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Original Article

Changes in body core temperature during the cycling segment of a triathlon

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Abstract:
This study investigates how body core temperature varies during the cycling segment of a triathlon under different outdoor temperatures. Because high external temperatures can mimic some effects of altitude training, we examined the impact of varying external temperatures on body core temperature, heart rate levels, blood lactate values, and perceived exertion. The research involved Slovak triathletes, aged 23(±2) years, who regularly compete in European Cup races.Probands completed 2 rides at the anaerobic lactate threshold level in two different outdoor temperatures, namely 18 °C and 30 °C on bicycle trainers. We assumed significant changes in all monitored parameters at a higher outdoor temperature and we assumed a significant relationship between the outdoor temperature and the monitored parameters. We found a significantly higher level of heart rate during riding at a higher temperature ($p < 0.01$**). We measured the subjective level of load using the Borg scale, and we also found a significantly higher level ($p < 0.05$*). The relationship between body core temperature and the subjective feeling of load came out at the level of $r = 0.8056$; $r2 = 0,6489$; $p < 0.01$** when riding in low temperature and $r = 0.6998$; $r2 = 0,4897$; $p<0.05$* when riding in high outside temperature. The relationship between core body temperature and blood lactate level was $r=0.695$; $r2 = 0,4830$; $p < 0.05$* when riding in low temperature and $r = 0.7356$; $r2=0,5411$; $p<0.05$* when riding in high temperature. In view of these findings, we recommend that when training in high temperatures, you monitor the parameters during the training in detail and pay attention to the exact execution of the training.
Key Words: **heart rate, body temperature, blood lactate, outdoor temperature**

Introduction

This thesis focuses on the study of changes in core body temperature during the cycling segment of a triathlon. Its significance lies in understanding the dynamics of body temperature during endurance sport performance that combines higher intensity with longer time duration. The aim was to investigate how body temperature changes during different phases of the cycling leg and to identify factors that may influence these changes. An important contribution of this work is to provide useful insights for coaches, athletes and clinicians interested in the effective management of body temperature during endurance sport performance, in order to maximise performance and minimise the risks of overheating or hypothermia.

The context of this work was the study of core body temperature during the cycling leg of a triathlon. This sport combines three different competitive disciplines: swimming, cycling and running, and challenges athletes in terms of physical performance and thermoregulation. The aim was to understand how body temperature changes during the cycling leg, which is part of an endurance competitive environment. The research focused on tracking the dynamics of body temperature as a function of the intensity and duration of the cycling leg, which may have important implications for the effective management of thermoregulation and optimization of athlete performance.

This study addresses the dynamic changes in core body temperature during the cycling segment of a triathlon, a demanding endurance sport comprising swimming, cycling, and running. The cycling phase presents athletes with a prolonged period of high-intensity physical exertion in varied environmental conditions, which significantly challenges thermoregulatory mechanisms. Understanding how core body temperature fluctuates during this segment is crucial for optimizing performance and mitigating the risks of heat-related illnesses or performance decrements. Therefore, this research aims to examine the patterns and factors influencing core body temperature changes during the cycling portion of a triathlon, contributing to better strategies for managing athlete thermoregulation in endurance sports.

Training in an elevated outdoor temperature result in an almost identical effect to training at high altitude. It can also improve the amount of hemoglobin and can improve our use of oxygen even at sea level. This training is easier to implement, but on the other hand, it is more dangerous. Training in high outdoor temperatures must be controlled and planned even more precisely than training at high altitude (Formánek, Horčic, 2003).

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Triathlon is characterized as an endurance triathlon in which the competitor must complete 3 disciplines that follow one another without a break. It places very high demands on endurance skills, as well as on the correct technical mastery of individual disciplines, but also the tactical mastery of the entire race. The competitor completes swimming, cycling, and running in this order without a break. Compared to other multi-sport events, where the result is the summation of individual performances, we speak of triathlon as a homogeneous performance (Formánek, Horčic, 2003).

Studies showed that the highest racing performance is then defined by the athlete's complex performance requirements in swimming, cycling, and running, as well as technical-tactical skills in the transition parts, we can say that performance in triathlon is the sum of 5 parts:

- Time of the swimming part.
- The time between leaving the water and starting to cycle.
- Time of the cycling part.
- The time between getting off the bike and starting to run.
- Time of the running part (Formánek, Horčic, 2003).

Improving the amount of hemoglobin is also possible by means other than regular training. It is here that the influence of the environment appears to be one of the best solutions. Given the fact that chronic exposure to altitude can significantly increase hemoglobin levels (Siebenmann et. al. 2017, Siebenmann et. al. 2015).

In contrast to training at altitude, during which an increase in hemoglobin is preceded by a rapid decrease in the volume of blood plasma, exposure to a hot environment leads to an expansion of blood plasma by almost 20% within a few days, which then stabilizes at approximately +10%. Although such an expansion may not affect training capacity despite the facilitation of a higher maximal cardiac output due to the accompanying decrease in blood oxygen content, it is thought that if the increase in blood plasma persists for several weeks, it may ultimately lead to an increase in the amount of hemoglobin, which can already facilitate sports performance (Sawka et. al. 2000).

Full and proper functioning of the body depends on maintaining a body temperature between 36.5°C and 38.5°C. Incorrect functioning of the body occurs precisely when this temperature dispersion changes. That is, if the temperature reaches below or above the limit of these values. The greater the difference from these values, the greater the problem for the body. When the temperature rises above 41.5°C or falls below 33.5°C, serious health complications occur, which can lead to various injuries or even cause death. Two mechanisms result in a change in body temperature. The first of them is manifested by a malfunction of one or more body systems accompanied by infection or contamination of the body, which results in fever. The second is the disruption of the very delicate balance between the amount of heat absorbed from the environment, metabolic heat production and the amount of heat emitted from the body, primarily through sweating. However, according to the authors, it should be noted that despite the differences between these two mechanisms and different treatments, both can have the same serious health consequences, even death (Saunders, 2019).

Material & methods

The research group consisted of targeted triathletes (n=9), calendar age 23 years (±2 years). The conditions for selection were participation in international triathlon races, a minimum sporting age of 7 years, and another leading position in Slovak Cup races and top events in Slovakia. The average volume of training hours per week had to be at least 27 hours (±4 hours). The average weight was 71.3 kg (±7 kg) and the average height was 177 cm (±12 cm).

Probands completed a total of 2 rides on a bicycle trainer, each lasting 90 minutes. One at an outside temperature of 18 °C and the other at 30 °C. The test protocol consisted of a 10-minute warmup, followed by a special warm-up using simulated straights 5x (20 s at VO2max level + 40 s recovery phase). This was followed by 60 minutes at the anaerobic lactate threshold level and the last part was a 15-minute cooldown. We divided 60 minutes at the anaerobic lactate threshold level into 3x20 minutes, but without a break. After each of these individual sections, we recorded the average mechanical power output, the average heart rate, the probands determined the degree of subjective load on the Borg scale, blood lactate was measured, and the average body core temperature was recorded for the last 30 seconds. The values on which the test took place were provided by the subjects from the lactate curve, which could not be older than 2 months. Due to the complexity of the research, they had an unlimited amount of water and 2 gels, each containing 25g of carbohydrates. The core body temperature sensor was placed on the Garmin chest strap, according to the instructions, and the probands were not wearing a jersey top.

We select the measured data from the graphs created for us by the Garmin Connect application. Data will be evaluated using basic statistical characteristics such as arithmetic mean, mode, median, maximum value, minimum value, range of variation and standard deviation. We used the non-parametric Wilcoxon T-test to determine the statistical significance of our data. We used correlation and correlation coefficient to determine the relationship between individual parameters and body core temperature.

Results

Borg scale level during measurements at both temperatures

Subjective load increased significantly with higher temperatures across all measurement phases ($p < 0.05^*$ for warm-up, special warm-up, and first 20-minute section; $p < 0.01^{**}$ for the third 20-minute section and cooldown). During warm-up at a temperature of 18°C, the average value of subjective load was 7, and at a temperature of 30°C it was 8. ($p < 0.05$). Figure 1.

In a special warm-up at a temperature of 18°C, the average value of the subjective load was 10, and at a temperature of 30°C it was 11. ($p < 0.05$). Figure 1.

In the first 20-minute section at a temperature of 18°C, the average value of the subjective load was 15, and at a temperature of 30°C it was 16. ($p < 0.05$). Figure 1.

In the second 20-minute section at a temperature of 18°C, the average value of the subjective load was 16, and at a temperature of 30°C it was 17. ($p < 0.05$). Figure 1.

In the third 20-minute section, at a temperature of 18°C, the average value of the subjective load was 16, and at a temperature of 30°C, it was 18. ($p < 0.01$). Figure 1.

During the cooldown, at a temperature of 18°C, the average value of the subjective load was 7, and at a temperature of 30°C, it was 8. ($p < 0.01$). Figure 1.

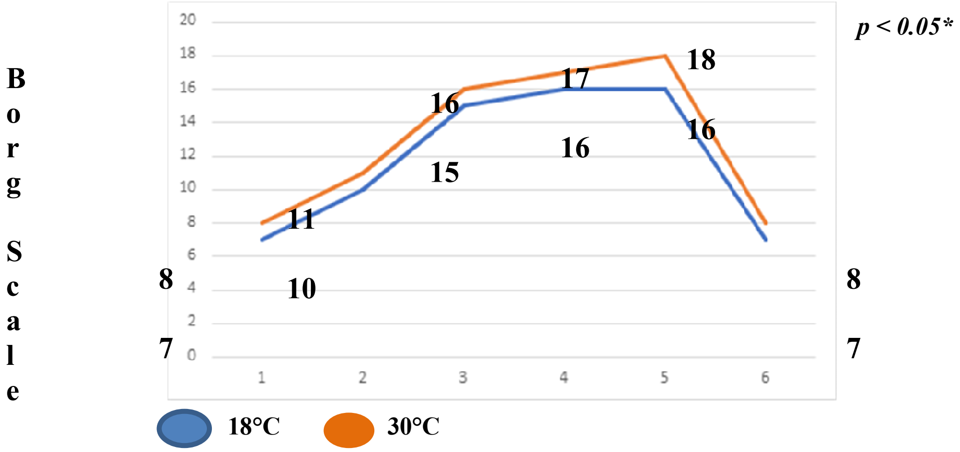


Figure. 1. Progress of the Borg scale in both measurements

Heart rate comparison during both runs in both temperatures.

When comparing rides in both temperatures, we found a significant difference when measured in high outside temperature, where our statement was confirmed at the 1% level of statistical significance ($p < 0.01$). High differences in average values can be seen already at the start, where the difference was 7 beats per minute ($p < 0.01$). Furthermore, during the special warm-up, it was 4 beats per minute ($p < 0.05$). When driving at the anaerobic lactate threshold level, the difference in the first section was only 4 beats per minute ($p < 0.05$). With the second, 7 beats per minute ($p < 0.01$), and with the last one even 8 beats per minute ($p < 0.01$). The biggest difference can be seen at the start, where the difference was even 17 beats per minute ($p < 0.01$). Thus, we can talk about a high influence of the external temperature on the heart rate during measurements at advanced times of the test, where with the same mechanical performance, the probands had to exert a higher effort on the cardiovascular system to cope with the same mechanical load. Figure 2.

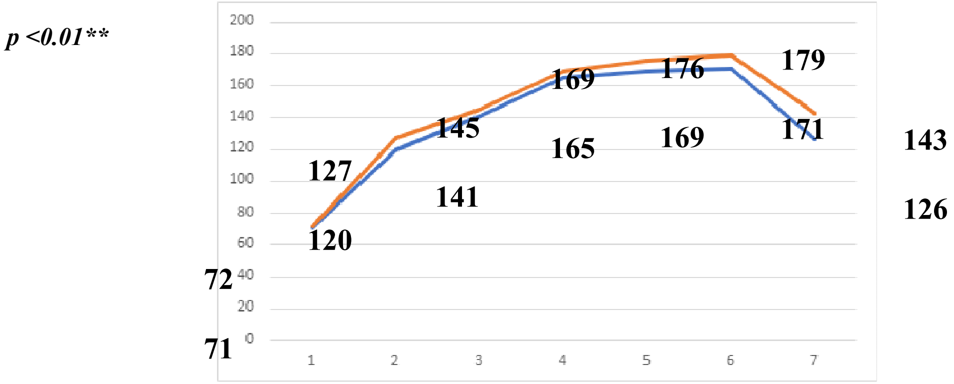
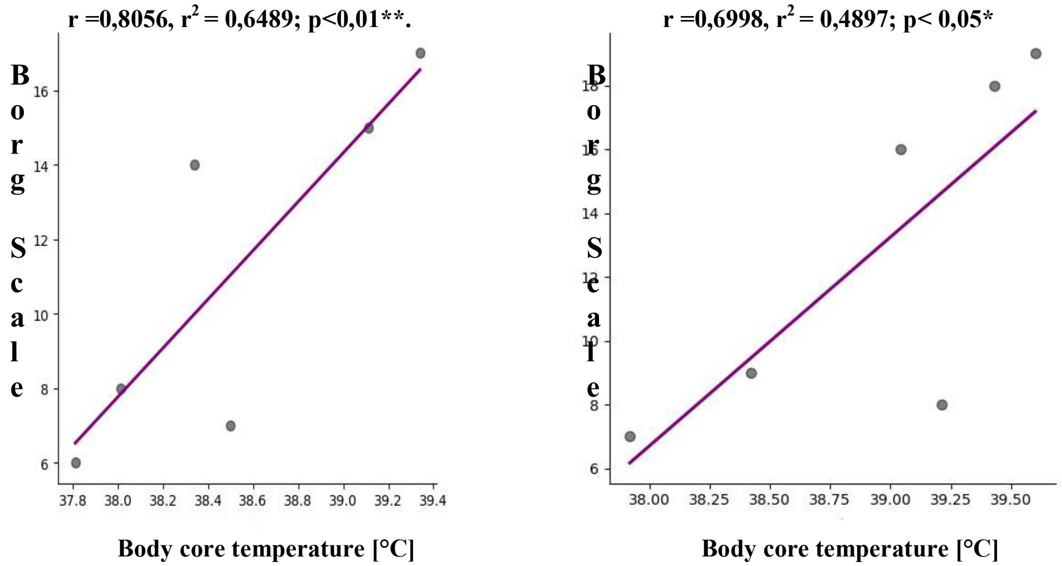


Figure. 2. Comparison of heart rate during measurements in both temperatures.

● 18°C ● 30°C

Level of relationship between subjective feeling of fatigue and body core temperature

There was a high correlation between subjective fatigue and body core temperature at 18°C ($r = 0.8056$, $p < 0.01$**) Figure 3 and a moderately high correlation at 30°C ($r = 0.6998$, $p < 0.05$*). Figure 4.

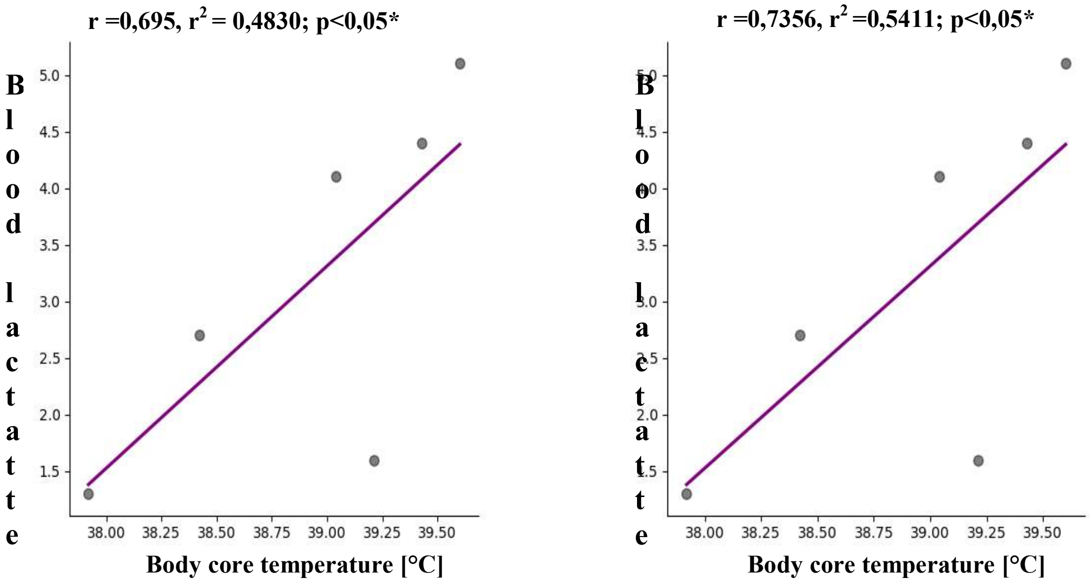


Figures 3 and 4. Relationship between body core temperature and subjective feeling of fatigue when measured in outdoor temperatures of 18°C and 30°C.

In both measurements, we found a positive relationship between the subjective feeling of fatigue and the temperature of the body's core. At an outside temperature of 18°C, we even recorded a higher effect and a higher level of statistical significance. However, this may result in the judgment of the probands, who may have underestimated or overestimated themselves, given that it is still a subjectively determined value. However, the probands also spoke about the significantly greater difficulty of driving in elevated outside temperatures. Driving in low temperatures, the last sections at the anaerobic lactate threshold level were difficult for them. However, when driving in high outside temperature, it was difficult even the start, the preparatory part, the last sections at the anaerobic lactate threshold level, but also the feeling of the ride, where we can see the difference in heart rate higher in the work.

Level of relationship between blood lactate level and body core temperature

Moderately high correlations were found between blood lactate levels and body core temperature at both 18°C ($r = 0.695$, $p < 0.05$*) Figure 5 and 30°C ($r = 0.7356$, $p < 0.05$*). Figure 6.



Figures 5 and 6. Relationship between body core temperature and blood lactate level when measured in an outdoor temperature of 18°C and 30°C.

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Discussion

The aim of our work was to determine changes in the level of body core temperature during the cycling part of the Olympic triathlon. During the ride in two different external temperatures, we noticed significant changes in the temperature of the body's core. Also recorded changes in other physiological performance indicators, such as heart rate or blood lactate. Furthermore, we recorded changes in mechanical performance during the tests, but subjective load also changed during individual sections at different temperatures.

Due to the fact that training in a high outdoor temperature can have the same effect on sports performance as training at altitude, we decided to investigate the differences between training in two different temperatures. Since the 1968 Mexico City Olympics, which took place at over 2,000 meters above sea level, endurance athletes have routinely engaged in altitude training. Prolonged exposure to high altitudes triggers physiological adaptations that can enhance performance in endurance events conducted at sea level. (Rusko, 2004). Although heat training has garnered interest in recent years, it is important to note that, unlike altitude training, there are no clearly established best practice recommendations (e.g., environmental temperature and humidity, duration of exposure). In the context of this review, heat training is defined as the practice of combining heat stress with exercise training, with the specific aim of enhancing adaptations to improve exercise performance in moderate temperature ranges (Corbett et. Al. 2014; Lorenzo, 2010).

When implementing altitude and heat training to enhance temperate, sea-level endurance performance, two key points should be emphasized. First, it is crucial to execute a properly planned and optimally timed training camp without taking any shortcuts. Notably, many studies that have failed to demonstrate performance improvements after heat or altitude training camps may have had insufficient exposure to hypoxia (i.e., inadequate elevation, duration of daily exposure, or total camp duration) or heat stress (i.e., unmeasured or insufficiently elevated core body temperature). Additionally, athletes may not have performed all high-intensity sessions at lower elevations or in temperate conditions. (Reeve et. al. 2017; Schmit , 2018; Chapman, 1998). These factors can limit adaptations to the environmental stressor and, consequently, any enhancement of endurance performance (Duke, 2012). The effectiveness of heat or altitude training camps is also influenced by the timing of their implementation before competition. Notably, the physiological adaptations achieved through acclimatization to either stressor are transient. Therefore, the peak volume of adaptations acquired and the subsequent rate of decay (both positive and negative) upon returning to sea-level temperate conditions will likely have a significant impact on performance optimization.
(Périard, 2015; Chapman, 2014; Daanen, 2018).

Second, for elite athletes aiming to enhance endurance performance, where changes as small as 0.5%–1.0% can significantly impact race outcomes, average and “statistically significant” improvements are less meaningful than an individual athlete’s response to a specific training intervention. Even when heat or altitude training is executed optimally, interindividual variations in hematological, physiological, and performance outcomes still exist (Périard, 2015; Chapman, 1998; Daanen, 2018) and should not be overlooked. Therefore, it is crucial for coaches, athletes, and sports physiologists to recognize that while these training methods may be beneficial for some athletes, others may not experience similar performance gains.

Hypervolemia theoretically enhances V̇O2max by increasing ventricular filling pressures, which in turn raises stroke volume and reduces heart rate response to a given workload (Périard, 2015; Boynton, 2019; Schmit, 2018; Mikkelsen, 2019), potentially improving endurance exercise performance. A study demonstrated that a 6.5% increase in plasma volume after 10 consecutive days of heat exercise sessions led to a 5% increase in maximal stroke volume and V̇O2max in trained male and female cyclists during graded exercise in a temperate environment (Périard, 2015). However, despite significant plasma volume expansion, long-term heat training practices have not consistently resulted in increases in V̇O2max or improvements in temperate endurance exercise performance. (Keiser, 2015).

In summary, although there is some overlap in the physiological adaptations resulting from heat versus altitude training, the primary mechanisms contributing to enhanced sea-level endurance performance in temperate conditions differ. Long-term exposure to a hypoxic environment directly influences hypoxic response elements (i.e., HIF-α) and their downstream targets. This leads to increased hemoglobin mass, which is likely the key factor enhancing aerobic capacity and performance in endurance-trained athletes after altitude training. In contrast, the primary mechanism through which heat training is believed to improve temperate endurance performance is through volume loading from expanded plasma volume. However, this benefit is unlikely for trained athletes without a concurrent increase in hemoglobin mass. While research on alternative mechanisms, such as enhanced skeletal muscle oxidative capacity, shows promise for improving endurance performance in temperate conditions after heat training, it is crucial to conduct carefully planned and controlled studies. Such studies are necessary to detect the potentially small effect sizes in trained endurance athletes. (Gore et. al. 2013).

There are physiological adaptations that occur after only three or four training interventions in the heat. However, for a clear and significant performance benefit, a minimum of 2 weeks of consecutive daily exposure to heat is recommended (Racinais, 2015).

Since adequate thermal stress is essential for adaptive responses, the effectiveness of heat training depends on the magnitude and duration of the increase in core body temperature during exercise. (Racinais, 2015).

Lorenzo (2010) and Périard (2015) emphasize the importance of adapting to specific thermal stresses, highlighting the maintenance of core body temperature around ± 38.5 °C. They suggest that adaptation to thermal stress may plateau over time, potentially limiting long-term improvements in athletic performance under external temperature conditions. To mitigate this, they advocate for progressively increasing thermal stress in consecutive heat training sessions to sustain core temperatures within the optimal range mentioned above.

Boynton (2019) observes that, similar to training at high altitude, the capacity to maintain a consistent training load diminishes as ambient temperatures rise.

Authors Reeve et. al. (2019) and Schmit et. al. (2018), talk about evidence suggesting that performing high-intensity exercise and training in high outdoor temperatures can result in temporary reductions in aerobic capacity and performance.

For another simulation of sports performance enhancement, Gibson et. al. (2020) proposed a training equivalent, the so-called live cool, train cool, acclimate hot. Heathcote et. al. (2018) discusses training interventions in normal outdoor temperatures but discuss the use of other passive heating strategies such as warm water immersion, sauna, or water-filled suits to increase core body temperature to at least 38.5 °C or higher, to at least 30 minutes after training performed in an environment with a moderate outdoor temperature.

Unlike altitude training, the main adaptation following training in high outdoor temperatures is a notable increase in blood plasma volume. Whether this adaptation can be credited with enhancing athletic performance remains a topic of debate (Coyle, 1990; Nybo, 2016). Long-term exercise in high outdoor temperatures significantly enhances skeletal muscle and skin vascular conductance, potentially facilitated by heightened nitric oxide synthase bioactivity (Salgado, 2014).

When core body temperature approaches ±38°C, skin blood flow is restricted by the cardiopulmonary baroreflex, which induces cutaneous vasoconstriction as a defense mechanism to maintain central venous pressure. The decrease in blood pressure and renal perfusion due to combined physical and thermal stress triggers a significant release of aldosterone. This hormone promotes an expansion of blood plasma volume by 4 to 15% above pre-acclimatization levels, typically observed after initial training sessions in high outdoor temperatures (Gonzáles-Alonso, 2008; Karlsen, 2015; Keiser, 2015).

Research by Karlsen (2015) discusses the ability to acclimatize athletes to performance and training in the heat. In this research, 9 trained cyclists completed 2 weeks of thermal acclimatization in a naturally elevated outdoor temperature (34°C) and 18% humidity. On the first, sixth, and thirteenth day, they completed a heat resistance test, and on the second, seventh, and fourteenth day, they completed a 43.4 km cycling time trial. During days 5-6, the concentration of sodium in sweat decreased and the rate of total sweat increased by almost 20%. Furthermore, the resting hematocrit also decreased by almost 6%. However, on the other hand, the mechanical performance in individual heat resistance tests increased. From the first to the second it was 11% and between the second and third there was a 5% improvement. However, the conclusion of this work shows that sudomotor adaptation (nervous system) and hematological adaptation occurred in trained athletes within 5-6 days of training days, while according to the conclusions, the additional improvement in sports performance after the entire period of acclimatization was not related to changes in these parameters.

As mentioned earlier, the main adaptations from altitude training and heat training are centered around physiological responses aimed at coping with reduced oxygen availability (such as increased hemoglobin mass and red blood cell volume) or adjustments in central blood pressure (like expanded plasma volume). (Baranauskas et al. 2021).

Hypervolemia theoretically enhances V̇O2max by boosting ventricular filling pressures, leading to increased stroke volume and reduced heart rate response to a given workload, potentially enhancing endurance exercise performance. (Lorenzo, 2010; James et. al, 2017; Schmit, 2018; Mikkelsen, 2019).

Research conducted by Lorenzo (2010) demonstrated that a 6.5% increase in plasma volume, achieved through 10 consecutive days of training in high outdoor temperatures, resulted in a 5% increase in maximal cardiac output and VO2max. This study involved trained male and female cyclists performing a graded exercise test in a temperate outdoor environment.

However, despite the significant expansion of blood plasma volume, the increase in VO2max and the improvement of performance under moderate endurance loads were not consistently observed during long-term training in the heat (Keiser, 2015).

It is therefore essential that coaches and athletes realize that perhaps these methods can be beneficial for some but may not create a similar increase in performance for others.

Conclusions

In our study, we confirmed our conclusions. We observed that at higher outdoor temperatures, subjects subjectively experienced greater effort during the mechanical performance they had to maintain. Additionally, we noted a significant increase in heart rate at higher outdoor temperatures, leading to a higher level of lactate in the subjects' blood.

We found the relationship between body core temperature and the subjective feeling of exertion to be moderately high. In the lower outside temperature, it was even confirmed to us at the 1% level of statistical significance compared to the higher outside temperature. However, this may result in the judgments of the probands, where they did not have to know what the test would be and could underestimate or overestimate themselves.

We also found the relationship between core body temperature and blood lactate level to be moderately high. At both temperatures, our statement was confirmed even at the 5% level of statistical significance. At a higher outside temperature, the subjects reached anaerobic lactate threshold at the end of 60 minutes even higher than the lactate value at this level of exercise.

In conclusion, we can recommend for practice that when training in high outdoor temperatures is included, it is necessary to monitor the performance and acute responses of the trainees during these trainings to a significantly higher degree than when training in normal conditions. We can also talk about the benefit of this training compared to training at altitude, where these two trainings can have an identical result and impact on sports performance. However, it is again necessary to emphasize the difficulty of such trainings and to pay attention to their exactness. In this case, the use of a body temperature sensor appears to be one of the necessary devices in such a training stimulus.

Conflicts of interest

No potential conflict of interest was reported by the authors.

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