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Cooling during exercise may induce benefits linked to improved brain perfusion.

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Running head: Impact of body cooling during exercise and recovery.

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Abstract:

The aim of this study was to evaluate the impact of using a cooling vest during physical exercise (per-cooling) in humid and temperate conditions ($\approx 22^{\circ}\text{C}$, $\approx 80\%$ relative humidity) on perceptual and physiological responses (tissue oxygenation and heart rate). Twenty physically active men performed twice a 30-min cycling exercise at 70% of their theoretical maximum heart rate with using an activated (experimental condition) and a deactivated (control condition) cooling system in a randomized crossover study. Heart rate and tissue (cerebral and muscular) oxygenation were continuously measured during exercise and recovery, and skin temperature was measured every 10 minutes. Perception of temperature, humidity and comfort were assessed at the end of the recovery period. Results showed a decrease in trunk skin temperature ($p < 0.05$), a faster heart rate recovery and an increase in the concentration of total hemoglobin at the brain level ($p < 0.05$) compared with control condition. Moreover, an improved subjective rating of thermal sensations, wetness and comfort compared to control values ($p < 0.05$) was noted. In conclusion, wearing a cooling vest during submaximal exercise improves perceptual and physiological responses in humid temperate conditions, which may be due to a better blood perfusion at the brain level and a better parasympathetic reactivation.

Keywords: Brain perfusion, Cooling device, Exercise, Per-cooling, Thermoregulation.

Introduction

The human thermoregulation process allows the body temperature to be kept within certain boundaries, even when the surrounding temperature is challenging. During physical exercise, only 20-30% of the chemical energy is used for mechanical muscle work and 70-80% is converted into heat. Exercise-induced increase in body temperature over 40 °C, also known as hyperthermia, may lead to the development of physiological disturbances and/or a decrease of performance levels [1].

Many occupational groups such as athletes and workers (e.g. military populations, farmers, etc) often perform challenging tasks in cold, moderate and hot environments. High body core temperature and thermal stress are due to a combination of metabolic heat production from physical activity, ambient temperature and sometimes protective clothing worn during the activity [2]. The increase in body temperature during exercise can be observed in cold, hot and humid conditions while performing continuous or high-intensity anaerobic exercises [3–5]. The heat produced by prolonged physical activity can reach 4500 to 5000 kJ.h⁻¹. This thermal load is sufficient to increase the body temperature by 1 °C every 5 to 7 minutes [6]. Indeed, the excessive increase of body core temperature during exercise has a negative impact on psycho-physiological functions and exercise performance. Moreover, an elevated body core temperature can lead to the prevalence of higher accidents and injury at work/competitions and can even lead to heat illnesses, such as, heat cramps, heat exhaustion or heat stroke [1].

The exercise-induced hyperthermia is often associated to several physiological impairments and disturbances of body homeostasis. However, the exact physiological mechanisms are still not fully understood. It is well recognized that an increase in body temperature causes central and peripheral physiological perturbations. It has been reported

that thermal load during exercise induces cerebral changes such as a vascular perturbation (decreased cerebral blood flow and cerebral oxygenation), limiting the body's capacity to remove heat from the brain. Also, neurotransmitter perturbations (dopamine/serotonin) are observed during exercise in hyperthermia. All these cerebral perturbations can lead to a reduction in the neural drive to locomotive muscles. Furthermore, other physiological peripheral disturbances may be involved such as changes in muscle metabolism and an increase in cardiovascular strain. Thermal stress induces a redistribution of a considerable amount of blood toward the skin, which subsequently reduces central blood volume and ultimately decreases cardiac output and stroke volume [7,8]. This may compromise blood flow and oxygen delivery to the muscles, and possibly to the brain [9,10]. However, muscle and brain oxygenation have not thoroughly been investigated during prolonged exercise in hot and temperate environments.

Therefore, strategies that can prevent excessive heat stress and reduce thermal strain during exercise are highly important even in temperate environments. Indeed, a decrease in skin temperature is essential to improve working conditions, reduce work stress and prevent the risk of accidents. To achieve these objectives, personal cooling systems have been designed to effectively reduce heat stress brought on by working or training in hot [11] and thermoneutral [12] environments. Cooling during exercise and recovery periods may overcome the physiological and perceptual problems triggered by the exercise-induced hyperthermia. It has been recognized that cooling the skin may attenuate cardiovascular strain [13] by lowering heart rate and decelerating cutaneous circulation. For instance, cooling garments lowered the heart rate significantly and elicited an increased cardiac filling via a cold-induced vasoconstriction of the skin, thus allowing for better maintenance of cardiac

output [14]. In this way, wearing a cooling jacket while exercising would reduce fatigue, physiological strain and perceived stress [15,16].

Furthermore, several studies show that increasing body-cooling during physical exercise (e.g. by using a cooling vest) can prolong its duration [17–20] and promote thermal comfort [12]. Recent meta-analyses and reviews concluded that cooling vests appeared to be the most effective method in performance improvement [17,18,21,22]. Therefore, it was established that wearing a cooling vest is an efficient cooling technique, especially when it covers a relatively large surface of the body [17]. Accordingly, torso cooling was recognized as an efficient technique to reduce physiological strain [15] and improve thermal comfort even in thermoneutral environment [12]. However, the exact physiological mechanism explaining the improvement of physical performance is not yet known [17]. Cooling vests vary according to the type of cooling technique used, namely cold packs [12,23], ice packs [15,24] or a ventilation system [25,26]. It was highlighted that the use of cooling vests involving a ventilation system provided a persistent cooling effect during physical exercise [27] and reduced physiological strain in environments with temperatures ranging from 30°C to 40°C and humidity ranging from 20% to 75% [26].

Based on the fact that the data concerning the effect of cooling during exercise on cerebral and peripheral responses are either lacking or contradictory, this study intends to evaluate the effect of an innovative cooling system based on the combination of a fan system and thermoelectric technology, on skin temperature, perceptual and physiological (cerebral and peripheral) responses. Since the physiological responses to cooling depend on the environmental conditions and that these responses are still unclear in temperate conditions, this study took place under humid temperate conditions.

Subjects and Methods

Subjects:

Twenty healthy and physically active (3-6 hours/week) male subjects (age: 23.6 ± 4.2 years; Weight: 71.6 ± 7.0 kg; Height: 175.1 ± 5.8 cm; BMI: 23.3 ± 2.1 kg.m⁻²) participated in this study on a voluntary basis. After being informed of the experiment objective and all associated risks, they provided their written informed consent prior to the experiment. Participants were asked to refrain from heavy exercise for 24 hours before the experiment; coffee and alcohol were forbidden 12 hours before the experiment. This protocol was evaluated and approved by our local ethical committee (ethical reference code: H20170802) and follows IJSM's ethical standards document [28].

Preliminary test:

During the first visit, the theoretical maximal heart rate ($220 - \text{age}$) was calculated. The heart rate (HR) was monitored continually using a heart rate monitor (Polar RS800CX, Finland). The subjects were asked to pedal on a Monark bicycle ergometer (Monark LC6 Novo, Vansbro, Sweden) at 30 Watts and increase by increments of 30 Watts every two minutes until they reached a target power corresponding to 70% of their theoretical max HR. The same ergometer was used in all experiments and the saddle was adjusted according to the participant's height before each experiment.

Experimental protocol:

Two different cycling tests were performed with a 1-week interval between trials using a randomized crossover design. The control trial was completed using a deactivated cooling

vest (CON) and the cooling vest was activated during the experimental trial (EXP). The two sessions were carried out under humid temperate conditions (temperature $T \approx 22^{\circ}\text{C}$; relative humidity $RH \approx 80\%$). Each subject was tested at the same hour of the day to minimize the effects of the circadian rhythm on the T_c and heart rate [12,29].

The perceptual scale was explained, and then the subject was asked to rest for 5 minutes to obtain baseline measurements. The subjects then cycled 5 minutes at 50% of the target power set in the preliminary test (warm-up) then the power was clamped at the adjusted power, set in the preliminary test, for 30 minutes followed by a recovery period of 5 minutes, comprising 2 minutes of active recovery (50% of exercise intensity) and 3 minutes of passive recovery.

Measurements

Heart rate (HR): HR was assessed continuously during the exercise and recovery phases using a heart rate monitor (Polar RS800CX, Finland).

Body weight: body weight was assessed at baseline and directly after completion of the exercise protocol using a composition analyser (Tanita BC 418 Tokyo, Japan). To ensure similar protocols, participants drank the same volume of water before both tests (EXP and CON).

Skin temperature (St): St was measured for the head, trunk and arms at rest and every 10 minutes during exercise (T_1 , T_2 and T_3) and at the end of recovery (T_4) with an infrared thermal camera (Fluke TIS, Mississauga, Canada). Subjects were instructed to stand in front of the thermal camera palms open and head straight. The image captured from the forehead

and to the upper thighs. SmartView™ was used to analyse the images to assess the mean skin temperature of the head, trunk and arms.

Ventilatory and gas exchanges variables: These variables were recorded continuously throughout the “ON” (EXP) and “OFF” (CON) tests using a METAMAX® 3B spirometer (Cortex Biophysik gmbH, Leipzig, Germany). The device was calibrated before each experiment; the parameters chosen for the analysis were: oxygen uptake (VO_2), carbon dioxide production (VCO_2), respiratory rate (RR), respiratory exchange ratio ($\text{RER} = \text{VCO}_2/\text{VO}_2$), ventilation (VE), and tidal volume (VT).

Cerebral and muscular oxygenation: These variables were measured continuously for the duration of the protocol (rest, exercise and recovery) by near infrared spectroscopy (NIRS) (OxyMon Mk III, Zetters, The Netherlands). NIRS is a non-invasive optical imaging technique whose principle is the absorbance of light at different wavelengths, by oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb). Based on the absorbed amount of light, oxy-Hb and deoxy-Hb concentrations can be calculated either at the cerebral or muscular level [30]. For cerebral oxygenation, the probes were attached to the left side of the forehead. The distance between the probe and the detector was set to 4 cm [31] and for muscular oxygenation, light transmitting and receiving optodes were connected and positioned longitudinally on the medial axis of the vastus lateralis (VL) ~10 cm above the knee joint [32]. To prevent movement and outer sources of light from disturbing the signal, an elastic bandage was wrapped around the optodes. Affixed in this way to the cerebral and muscular sites, this device provided concentration changes ($\Delta\mu\text{mol/L}$) in oxygenated (O_2Hb), deoxygenated (HHb) and total (THb) hemoglobin and the difference between $[\text{O}_2\text{Hb}]$ and $[\text{HHb}]$ ($[\text{diffHb}]$) as well as the tissue oxygenation saturation index ($\text{TSI} (\%)$), which reflects

the amount of oxygen saturation independent of blood volume changes in cerebral/muscular tissue [33]. NIRS data were collected at one-second intervals continuously at a rate of 10 Hz.

Subjective rating of thermal sensation, comfort and wetness: These variables were estimated after the end of the recovery period. Participants were asked to provide their overall perception throughout the exercise and recovery. Rating scores for thermal perception ranged between - 6: very cold and 4: hot; for comfort, ratings ranged from - 6: very uncomfortable to 4: comfortable; for wetness, it ranged from - 6: wet to 4: dry [34]. Thermal and wetness sensation are reported to be good markers for determining the effectiveness of a cooling system intended for real workplace [35].

Rating of perceived exertion: This rating was assessed every 10 minutes during the cycling exercise using the 10-point BORG scale, in which 0 corresponds to rest ("no effort") and 10 maximal exertion [12,36].

Cooling system:

In the two test conditions, "ON" (EXP) and "OFF" (CON), participants wore a Mawashi Advanced Personal Thermoregulation System (Mawashi Science & Technology, Canada). The hybrid system consists in a combination of two cooling systems. The first is a fan that evaporates perspiration and evacuates excessive heat; the second is a controllable thermoelectric module. It transmits heat or cold by conduction, depending on the user's preference. This device reaches its maximum efficiency when both systems are simultaneously active, creating a controllable microclimate regulator. The cooling vest was worn in contact with the skin because the equipment specifications indicated that heat loss is greater when no T-shirt is worn under the vest (without t-shirt $Q = 180 \text{ W} \cdot \text{m}^{-2}$ vs. with t-shirt

$Q = 120 \text{ W} \cdot \text{m}^{-2}$) [37]. Consequently, the tests were conducted with subjects wearing the vest in direct contact with their skin.

Statistical Analysis:

Standard statistical methods were used for the calculation of means and standard deviations. Gaussian distribution of the data was verified by the Shapiro–Wilk test and homoscedasticity by a modified Levene’s Test. The compound symmetry, or sphericity, was checked by the Mauchly’s sphericity test. When the assumption of sphericity was not met, the significance of F-ratios was adjusted according to the Greenhouse–Geisser procedure when the epsilon correction factor was < 0.75 , or according to the Huynh-Feldt procedure when the epsilon correction factor was > 0.75 . On each physiological measure, we performed a two-way analysis of variance with repeated measures (ANOVA: Condition (ON/OFF) \times Time). Multiple comparisons were made with the Tuckey post- hoc test. We also realized student T test to perform comparison between condition for perceptual response, temperature and for T30, T60 and T120. The significance level was set at $p < 0.05$ for all analyses. Moreover, we also estimated during the recovery period the parasympathetic reactivation, using T30, T60 and T120 indices. For example, the heart rate recovery (T30) represents the regression line between the natural log of heart rate and elapsed time from the first 30 seconds after exercise. This index gives an idea of heart rate recovery state between the 10th and 40th second following the end of the exercise [38].

Results

A lower skin temperature at the trunk level was found at the end of the exercise and recovery period when the cooling vest was “ON” ($p<0.05$). No difference between test conditions was observed for the head and the arms. All skin temperature data are presented in Table 1. We did not observe any difference in body weight between the two conditions ($p>0.05$). The body weight was 71.8 ± 7.3 kg before the two experimental sessions. After the experimental exercise in “ON” condition the body weight was 71.3 ± 7.4 kg and 71.3 ± 7.3 kg after the “OFF” condition.

For the perceptual responses, a significant lower thermal sensation score, lower score of perception of humidity and greater thermal comfort were observed when the cooling vest was “ON” compared to the “OFF” condition ($p<0.05$). No differences in RPE were found whether the vest was “ON” or “OFF” (Figure 1).

Concerning the oxygen consumption and ventilatory responses, a main effect during the time of the experiment ($p<0.05$) was observed, but no difference was noted between the tested conditions (Figure 2).

Regarding heart rate response, we found no differences between the tested conditions during the exercise phase, but we found a faster heart rate recovery (T30) when the vest was “ON” ($p<0.05$) (Figure 3). Nevertheless, we also estimated during the recovery period the parasympathetic reactivation, using T30, T60 and T120 indices. At T 30, we were able to show that the parasympathetic reactivation was stronger in the “ON” than in the “OFF” condition.

The results concerning muscular and cerebral oxygenation are presented in Figures 4 and 5. We found for all measures a main effect of time ($p<0.05$). However, no differences between the tested conditions for all muscular responses were noted. Interestingly, we found a significant interaction between the tested conditions and time for cerebral ThB ($p<0.05$)

during exercise. A significant increase in ThB in the “ON” condition was found starting from the 20th minute of the exercise until its end whereas the ThB in “OFF” condition stayed stable during the same period.

Discussion

The aim of this study was to examine the use of a cooling vest, in particular, its effect on perceptual and physiological responses during submaximal exercise and recovery in humid temperate conditions (temperature $\approx 22^{\circ}\text{C}$; humidity $\approx 80\%$). The most important findings are that wearing a ventilated cooling vest during exercise and recovery under temperate conditions (1) improved perceptual sensations of temperature, comfort and humidity, (2) accelerated the heart rate recovery (3) decreased the trunk skin temperature at the end of the exercise phase and during recovery and (4) enabled a better cerebral perfusion. A growing body of literature has studied the effectiveness of cooling vest in a hot environment. However, our study is the first to test this kind of cooling vest in temperate condition and to investigate its impact on perceptual and physiological responses and particularly on muscular and cerebral oxygenation.

The type of cooling vest used in this study involves a ventilation system. It seems that this type of cooling system is an effective strategy for the dissipation of heat during physical work by enhancing sweat evaporation [26]. This vest may procure more comfort during exercise and recovery than an ice vest, which has been known to cause discomfort and produce severe cooling with a risk of erythema [39]. Hence, a ventilated vest could have a beneficial effect on the reduction of physiological strain during exercise and post-exercise recovery [40] by increasing sweat evaporation and decreasing the levels of thermal and cardiovascular stress [41,42].

First, the present study demonstrated that wearing the activated cooling vest significantly reduces trunk skin temperature at the end of the exercise and during recovery, while the temperature of the arms and head were not affected as shown by previous works [37,43]. These results were expected since the evaporative function was effective on the torso area [37]. According to a previous study [27], the local regions where the air ventilation fans are placed experienced the highest cooling effects in comparison with other local regions. In addition, the reduced skin temperature of the trunk can be explained by the great vascularization of this zone. Indeed, its exposure to cold makes it possible to cool substantial amounts of blood [44]. However, the reduction in skin temperature at the torso level in our setting was not able to induce a global skin reduction. Our results were consistent with those observed in a previous study conducted in temperate conditions (25°C). This study demonstrated that the use of a cooling vest significantly decreases skin temperature at the chest level during a 5-km time trial [12]. This result is very interesting since the relationship between cooling and skin temperature is not clear [17]. Indeed, skin temperature is a strong factor influencing perceived sensations and the level of exertion rather than core temperature [45]. Since thermal sensation could have an impact on physiological functions [46], the perception of thermal stress plays a major role in human behavioral thermoregulation and possibly exercise performance [2].

It is well known that thermal sensation rises during exercise proportionally to the increase in metabolic heat production. Cooling the skin was proposed to be a suitable solution to improve thermal sensations in participants [1]. The cooling vest used in the present study consists of active cooling (ventilation) known to stimulate heat loss and provide a feeling of freshness [40]. Additionally, the chest and back are two large body areas sensitive to cold. Cooling these body areas through a cooling vest can result in improved thermal sensation [12,47]. Therefore, participants felt cooler and drier when wearing the activated cooling vest

compared to the control condition in which the vest was deactivated. The improved thermal sensation rating may be explained either by the capacity of the ventilated vest to enhance the sensation of cooling, or by the large sensitivity of the chest to cold [48]. Indeed, it has been proposed that exposure of the cutaneous cold receptors to a cold stimulus lowers the perception of thermal sensation [46]. Our results were consistent with previous investigations using ventilated-ambient air cooling during exercise and recovery [26,42,49]. It should be noted that previous studies were mainly conducted in hot conditions. They suggest that air-cooling improves comfort and reduces heat strain either in sports [50] or military work [25]. However, we did not observe any difference in perceived exertion between the two tested conditions “ON” and “OFF”. RPE increases during exercise, however the cooling vest was ineffective to reduce it, as found in a previous study conducted in temperate conditions (25°C) [12]. Likewise, other studies reported that the use of a ventilated vest does not affect the rating of perceived exertion under different ambient conditions [37,42]. Similarly, wearing a cooling vest has been reported to be ineffective in reducing perceived exertion during cycling even in warm and humid conditions [15,43]. This finding may be explained by the fact that the rating of perceived exertion depends largely on the intensity of the exercise [40,51], which was constant in the present protocol.

In agreement with the results of RPE, we found that the activated vest had no effect on oxygen consumption nor on ventilation. A recent study conducted in the same environmental conditions as the present study found that mild body cooling during moderate exercise did not induce a change in oxygen consumption during exercise [52]. Likewise, these results were consistent with previous studies using a cooling vest in hot conditions [39,43].

Reduced skin temperature and perceptual responses during this study were associated to improved physiological responses. The present study showed that wearing an activated cooling vest did not change the average heart rate during exercise but allowed a faster

recovery of heart rate compared to the control conditions. The results are contradictory concerning the impact of the cooling vest on heart rate responses [17]. The lack of heart rate reduction during exercise has been demonstrated in previous studies using cooling vests [39,53]. It was suggested that the superficial cooling as used in the present study was not useful in reducing cardiovascular strain [1]. Most studies which reported a decrease in heart rate during exercise were systematically conducted in extreme environments in terms of temperature and humidity [24,37,54]. Thus, our results were in agreement with previous studies reporting no beneficial effect of the cooling vest on heart rate changes during exercise [15,39]. However, a slight decrease of HR at the end of exercise and during recovery was observed.

Mechanisms underlying the faster recovery of the heart rate after exercise with cooling vest are well described. A previous study using a cooling vest during recovery [55] indicates that the reduced heart rate might be explained by the peripheral vasoconstriction produced by skin-cooling, which may lead to an increase in central blood volume [52] and a reduction in heart rate [39,56]. However, we found no decrease of heart rate at the end of the exercise phase. Another explanation for reduced heart rate during recovery is an enhanced parasympathetic response. Skin-cooling may allow a better parasympathetic reactivation after exercise [57]. The thermal sensation could also have an impact on the central nervous system and have a positive impact on the cardiac autonomic control of the heart due to a better parasympathetic activation. Our results suggested that the reduced thermal strain during exercise and recovery while wearing cooling vest was associated with an accelerated heart rate recovery.

Currently, the effect of cooling on tissue oxygenation is not known. To the best of our knowledge, this study is the first to examine the effects of wearing a cooling vest on cerebral (prefrontal cortex) and muscular oxygenation. Regarding cerebral oxygenation changes, we

observed a significant increase in the relative concentration of total hemoglobin when the cooling vest was functioning. Skin-cooling, achieved by wearing a cooling vest, has been reported to reduce the blood flow in the skin [58], owing to peripheral vasoconstriction and a stimulation of the sympathetic nervous system. Hence, blood flow may be redirected from the skin to the central organs, such as the brain [59], thereby influencing the cerebral blood flow. It should be noted that the NIRS signals depend on blood flow changes in the skin [60,61]. A previous work [31] reported a strong correlation ($r=0.71$, $p=0.009$) between changes in cerebral oxygenation and forehead skin blood flow changes when applying facial cooling during a moderate-intensity steady-state cycling exercise (60% HR max). That same study concludes that NIRS signals are strongly influenced by thermoregulatory changes in skin blood flow. This finding was confirmed by another study [62], which examined the changes in cerebral oxygenation under different environmental conditions. Those authors concluded that prefrontal cortex oxygen saturation (TSI) was maintained in cold conditions (18°C), but declined in hot conditions (40°C). Accordingly, applying cooling during exercise may increase central blood volume, resulting in increased cerebral blood flow and cerebral oxygen availability. These results are of utmost importance since the decrease in cerebral oxygenation could be associated to central fatigue leading to decrease in physical performance. Concerning muscle oxygenation, the lack of significant results is in accordance with the results on oxygen consumption and perception of exertion. Our study being the first to assess the impact of wearing cooling vest during exercise on muscle oxygenation, further studies are warranted in this area. Moreover, we did not observe any positive effects due to the use of a cooling vest on metabolic system associated with the perception of exertion.

Our results do not refer to fluid loss since the cooling vest did not seem to have any impact on body weight. A previous study demonstrated that fluid loss remained unchanged while wearing a cooling vest during a cycling exercise at 60% of maximal power output until

exhaustion in hot conditions [23]. Likewise, another work [12] conducted in the same environmental conditions as the present study, reported that fluid loss was unaffected by the cooling vest. The lack of fluid loss while wearing the cooling vest may be explained by the fact that the vest's insulation might be preventing the appearance of sweat.

Limitations.

The lack of change in some variables (such as metabolic changes and tissue oxygenation) is probably due to the moderate ambient conditions (about 22°C) under which our subjects performed the cycling exercise. Moreover, the majority of the previous studies used higher intensity exercises (maximal exercise vs submaximal exercise in the present case) which may also influence the responses. A previous study mentioned that the cooling capacity effects of the cooling vest are more pronounced in higher heat loads [12]. In the same way, precooling studies demonstrated that cycling performance and thermoregulatory responses were enhanced in environmental temperature of 30°C, but not in environmental temperature of 25°C [15,58,63].

Also, rectal or tympanic temperature were not determined in our study. However, our hypothesis was that reduced skin temperature and thermal sensations have a direct impact on physiological responses as expressed by Cheung et al [2]. We also have estimated the subjective feelings of thermal sensation, comfort & wetness at the end of the recovery period and this could be presented as a limitation of our work since subjects may forget their perceived sensation during exercise and gave their feeling at the end of the recovery period, only.

Conclusion

Wearing a cooling vest during submaximal exercise under humid temperate conditions ($\approx 22^{\circ}\text{C}$, $\approx 80\%$ relative humidity) improves thermal comfort by reducing the perceptions of temperature and humidity and by enhancing a general sense of well-being. The use of such garment should therefore be considered in the context of physical exercise (sport and occupational activities) but also in the context of pathologies, e.g. for multiple sclerosis patients [64]. Regarding physiological responses, this personnel-cooling vest seems to reduce the trunk temperature during exercise and recovery and to allow greater cerebral perfusion and a faster heart rate recovery. Further studies are warranted to investigate the underlying mechanisms of the improvement of cerebral oxygenation while wearing a cooling vest and to examine whether cognitive capacities can be affected.

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Figure captions:

Figure 1: Perceptual responses during exercise and recovery for perceived exertions (RPE), thermal sensation, thermal comfort and wetness. *Significant difference between conditions ($p < 0.05$). T1: 10 minutes after the start of the exercise, T2: 20 minutes after the start of the exercise, T3: 30 minutes after the start of the exercise.

Figure 2: Oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), ventilation ($\dot{V}E$) and respiratory exchange ratio ($RER = \dot{V}CO_2 / \dot{V}O_2$) at baseline, exercise and recovery. The dash lines represent the end of the exercise period and the beginning of the recovery period.

Figure 3 : Heart rate at baseline, during exercise and recovery. * significant difference between condition ($p < 0.05$).

Figure 4: Concentration changes ($\Delta\mu\text{mol/L}$) in muscular saturation index of oxygenation (TSI (%)) and in total (THb), oxygenated (HbO_2), deoxygenated (HHb), muscular hemoglobin at baseline, exercise and recovery. The dash lines represent the end of the exercise period and the beginning of the recovery period.

Figure 5: Concentration changes ($\Delta\mu\text{mol/L}$) in cerebral saturation index of oxygenation (TSI (%)) and in total (THb), oxygenated (HbO_2), deoxygenated (HHb), cerebral hemoglobin at baseline, exercise and recovery. * significant difference ($p < 0.05$). The dash lines represent the end of the exercise period and the beginning of the recovery period.

Table caption:

Table 1: Skin temperature (°C) of the trunk, arms and head at baseline, every 10 minutes during exercise (T1, T2 and T3) and during recovery (T4).

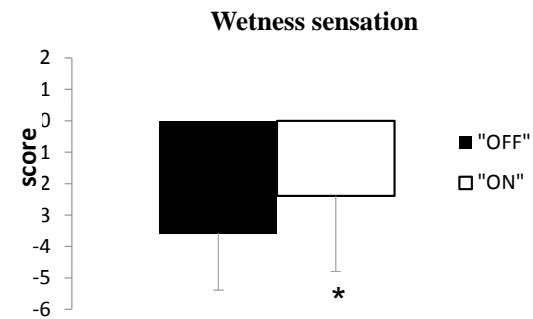
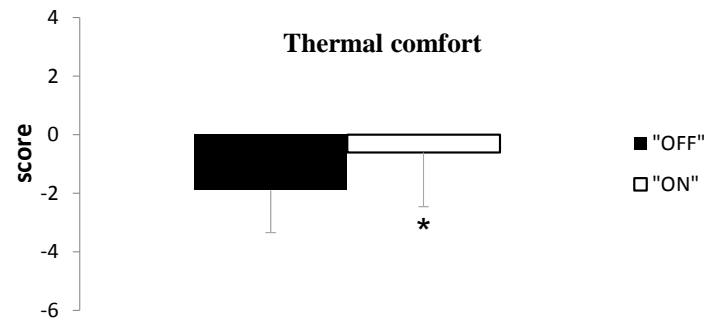
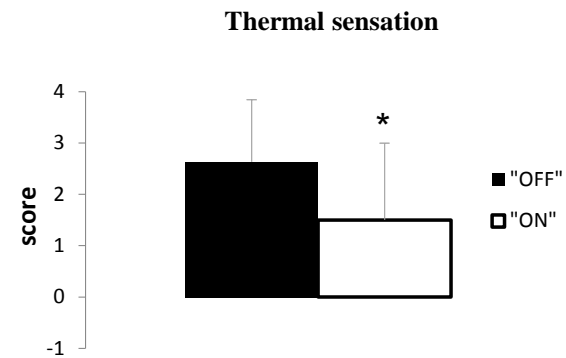
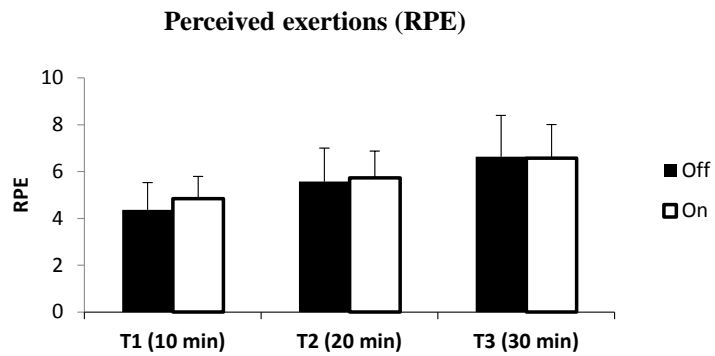


Figure n°1: Perceptual responses during exercise and recovery for perceived exertions (RPE), thermal sensation, thermal comfort and wetness. *Significant difference between conditions ($p < 0.05$). T1: First 10 minutes, T2: Second 10 minutes, T3: Third 10 minutes of the exercise.

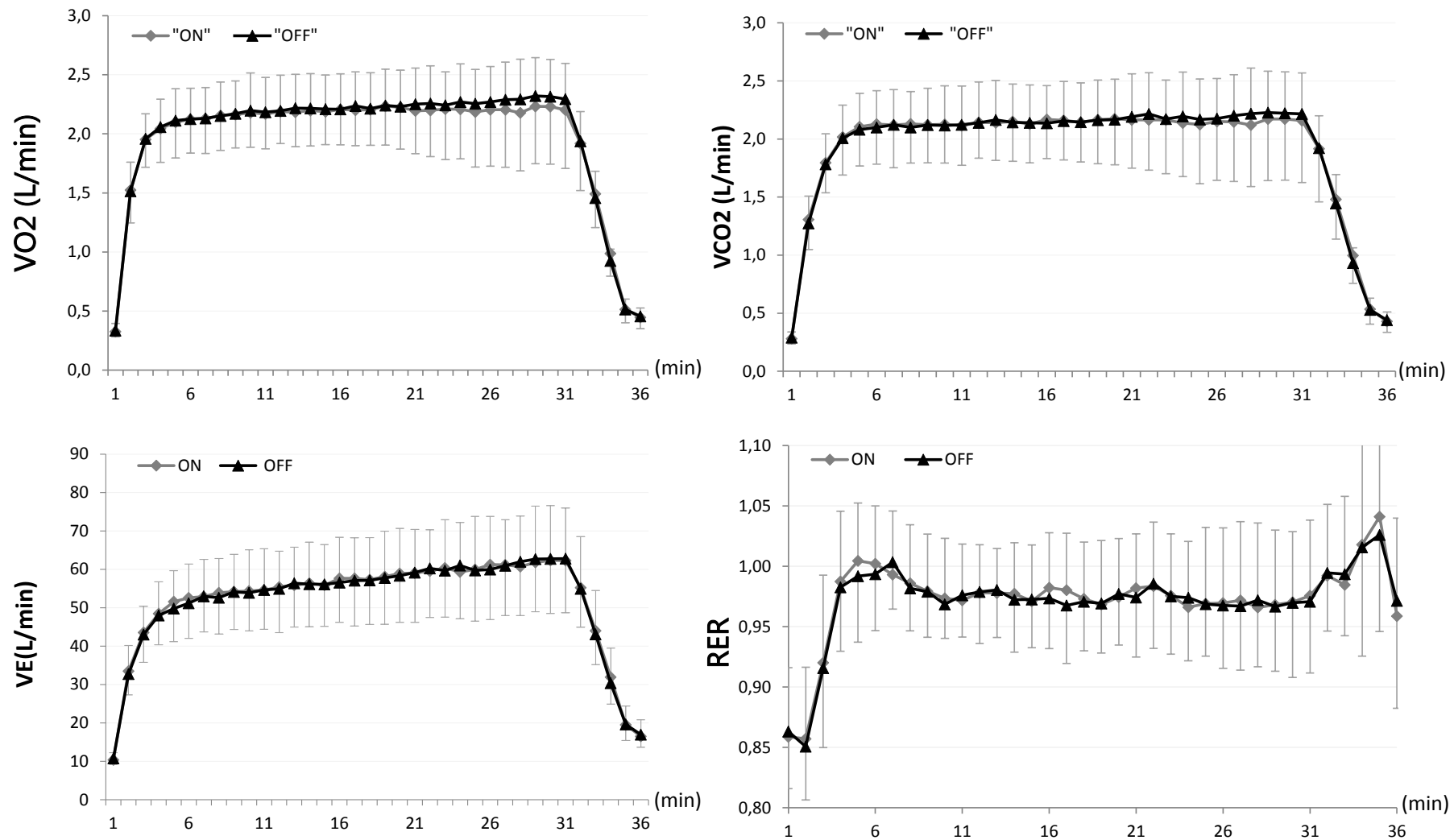


Figure n°2: Oxygen uptake (VO₂), carbon dioxide production (VCO₂), ventilation (VE) and respiratory exchange ratio (RER= VCO₂/VO₂) at baseline, exercise and recovery.

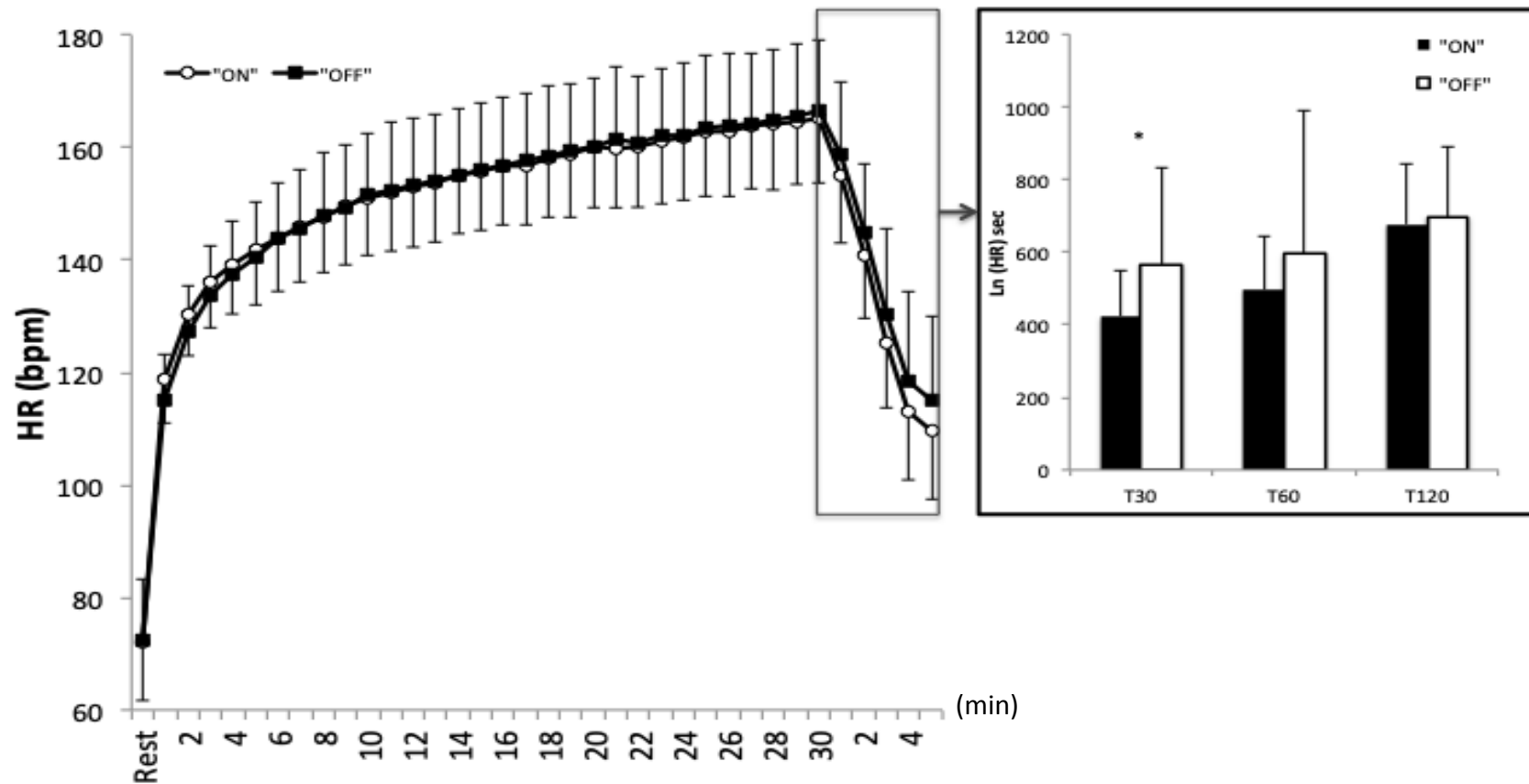


Figure n° 3 : Heart rate at baseline, exercise and recovery. * significant difference between condition (t30) ($p < 0.05$).

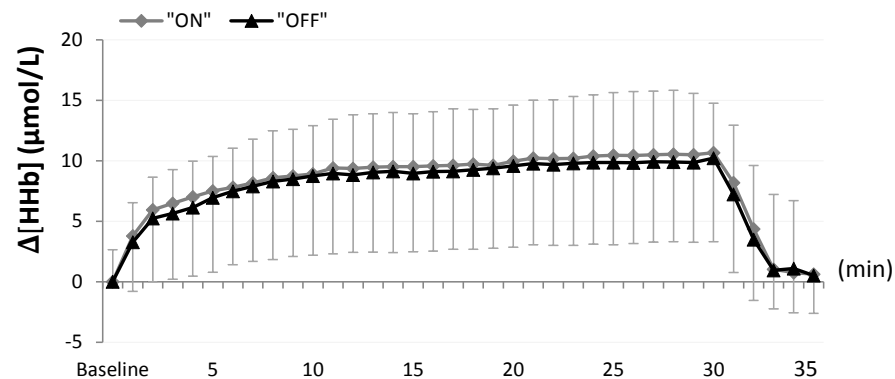
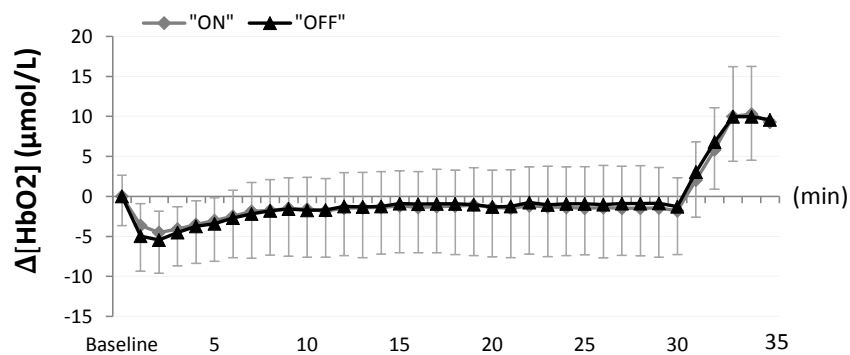
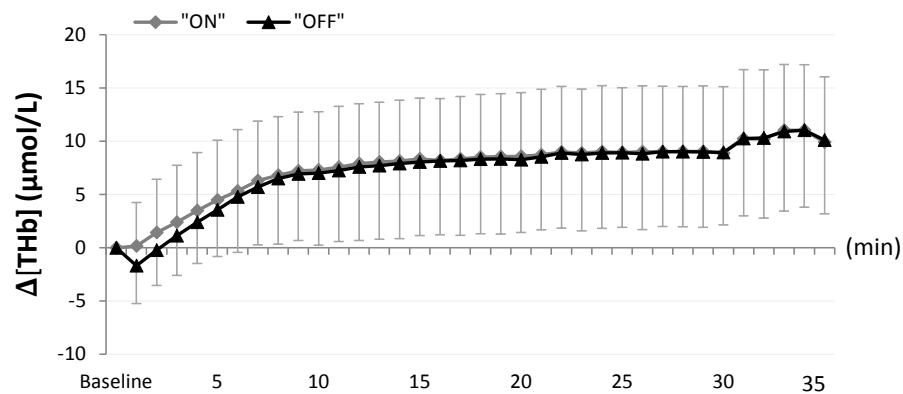
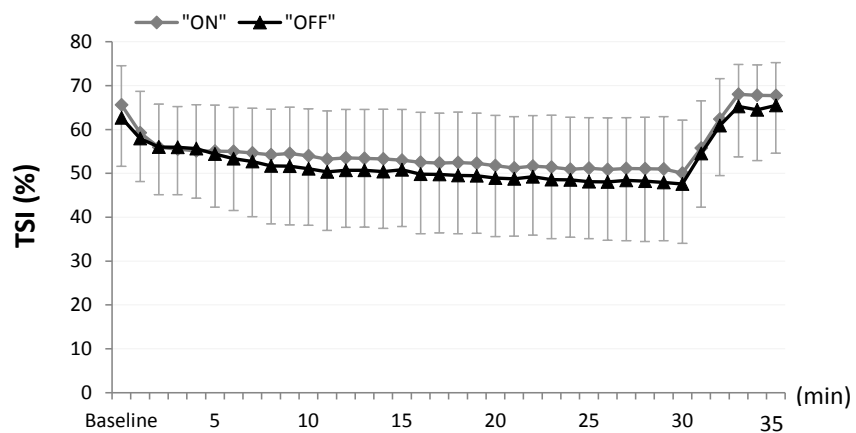


Figure n°4: Concentration changes ($\Delta\mu\text{mol/L}$) in muscular saturation index of oxygenation (TSI (%)) and in total (THb), oxygenated (HbO₂), deoxygenated (HHb), muscular hemoglobin at baseline, exercise and recovery.

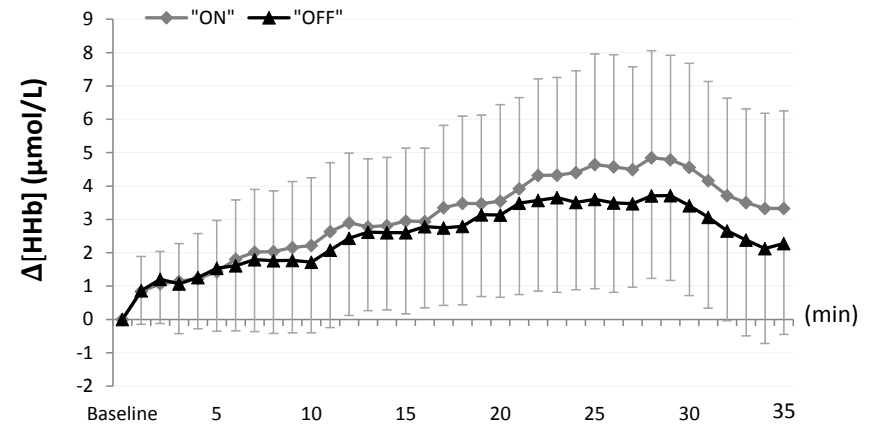
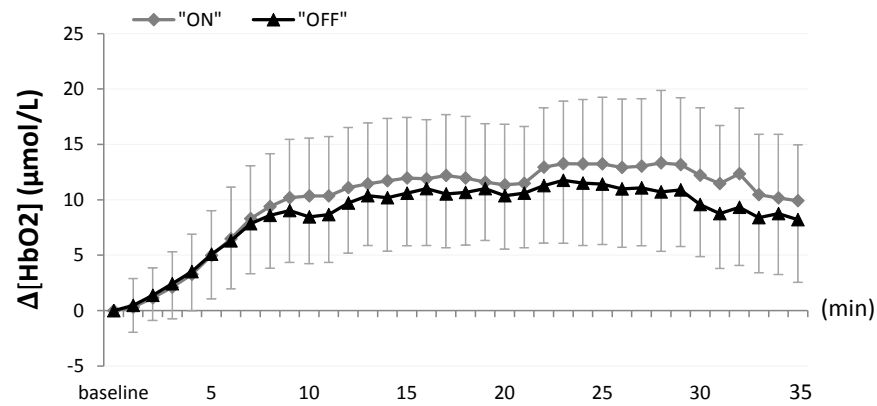
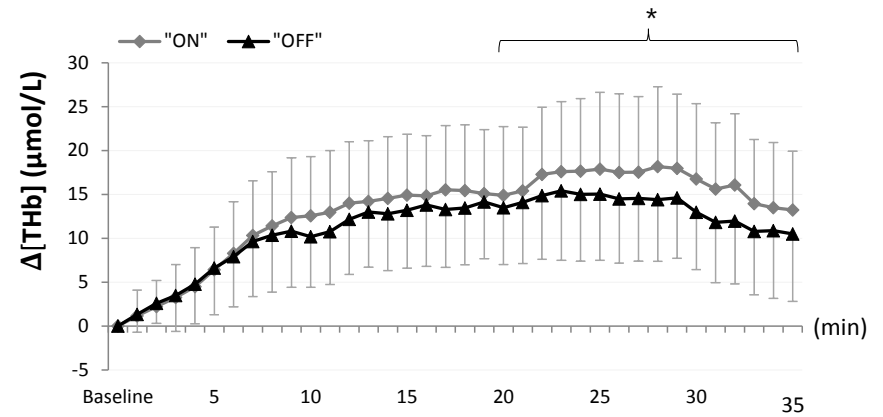
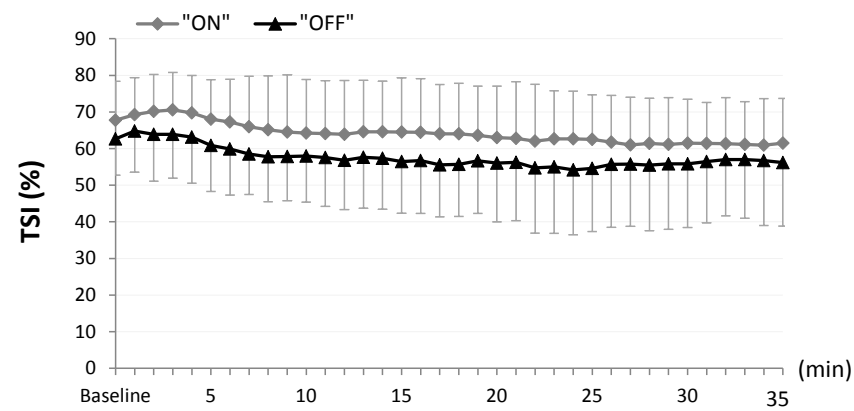


Figure n°5: Concentration changes ($\Delta\mu\text{mol/L}$) in cerebral saturation index of oxygenation (TSI (%)) and in total (THb), oxygenated (HbO₂), deoxygenated (HHb), cerebral hemoglobin at baseline, exercise and recovery. * significant difference between condition ($p < 0.05$).

Table 1: Skin temperature (°C) of the trunk, arms and head at baseline, every 10 minutes during exercise (T1, T2 and T3) and during recovery (T4).

Skin temperature (°C)	Baseline		T1		T2		T3		T4	
Trunk “OFF”	31.6±1.8	ns	31.5±1.4	ns	31.8±1.7	ns	31.9±1.6	*	31.6±1.3	*
Trunk “ON”	31.5±1.7		31.4±1.6		31.5±1.9		30.9±1.5		30.9±1.1	
Arms “OFF”	33.9±1.7	ns	32.9±1.1	ns	33.6±1.4	ns	33.8±1.5	ns	33.6±1.1	ns
Arms “ON”	33.8±1.4		33.1±1.5		33.7±1.6		33.7±1.3		33.5±1.0	
Head “OFF”	32.6±1.5	ns	33.2±1.4	ns	33.4±1.5	ns	33.4±1.6	ns	33.4±1.4	ns
Head “ON”	32.4±1.4		33.3±1.4		33.4±1.5		33.2±1.2		33.1±0.9	

ns: non significant, * significant (p<0.05)