Physiological Impact of Personal Protective Equipment in Distinct Thermal Environments

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Abstract. Chemical, biological, radiological, and nuclear (CBRN) military teams face extreme conditions due to the hazardous nature of their work and the characteristics of personal protective equipment, which can cause a rapid and dangerous increase in vital physiological parameters in hot climates. This study investigated the physiological impact of personal protective equipment in distinct thermal environments (high vs ambient). A sample of Military Academy students, with characteristics similar to members of CBRN teams, performed a 30 min physical protocol while wearing personal protective equipment. The primary aim was to analyse the variation of physiological parameters (core temperature, skin temperature, and heart rate) and subjective perceptions of thermal stress (thermal sensation, thermal comfort, perception of skin moisture, and rate of perceived exertion) in military personnel. The data was analysed using various descriptive statistical methods, combined with adequate statistical inference techniques considering non-parametric statistical methods for hypothesis testing development. The results demonstrated that personal protective equipment use exacerbates thermal strain, particularly in hot environments, leading to increased core and skin temperatures, as well as heart rate. The perception of thermal discomfort and skin moisture also increased in warmer conditions. Particularly, male participants tended to report feeling warmer, less comfortable, and experiencing more skin moisture at ambient temperature compared to females. It is concluded that understanding the impact of personal protective equipment under varying thermal conditions is crucial for preventing adverse clinical situations and optimizing the safety and performance of military personnel in risk scenarios. The implemented protocol may also be valuable in assessing the adaptability to different environments in admission tests for CBRN teams.

Keywords: CBRN · physiological impact · thermal perception · non-parametric analysis

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1 Introduction

Environmental conditions can be predictably extreme and severe, such as deserts, polar, alpine regions and deep oceans. However, even under normal habitat conditions, individuals may be exposed to transient, life-threatening extreme conditions due to daily work activities. Exercising/working in the heat has been shown to impair the ability to effectively regulate body temperature and may lead to decreased performance but also lead to possible injury or death [1].

Indeed, chemical, biological, radiological and nuclear (CBRN) military personnel are exposed to these types of extreme working conditions, due not only to the dangerous nature of the work (permissive, uncertain and hostile), but also to the characteristic of protective clothing, which causes a rapid and dangerous rise in vital physiological parameters in hot climates up to 45 °C [2].

Thus, CBRN threats are extremely dangerous to human life and rapid remediation actions are crucial to save lives, after an incident occurs. Mitigation responses are usually made by deploying military personnel to scenarios of extreme risk to human life, which require high-safety procedures. The response process usually includes: reconnaissance of the affected area, initial detection of the agent, sample collection, decontamination, first aid, medical evacuation, among others. One of the common aspects to all stages of the response process is the use of personal protective equipment (PPE), which may disturb the proper functioning of the human physiological systems.

1.1 Physiological Impact of Personal Protective Equipment

Whether in CBRN war scenarios or CBRN incidents of an accidental or deliberate nature, the military personnel in these teams present an additional risk associated with the use of PPE. The specificity of this equipment causes challenges in the regulation of body temperature through the increase of the energy cost of exercise as well as the reduction of movement efficiency.

Furthermore, the thickness of the PPE limits evaporation which does not allow correct heat loss and can lead to fast and unpredictable fatigue states. The prevention of extreme clinical situations such as: heat stroke, hyperthermia are fundamental in these cases thus ensuring the efficiency of the mission and health of the soldiers.

1.2 Thermoregulation and Thermal Perception

Heat balance can be affected by a number of external factors such as ambient environment, protective equipment and clothing, intensity and duration of the work, but also by internal factors as body composition, and degree of acclimation [2, 3].

Humans' thermal regulation system and the thermal perceptions depend on the proper functioning of the thermal receptors and the transmission of that information to the brain. These thermoreceptors are found along the surface of the skin and send inputs from cutaneous temperature to the brain [4].

The assessment of thermal perception is based on a subjective assessment, but do not always convey a direct relationship with the environmental conditions [5]. In this sense, in order to have a more complete assessment of the thermal perception one of the

options is to apply scales that measure different thermal perceptions. These perceptions regarding thermal sensation and thermal comfort should be analysed at the same moment during the protocols [4, 6].

2 Objectives and Methods

2.1 Objectives

The primary aim was to analyse the variation of physiological parameters (core temperature, skin temperature, and heart rate) and subjective perceptions of thermal stress (thermal sensation, thermal comfort, perception of skin moisture, and rate of perceived exertion) in military personnel.

2.2 Description of the Protocol

All participants were instructed to hydrate with 45 ml of water per kg of body weight during the 24 h prior to the protocol. The experimental protocol consisted of 3 consecutive exercise cycles with a total of 30 min, conducted in two environmental conditions of 18,28 ± 0,7 °C (ambient temperature) and 26,92 ± 0,7 °C (high temperature). The test begins with the participant standing facing a 5 kg sandbag placed on the floor adjacent to a wall. Upon the "start" command, the individual must: Lift the sandbag and touch a pre-marked wall target at 1 m height, carry the sandbag while walking 5.7 m in a straight line to the opposite wall, repeat the touch maneuver with an identical 5 kg sandbag and wall marker. This sequence constitutes one complete repetition, performed continuously for 4 min (Exercise 1) following a metronome-paced rhythm of 6 beats per minute (primary movement cues) 13 sub-beats between main beats (providing intermediate timing reference), followed by 1 min rest for subjective assessments. Each metronome beat requires the participant to complete one wall touch with the sandbag, maintaining strict synchronization throughout the testing period.

After, participants performed step exercise for 4 min (Exercise 2), at 15 cycles/min, completing full step ascents and descents with each auditory cue, and an additional 1 min of rest, followed by a final 4 min recovery period after the 3 consecutive exercise cycles (Fig. 1). Exercises were performed with personal protective equipment (PPE) and followed metronome-controlled rhythms.

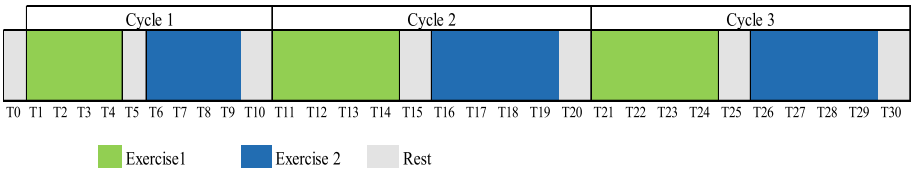

Fig. 1. Description of the protocol

2.3 Physiological Responses to Heat Stress

Core Temperature

The temperature in the abdominal area is representative of the Core Temperature (CT) of the trunk [7]. This measurement is done using a reduced size sensor, which after ingestion, travels throughout the digestive system. During its course, the temperature varies depending on its location, which is higher in the areas near blood vessels and organs with higher metabolism and lower in the areas of abdominal walls [8]. The interpretation of the values is contingent on the time elapsed since the ingestion and the speed of the subject's gastrointestinal transit, reflecting different thermal patterns in different parts of the digestive system [8]. CT was assessed by the E-Celsius performance capsule, consisting in a telemetric system for continuous gastrointestinal temperature monitoring.

Skin Temperature

Skin Temperature (ST) can vary in a much wider range than that of the deep tissues of the body. While in hot environments the ST tends to be uniform throughout the body, in cold environments the extremities of the body tend to have a lower temperature than the torso and head [9].

ST is influenced by thermal exchanges as conduction, convection, radiation and evaporation on the surface, the variation in blood flow and temperature of arterial blood arriving at a particular area of the body [10].

During actual exercises, the military will be continuously monitored using the PLUX Biosignalsplux Integrated System. The collected signals will include 2 sensors for ST which were developed for research applications where it can be used to measure corporal or ambient temperatures. The sensor produces an accurate analog output signal with short response times to temperature alterations.

Heart Rate

Heart Rate (HR) is influenced by both branches of the autonomic nervous system however, it also depends on the endocrine system, whereas specific hormones contribute to the reabsorption of water for the regulation of blood pressure [11].

The relationship between the increase in HR and the increase in internal temperature is known as the cardiac response to temperature, measured in beats.min^{-1} ºC^{-1} [12]. Furthermore, the individual variations play a crucial role, as they are influenced by the exercise mode, as well as by the origin of the heat stress, in this case exogenous (climatic conditions) or endogenous (metabolic) factors [13]. HR was monitored throughout the test (Polar H10; Kempele, Finland).

Rate of Perceived Exertion

The rate of perceived exertion (RPE) is an indicator that is measured using the RPE scale. This indicator works as a self-assessment instrument of fatigue, difficulty and physical exertion. This scale ranges from 6–20, where 6 refers to "Very Easy" and 20 to "Exhaustive" [14] and has been considered adequate to assess physical exertion in the military context [15].

2.4 Thermal Perception Analysis

Thermal Sensation

Although thermal sensation is a subjective variable that differs according to individual perceptions from individual to individual, it tends to increase with the increase in ambient temperature [5].

The most used scale to assess thermal sensation is the scale developed by ASHRAE, which consists of assessing the perception of thermal sensation and is graded between "Very Cold", "Cold", "Cool", "Slightly Cool", "Neutral", "Slightly Warm", "Warm", "Hot" and "Very Hot". This scale is often used to establish a relationship between variation of physiological factors monitored through specific devices with the thermal sensation perceived by individuals [16].

Thermal Comfort

The perception of thermal comfort is a subjective assessment that varies from individual to individual and is related to the variation in ambient temperature, ST, thermoregulation capacity and the thermal sensation inherent to each individual [6].

Thermal comfort has been shown to depend on the perception of moisture in the skin, since in warmer environments, temperatures considered less comfortable are associated with higher perceptions of moisture in the skin [4]. The scale that was utilized allows the perception of Thermal Comfort to be assessed, which is graded between "Very Uncomfortable", "Uncomfortable", "Slightly Uncomfortable", "Slightly Comfortable", "Comfortable" and "Very Comfortable" [4].

Perception of Moisture in the Skin

When performing physical activity in warmer environments, the perception of comfort and thermal sensation is more dependent on the perception of moisture in the skin and the sweating rate than on the temperature in the skin itself, because the ST values are constantly oscillating in order to adapt to the ambient temperature and facilitate the heat dissipation process. Thus, the perception of moisture in the skin is considered a good indicator to assess thermal comfort, especially in warmer environments [17].

According to Garson (2016), when more waterproof equipment is used, since this material restricts the heat dissipation capacity, the moisture in the skin tends to increase. In this study, we used a graduated scale of "Very Dry", "Dry", "Slightly Wet", "Wet", "Very Wet", "Wet" and "Very Wet" [4].

2.5 Statistical Methodology

In order to validate whether the Physical Protocol makes it possible to assess and draw conclusions about the heat tolerance of military personnel wearing PPE, analysing the variation in physiological variables and thermal perceptions throughout the performance of the protocol at different temperatures, a sample of 2nd and 5th year students from the Military Academy was selected, male and female. The protocol implementation was scheduled according to the students' availability between 11 March and 2 May of 2024. This is a quantitative study as it uses information collected in the field, based on a previously defined sample of soldiers, considering standardised information collection

instruments as sources of analysis. The data collected on the physiological parameters monitored in the participants, who were exposed to exercises with different intensities of physical stress, with and without equipment and in different temperature environments, were structured and statistically analysed using IBM SPSS Statistics 28 and Microsoft Excel software, exploring the relevant variables, from those that correspond to physiological indicators (CT, ST and HR) to those associated with thermal perception indicators (RPE, thermal sensation, thermal comfort and perception of moisture in the skin). The data was analysed using various descriptive statistical methods, combined with adequate statistical inference techniques and probability models. Point estimation, interval estimation and implementation of various hypothesis tests for the parameters of interest (median value) are considered, taking into account the enunciated problem, with a significance level of 10% [18]. Considering non-parametric statistical methods for hypothesis testing development, considering the Wilcoxon test and also using the Kruskal-Wallis test, with multiple pairwise comparisons, the study is performed [18].

3 Results Analysis and Discussion

In this research, the population to be analysed was the military personnel who make up the CBRN teams. Thus, the necessary conditions have been created for this purpose so that the study can be validated by means of a quantitative method. This assessment was carried out using protocols in a controlled laboratory in order to measure, using both invasive and non-invasive methods, the chosen variables of military personnel while wearing PPE.

The active-duty military personnel have been chosen among the Military Academy students who have been considered as members of a possible CBRN team in order to constitute a representative sample. The participants were between 21 and 31 years old with an average of 23,22 years and a standard deviation (sd) of 2,5 years. Weight was between 53,25 kg and 82,15 kg, with an average of 68,07 kg and a SD of 11,93 kg; The height of the subjects ranged from 161 cm and 183 cm with an average of 170,2 cm and a SD of 7,31 cm. In terms of body mass index (BMI), lies between 20,3 kg/m^2 and 26,5 kg/m^2 with an average of 23,29 kg/m^2 and a SD of 2,34 kg/m^2. The male subjects have an average age of 24,4 $\pm$ 2,4 years (considering that the second value is the standard deviation), a height of 175,2 $\pm$ 5,3 cm and an average weight of 76,9 $\pm$ 7,1 kg, a BMI of 25,0 $\pm$ 1,4 kg/m^2. With regard to the female members, they have an average age of 21,8 $\pm$ 2,1 years, a height of 164,0 $\pm$ 3,5 cm and an average weight of 57,1 $\pm$ 4,5 kg, a BMI of 21,2 $\pm$ 1,1 kg/m^2. Table 1 summarizes the mentioned main statistics.

In addition, resting blood pressure and HR were measured as a safety protocol to check for any untimely medical conditions before carrying out the protocols at different temperatures. All the sample members were physically active, healthy, non-smokers, did not have any type of heart or respiratory disease or any injury that could influence their physical performance in this study.

3.1 Physiological Indicators Variation - Ambient vs High Temperature

The Physical Protocol was carried out at Ambient Temperature (18,28 ºC $\pm$ 0,7 ºC) and at the High Temperature (26,92 ºC $\pm$ 0,7 ºC). The data collected during these two

Table 1. Characteristics of the participants (values are mean ± sd)

Statistics	Age (years)	Weight (Kg)	Heigh (cm)	Body mass index
Mean Male	24,40 ± 2,41	76,88 ± 7,14	175,20 ± 5,31	24,97 ± 1,41
Mean Female	21,75 ± 2,06	57,05 ± 4,48	164,00 ± 3,46	21,19 ± 1,14
Mean	23,22 ± 2,54	68,07 ± 11,93	170,22 ± 7,31	23,29 ± 2,34

environments, with controlled temperatures of 18,28 ºC ± 0,7 ºC and 26,92 ºC ± 0,7 ºC were analysed in order to obtain the results in relation to the variation in physiological parameters, CT, ST and HR, throughout the physical protocol.

3.1.1 Core Temperature Throughout the Protocol at Different Environments

When analysing this physiological parameter, the average of the values within each minute was taken into account. It is evident that there was a slight increase in the CT of all the individuals during the 29 min of work at both temperatures. For ambient temperature, the values for the average variation in CT of the entire sample over the 29 min did not very much, with the average value being 37,41 ºC ± 0,27 ºC, the minimum value being 36,57 ºC and the maximum 37,97 ºC. With regard to the variation in the average for the entire sample during the 29 min protocol at the high temperature, although there was no great variation in the results, this variation was higher in all the individuals when compared to the variation obtained in the Ambient Temperature, as can be seen from the range of results obtained between the minimum and maximum values measured in both environments (see Fig. 2). The general average in this environment was 37,40 ± 0,32 ºC, the minimum value collected was 36,66 ºC and the maximum 38,19 ºC.

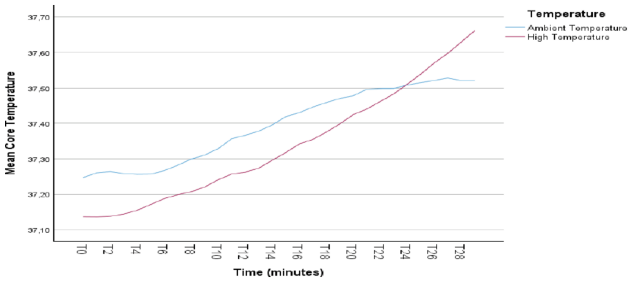

Fig. 2. CT Variation Throughout the Protocol at Different Temperatures.

For the null hypotheses H0: The median value of the CT is the same across times for Exercise 1, when going through the non-parametric statistical test, the hypothesis is not rejected in Ambient Temperature (p-value = 0,145), as well as for High Temperature (p-value = 0,552) (Fig. 3). Across times for Exercise 2, the same conclusion is reached,

in Ambient Temperature (p-value = 0,128), as well as for High Temperature (p-value = 0,206) (Fig. 4).

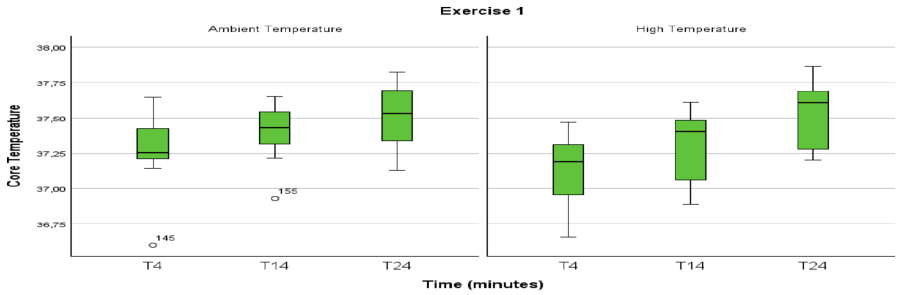

Fig. 3. Boxplot relative to CT across times (Exercise 1) in Ambient Temperature (left) and High Temperature (right).

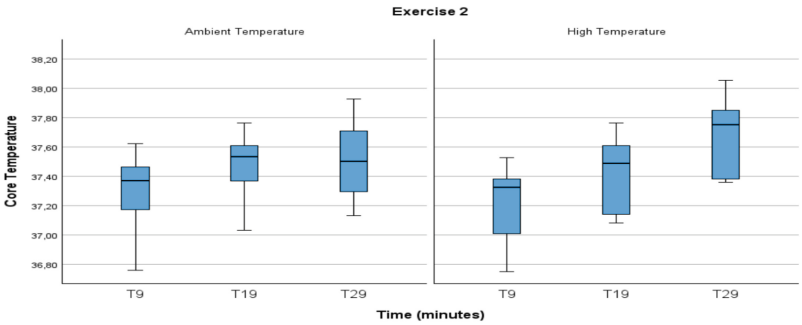

Fig. 4. Boxplot relative to CT across times (Exercise 2) in Ambient Temperature (left) and High Temperature (right).

In the present study, this protocol was used to analyse the differences between the CT medians for the different sexes during exercise 1 (in the moments T4, T14 and T24) and during exercise 2 (in the moments T9, T19 and T29) in both environments with different temperatures. The Wilcoxon non-parametric statistical test applied between categories of sexes in Ambient Temperature, for the null hypotheses H0: The median value of the CT is the same across categories of sex, is rejected (p-value = 0,021), in Exercise 1 (Fig. 5). For High Temperature they are not significantly different (p-value = 0,125), obtaining this same conclusion when analysing Exercise 2 for both temperatures (0,122 < p-value < 0,128) (Fig. 6).

3.1.2 Skin Temperature Throughout the Protocol at Different Environments

Taking into account the values within each minute over the 29 min of work in the carried-out protocol, at both ambient temperatures, the variation in ST was analysed. The average value during the 29 min of the protocol carried out at ambient temperature was 35,56 ºC ± 1,21 ºC, with a minimum of 32,22 ºC and a maximum of 36,85 ºC. With regard to the

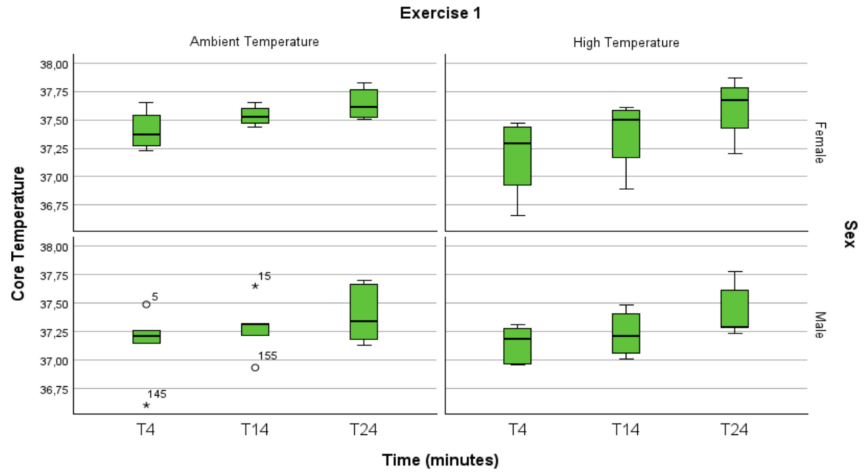

Fig. 5. Boxplot relative to CT (Exercise 1) across sex categories in Ambient Temperature (left) and High Temperature (right)

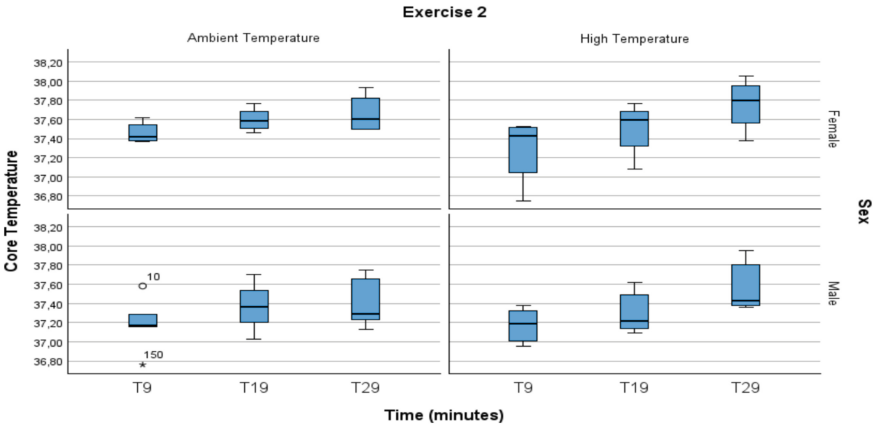

Fig. 6. Boxplot relative to CT (Exercise 2) across sex categories in Ambient Temperature (left) and High Temperature (right).

data collected in the environment with the highest temperature, similarly to what was observed at ambient temperature, there was a slight increase in the average variation of the sample in relation to the protocol, obtaining an average value at 29 min of 36,79 ºC ± 0,53 ºC, with a minimum temperature of 35,24 ºC and a maximum of 37,89 ºC. Thus, a slight increase in the sample average over the 29 min of the protocol in both environments is observed.

From the perspective of the ST variable, given the null hypothesis, H0: The medians are the same across times of the graded Exercise 1, for Ambient temperature as well as for High temperature, through the Wilcoxon test, H0 are rejected. So significant differences emerged between T4 and T14 (0,018 < p-value < 0,046) and between T4 e T24 (0,018

$<$ p-value $<$ 0,072) for in Ambient Temperature and also for high temperature (Fig. 7). In terms of Exercise 2 protocol, this shows only significant differences in Ambient temperature between T9 and T19 (p-value $=$ 0,046) and between T9 e T29 (p-value $=$ 0,005), and no significant differences between times at high temperature emerge (Fig. 8).

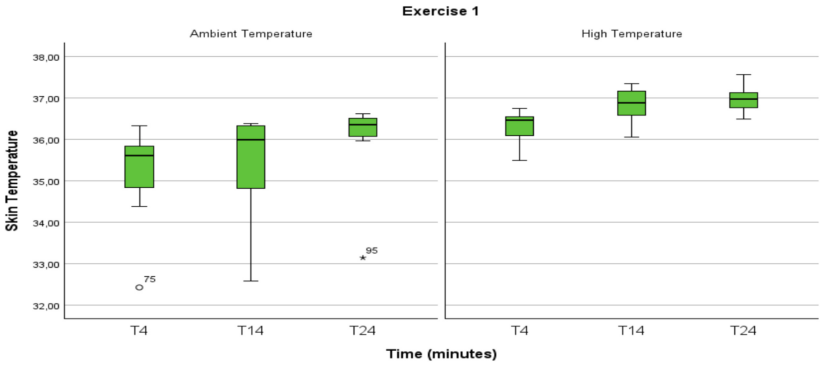

Fig. 7. Boxplot relative to ST across times (Exercise 1) in Ambient Temperature (left) and High Temperature (right).

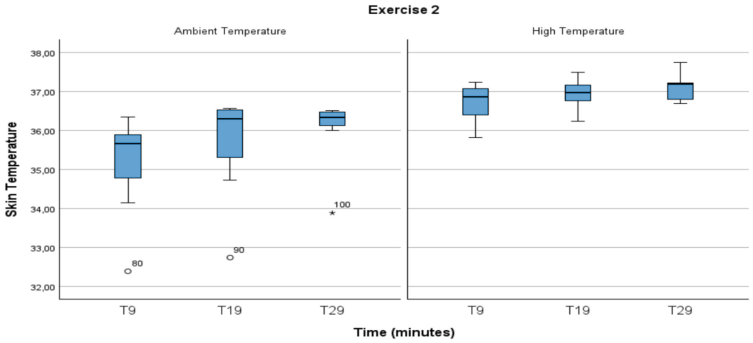

Fig. 8. Boxplot relative to ST across times (Exercise 2) in Ambient Temperature (left) and High Temperature (right).

The differences between the ST medians for the different sexes during exercise 1 (in the moments T4, T14 and T24) and during exercise 2 (in the moments T9, T19 and T29) in both environments with different temperatures are considered (Figs. 9 and 10).

Going through analysis between categories of sexes in ST, by applying the non-parametric statistical test, for the null hypotheses H0: The median value of the ST is the same across categories of sex, is rejected in Exercise 2 for high temperature (0,128 $<$ p-value $<$ 0,414) (Fig. 10). In Exercise 1 for Ambient temperature as well for High Temperature differences are not detected (0,122 $<$ p-value $<$ 0,128) (Fig. 9).

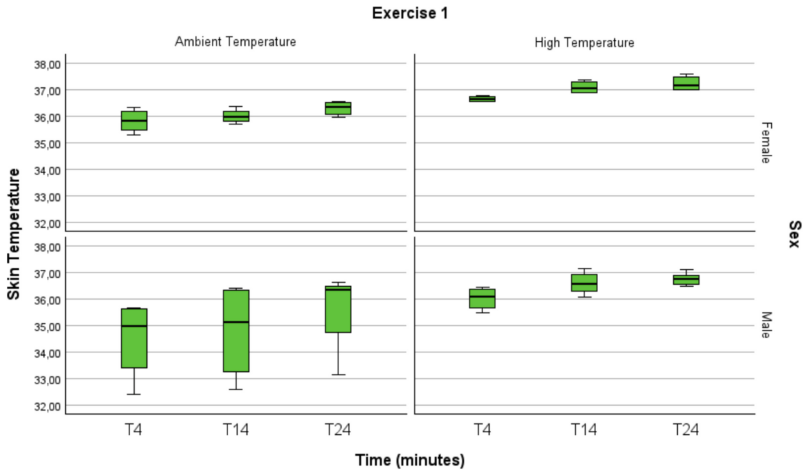

Fig. 9. Boxplot relative to ST (Exercise 1) across sex categories in Ambient Temperature (left) and High Temperature (right).

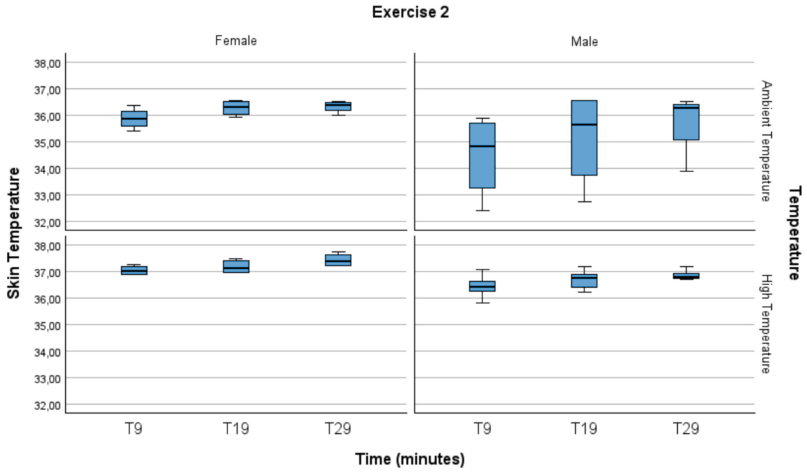

Fig. 10. Boxplot relative to ST (Exercise 2) across sex categories in Ambient Temperature (left) and Warmest Temperature (right).

3.1.3 Heart Rate Throughout the Protocol at Different Environments

Regarding the variation in HR values over the 29 min of implemented protocol, the average of the HR values for each minute was considered. Since HR values are influenced by the physical demands that the participants are subjected to, a slight decrease in HR during the resting minutes (between T4 and T5, T9 and T10, T14 and T15, T19 and T20, T24 and T25), is noted. At ambient temperature, the sample's average HR over the 29 min of the protocol was 101,16 bpm ± 12,23 bpm, with a minimum HR of 56 bpm and a maximum HR of 125 bpm. On the other hand, at a higher temperature, the average

HR over the 29 min of the protocol was 115,16 ± 16,00 bpm, with a minimum HR of 68 bpm and a maximum HR of 150 bpm.

It was therefore observed that, at both temperatures, there was an increase in HR during the course of the physical protocol, with greater variation in the protocol carried out at a higher temperature (Fig. 11).

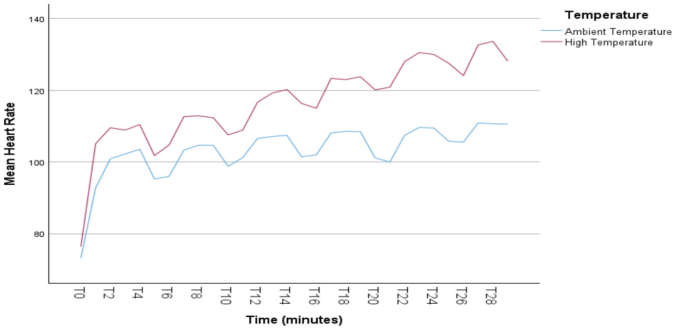

Fig. 11. HR Temperature Variation Throughout the Protocol at Different Temperatures.

For the null hypotheses H0: The median value of the HR is the same across times in Ambient Temperature, through the non-parametric statistical test, the hypothesis is rejected (0,127 < p-value < 0,552), for both Exercises, however, at high temperature, both exercises show significant differences (0,003 < p-value < 0,060), and when we go through the pairwise comparisons between times stands out that, for Exercise 1, T4 and T14 are significantly different (p-value = 0,018), and for Exercise 2, we conclude that between T9 and T29 (p-value = 0,0016) (Fig. 12). The differences between the HR medians for different sexes during exercise 1 (in the moments T4, T14 and T24) and during exercise 2 (in the moments T9, T19 and T29) are analysed for in both environments with different temperatures (Fig. 13).

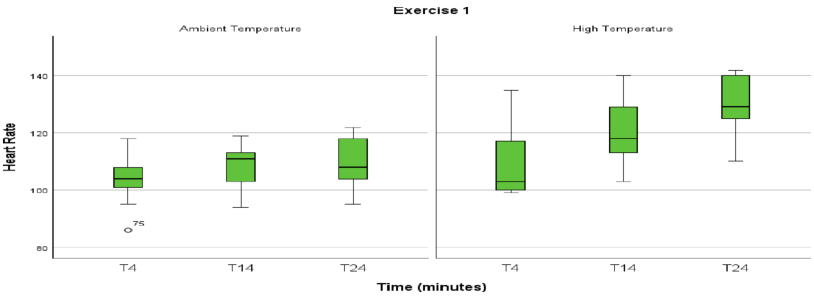

Fig. 12. Boxplot relative to HR across times (Exercise 1) in Ambient Temperature (left) and High Temperature (right).

Following the aim of the investigation for the third physiological indicator under analysis, and taking into account the null hypothesis, H0: The medians are the same

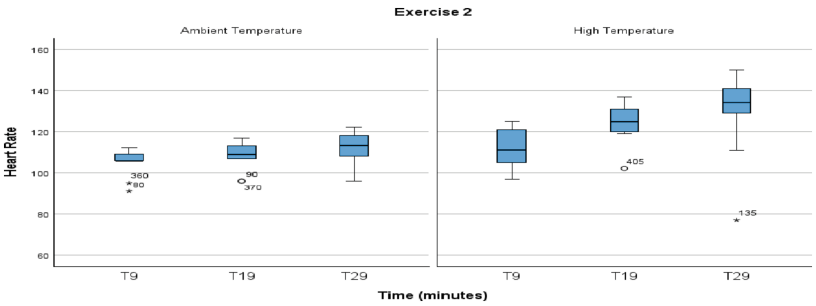

Fig. 13. Boxplot relative to HR across times (Exercise 2) in Ambient Temperature (left) and High Temperature (right).

across categories of Sex, the ambient temperature and high temperature, are compared in terms of HR, in each exercise of the protocol. When the non-parametric test is applied, the null is not rejected for both exercises (p-value ≈ 0.999), therefore from this level no significant differences are provided depending on the sex category (Figs. 14 and 15).

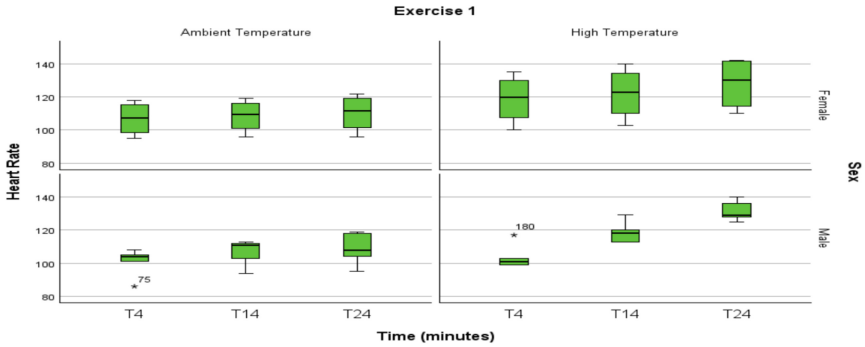

Fig. 14. Boxplot relative to HR (Exercise 1) across sex categories in Ambient Temperature (left) and High Temperature (right).

3.2 Thermal Perception Variables - Variation Throughout the Protocol at Different Temperatures

It seems that the physical protocol applied in environments with different temperatures does not require intense physical efforts, as variation of the RPE was not apparently different neither during the performance of the protocol at each of the temperatures, nor when comparing the values referring to the same exercise at the two temperatures (Fig. 16).

Regarding Thermal Comfort, Thermal Sensation and Moisture of the skin, we can verify that there is a relationship both in the isolated analysis of the protocols at the two temperatures, and it is also possible to verify a relationship between the variation of these

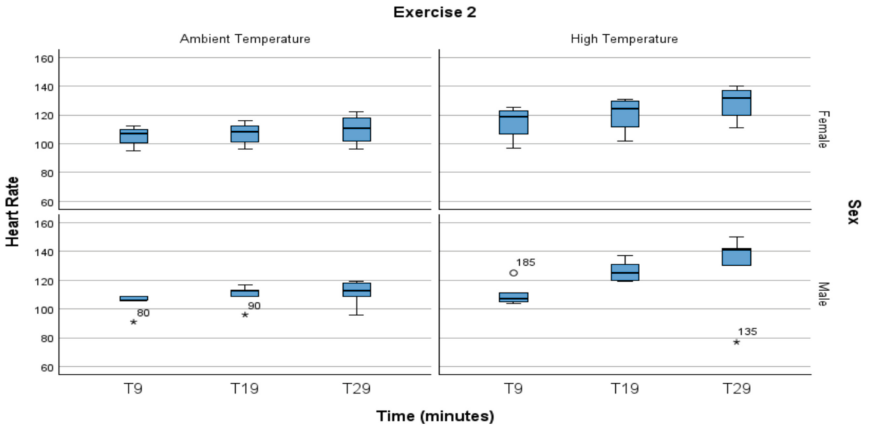

Fig. 15. Boxplot relative to HR (Exercise 2) across sex categories in Ambient Temperature (left) and High Temperature (right).

indicators for the same exercises of the physical protocol, but at different temperatures. The analysis carried out regarding the variation of Thermal Comfort, Thermal Sensation and Humidity in the Skin in the protocols at different temperatures in isolation is in accordance with the results obtained by other authors [6, 19].This increase in internal temperature, both in the protocol carried out at a temperature of 18,28 ºC ± 0,7 ºC and in the protocol carried out at 26,92 ºC ± 0,7 ºC was found that the perception of Moisture in the Skin and Thermal Sensation tend to increase and Thermal Comfort tends to decrease. When analysing the data regarding the perception of Thermal Sensation, Moisture of the skin and RPE in the same exercises, but performed at different temperatures, it was found an increase in ambient temperature and consequent increase in internal temperature, temperature in the skin, while Thermal Comfort tends to decrease [4, 5].

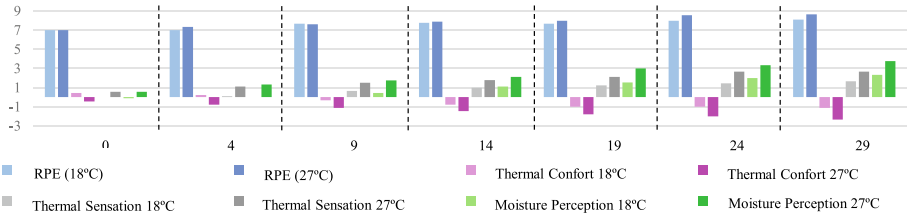

Fig. 16. Variation of thermal perception throughout the protocol at different temperatures

3.3 Thermal Perception Variables – Differences Between Sexes Throughout the Protocol at Different Temperatures

The analysis of the variation of heat stress indicators between sexes during the performance of the physical protocol at 18,28 ºC ± 0,7 ºC with the PPE shown in Fig. 17,

shows that, although there are no differences, male elements tend to consider this temperature warmer and less comfortable when compared to female elements. Also in this environment, the biggest differences found between the two sexes were in relation to the perception of Moisture in the skin, and the male elements felt a considerably higher humidity in the skin.

The analysis of the variation of heat stress indicators between sexes during the performance of the physical protocol at 26,92 ºC ± 0,7 ºC with the PPE shown in Fig. 18, similarly to what happens in the protocol performed at Ambient Temperature, although there is a slight tendency in male elements to consider the temperature of the environment warmer and less comfortable when compared to female elements. In this case, there was a smaller discrepancy both in the perceptions of sensation and thermal comfort and in the perception of moisture in the skin.

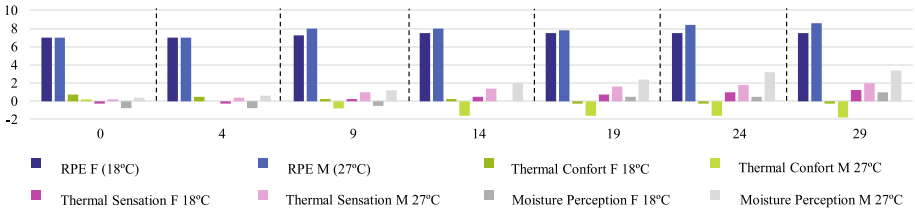

Fig. 17. Differences between sexes at Ambient temperature of thermal perception

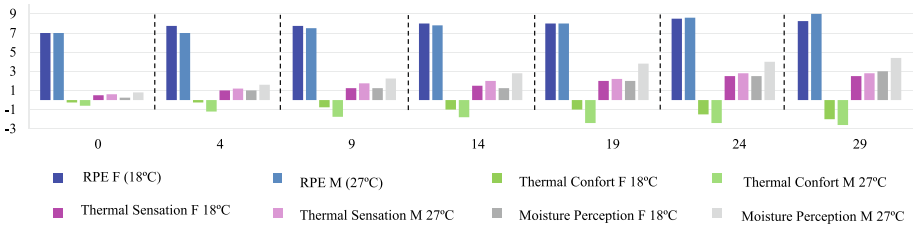

Fig. 18. Differences between sexes at High temperature of thermal perception

4 Conclusions and Final Remarks

The present research work analyses the variation of physiological factors and heat tolerance of a representative sample of members belonging to the CBRN teams, during the performance of a physical protocol with personal protective equipment, in environments with controlled temperatures of 18,28 ºC ± 0,7 ºC and 26,92 ºC ± 0,7 ºC.

The analysis carried out on the variation of physiological factors such as CT, ST and HR and the subjective perceptions of thermal *stress* such as Thermal Sensation and Thermal Comfort during the use of PPE, is based on the fact that there are several military contexts in environments with high temperatures and where there is the possibility of using the elements from the CBRN team. In this sense, it is important to understand the

impact that the ambient temperature can have on the body during the performance of various tasks that require physical effort with PPE and thus be able to prevent undesirable clinical situations related to the use of these soldiers in the heat.

On the other hand, the variation of these physiological factors and heat tolerance also depends on the ability of individuals to acclimatize to environmental conditions. In this way, this protocol can also be used in the admission tests for CBRN teams in order to verify the ability of individuals to adapt to environments with different characteristics in the face of the practice of physical activity with the use of PPE.

Physiological indicators showed notable variations under different thermal conditions. Core temperature experienced a slight increase during the protocol at both ambient and high temperatures, with a slightly larger variation at the higher temperature; interestingly, a significant difference between sexes was observed during Exercise 1 at ambient temperature only. Skin temperature also increased slightly in both environments, with significant changes over time noted for Exercise 1 at both temperatures and for Exercise 2 at ambient temperature; a significant sex difference in ST emerged during Exercise 2 at the high temperature. Heart rate demonstrated a clear increase throughout the exercise protocol at both temperatures, with a more pronounced rise in the warmer environment; however, no significant differences in HR were found between male and female participants under either temperature condition.

Thermal perception variables were significantly influenced by the ambient temperature. The rate of perceived exertion did not show substantial differences across temperatures or exercises, suggesting the protocol did not induce extreme physical strain. However, thermal comfort decreased, while thermal sensation and the perception of moisture in the skin increased with rising ambient temperatures and the physiological strain induced by the PPE.

Nonetheless, the present investigation encountered certain inherent limitations. Firstly, the sample universe proved restricted, given that the time-consuming nature of the applied protocols precluded the participation of a larger number of individuals. Additionally, the protocol as devised and implemented did not generate the anticipated impact, with only a slight alteration observed in the physiological parameters even under elevated temperature conditions. These constraints affect the capacity for generalizing the obtained results and, particularly, the robustness of the analysis, especially concerning a precise prediction of internal temperature.

Considering the results achieved and the identified limitations, future lines of research should seek to bridge these gaps. Among the future projects outlined, is the remodeling of the study protocol, adjusting it based on the data gathered from the various physiological parameters analysed, with the expectation of provoking more pronounced effects. It is equally crucial to significantly increase the sample size in order to consolidate the algorithm intended for predicting internal temperature. In parallel, the creation of specific tables for assessing heat tolerance directed at CBRN teams is imperative, these tools being crucial for selection processes (access), evaluation of operational readiness, and supporting decisions on return to duty after absence due to illness. The realization of these steps is fundamental for deepening understanding, improving the predictive capacity, and effectively mitigating the physiological challenges faced by CBRN personnel in

demanding environments, thus preventing undesirable clinical situations associated with their deployment in conditions of extreme heat.

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