (white) in HUMID (30 °C), DRY (35 °C) and NEUTRAL (22 °C) conditions. Means ± SEM for 10 participants. * Significantly different from POST \( (p \leq 0.05) \).

Repeated measures ANOVA revealed a significant main effect of Condition \( (p = 0.036, \eta_p^2 = 0.56) \) and the Condition × Period interaction \( (p = 0.047, \eta_p^2 = 0.98) \) for %iEMG. The %iEMG activity was not different at the start of the trials, and no significant differences were found during the first 7 km of the trials between conditions, but %iEMG in HUMID was lower than in NEUTRAL at 11, 15 and 19 km, and lower than in DRY at 15 and 19 km (Figure 4).
Figure 4. Integrated electromyogram from the vastus lateralis muscle at 3, 7, 11, 15 and 19 km during trials in the three conditions HUMID (black), DRY (gray) and NEUTRAL (white). Means ± SEM for 10 participants. * Significantly different from NEUTRAL ($p \leq 0.05$) + Significantly different from DRY ($p \leq 0.05$). \%iEMG: Percentage of integrated electromyography.

Repeated measures ANOVA revealed a significant main effect of Period ($p = 0.016$, $\eta^2 = 0.64$) for HR. HR was significantly greater in HUMID ($p = 0.003$) and DRY ($p = 0.050$) than in NEUTRAL (Figure 5).

Figure 5. HR during the 20-km tests in the three conditions HUMID (black), DRY (gray) and NEUTRAL (white). * Significantly different from NEUTRAL ($p \leq 0.05$).

Figure 6 shows the change in rectal temperature (A), skin temperature (B), the rate of heat storage (C) and the core to skin gradient (D) throughout the experiments. Repeated measures ANOVA revealed a significant main effect of Period ($p < 0.0001$, $\eta^2 = 0.94$), Condition ($p = 0.015$, $\eta^2 = 0.37$) and the Condition × Period interaction ($p = 0.046$, $\eta^2 = 0.27$) for rectal temperatures. Significantly higher rectal temperatures were found in HUMID compared with NEUTRAL at 15 and 20 km, and in DRY compared with NEUTRAL at 20 km. Repeated measures ANOVA revealed a significant main effect of Period ($p < 0.001$, $\eta^2 = 0.94$), Condition ($p = 0.015$, $\eta^2 = 0.37$) and the Condition × Period interaction ($p = 0.046$, $\eta^2 = 0.27$) for rectal temperatures.
ηp2 = 0.67), Condition (p < 0.001, ηp2 = 0.88) and the Condition × Period interaction (p < 0.001, ηp2 = 0.46) for skin temperatures. Significantly higher mean Tskin was found in HUMID compared with DRY at 15 and 20 km, and in HUMID and DRY compared with NEUTRAL throughout the trial. Repeated measures ANOVA revealed a significant main effect of Condition (p = 0.031, ηp2 = 0.57) for heat storage. The rate of heat storage was significantly greater in HUMID (p = 0.008) and DRY (p = 0.018) compared with NEUTRAL.

Figure 6. Core temperature (A), mean skin temperature (B), rate of body heat storage (C), core to skin gradient (D) in the three conditions HUMID (black), DRY (gray) and NEUTRAL (white). * Significantly different from NEUTRAL. † Significantly different from DRY.

The rate of BML in kg·h⁻¹ was 2.6 ± 0.5, 2.5 ± 0.9 and 1.7 ± 0.5 in HUMID, DRY and NEUTRAL, respectively. Repeated measures ANOVA revealed a significant main effect of Condition (p = 0.008, ηp2 = 0.70) on the rate of BML and it was significantly higher in HUMID (p = 0.001) than in NEUTRAL. The rate of water intake in L·h⁻¹ was 1.1 ± 0.6, 1.3 ± 1.2, 0.5 ± 0.3 in HUMID, DRY and NEUTRAL, respectively. Repeated measures ANOVA revealed a significant main effect of Condition (p = 0.030, ηp2 = 0.58) on the rate of water intake and it was significantly higher in HUMID (p = 0.009) and DRY (p = 0.008) than in NEUTRAL.

3. Current Insights

It has been demonstrated that the peripheral fatigue developed during exercise in the heat is not a direct cause of decreased aerobic performance, which might instead be due to “central fatigue” [5]. In hot/humid climate, aerobic performance is also impaired because of the high RH of the air. Interestingly, in this study the participants declared a significantly greater RPE, which is a subjective parameter, in HUMID compared with DRY and NEUTRAL, reflecting the strain of the environment. The force produced in the vastus lateralis muscle during the MVCs was affected by exercise to the same amplitude in the three conditions. Nevertheless, we found that TWq remained the same in NEUTRAL, DRY and HUMID, indicating that the capacity of the skeletal muscle to produce force was not altered. Thus, %iEMG significantly decreased during exercise only in the HUMID condition. The %iEMG was reduced from the 15th km in HUMID compared with DRY and from the 11th km in HUMID compared with NEUTRAL. It has been shown
that a hot ambient temperature causes a reduction in iEMG \[2\], whereas our study demonstrated that ambient humidity was responsible for the reduction in iEMG. This result is the major novelty of this study. According to the literature, a 2 °C difference impairs perceptual responses (without impact on performance) \[6\], whereas in our study, even a 1 °C difference in Tskin was associated with lower iEMG (but not performance). Moreover, the core to skin temperature gradient was enhanced in NEUTRAL compared with DRY and HUMID, indicating that convective heat loss was facilitated in NEUTRAL. In other words, a lower core to skin temperature gradient measured in the heat could be responsible for the diminution of the performance \[1\]. The highest speed over any 10% interval was therefore recorded in the last 10% for all three conditions, indicating that the participants had the ability to voluntarily activate skeletal muscles when cycling at maximum speed in the trials. With regard to the proposition that the CNS limits exercise-induced hyperthermia by reducing the power output of exercise, we can hypothesize that decreased motor control (at a cortical and/or spinal level) early in HUMID and DRY (at the 15th km) adjusted the motor unit recruitment. Interestingly, Trec was not different between DRY and NEUTRAL for the first 15 km or between HUMID and NEUTRAL for the first 10 km. However, %iEMG was diminished, even though the participants’ core temperatures did not reach critical values. Additionally, the assumption that a critical core temperature would be reached, leading to exhaustion \[7\]|\[8\], was not corroborated by our study, because the participants finished the time trials without a critically high Trec (39.2 ± 0.5 °C in HUMID, 39.1 ± 0.5 °C in DRY and 38.5 ± 0.4 °C in NEUTRAL) and showed no evidence of heat illness at the end of the trials. Furthermore, when participants experience dehydration under heat stress in hot/dry climate, this combination can lead to a reduction in skeletal muscle blood flow \[9\]. In hot/humid climate, sweating does not result in heat loss and athletes performing aerobic exercise will become increasingly dehydrated \[10\], with impaired endurance performance \[11\]. A recommendation to ingest 600 mL before arriving at the laboratory was given to the participants to prevent dehydration. In addition, they were allowed to drink ad libitum which has been demonstrated to assure an optimal rate of fluid absorption in the laboratory and in ecological experiments \[12|13\]. In the present laboratory study, the rate of BML was significantly higher in HUMID than in NEUTRAL. Yet, current studies completed in ecological conditions have suggested that BML is not directly linked to a decreased in aerobic performance \[14\]. Similar BMLs in hot/humid environment have been described for a 27-km trail running race, i.e., a decrease of 3.9 ± 1.1% \[4\]. Likewise, the authors demonstrated in a half-Ironman triathlon that athletes did not conserve their body mass within the recommended range of 2–3% \[2\], but this did not indicate that the participants were hypohydrated \[15\], even though urine osmolality was significantly augmented after the race compared with immediately before. Indeed, it has been demonstrated in well-trained unacclimatized male runners that fluid ingestion failed to provide any ergogenic benefit in attenuating thermoregulatory and circulatory stress during exercise not only in warm dry conditions, but also in warm humid environment \[16\]. We observed a decreased BML of 2.6 ± 0.5 kg·h\(^{-1}\) (equivalent to 2.7 ± 0.5 % of BMLs) in HUMID conditions. This result indicates that although sweat evaporation was unproductive, the sudation did not stop or diminish compared to DRY, even in acclimated participants, in accordance with previous observations \[17\].

Authors have reported that an increased Trec is correlated with RPE during a dynamic exercise \[5|18\]. Trec is usually considered to have a greater impact than Tskin on the impairment of aerobic performance \[19\]. Indeed, a 1 °C-variation in Trec provides from ~70% to 90% of the circulatory response at the skin level and rate of sweating, in the thermoregulatory mechanisms \[20\]. Nevertheless, during exercise in the heat, an elevation in the skin temperature will not only trigger the thermoregulatory mechanism, but might also initiate afferent signals from thermo-receptors in the cutaneous tissues, which could be responsible for thermal perception in the control of human thermoregulatory behavior. A correlation was shown between high skin temperature and thermal discomfort, and this could play an important role in the selection of the intensity of a prolonged self-paced exercise \[21\]. In our study, we found that mean Tskin was higher in HUMID compared with DRY at 15 and 20 km and throughout the HUMID trial compared with NEUTRAL. A rise in Tskin could thus generate afferent feedback that reduces the CNS recruitment of skeletal muscle. This would explain the decrease in %iEMG in HUMID at 11, 15 and 19 km compared with NEUTRAL, and at 15 and 19 km compared with DRY. It has in fact been suggested that the CNS combines several afferent
signals from different systems involving respiration, heart, muscles and thermoreceptors, and that it regulates motor command in order to defend organ integrity during exercise [22][23]. We speculate that this concept of a “central governor” could be generalized to heat, given that working muscles generate heat, which is then enhanced by the environmental strain of a hot/humid climate.

References


