Metabolic Cost of Load Carriage in a Special Forces Team – A Non-parametric Approach

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Abstract. Military missions are often comprised of heavy load carriage whilst marching in difficult terrains. Furthermore, the ability of carrying a load is a fundamental requirement for successful missions and safety in these populations. The aim of the present study was to quantify the metabolic cost of load carriage in a Portuguese special forces team. Ten active-duty military personnel of a special forces team performed a graded protocol of until exhaustion on a treadmill in a thermoneutral environment in two different conditions: Unloaded and Fully loaded for combat. Using non-parametric statistical methods for hypothesis testing development, considering the Wilcoxon Test to compare two groups and Kruskal-Wallis test for analysing the differences by step in the different variables, with multiple pairwise comparisons, the study is performed in two main phases. First, considering the Unloaded and Fully loaded groups, it was analysed if it provided different results of peak oxygen uptake, heart rate and blood Lactate. Second, taking into account that higher differences were detected across categories (steps), we are interested in conducting an analysis which enables the definition of the ventilatory threshold and peak oxygen uptake for each condition. The fully loaded for combat condition showed higher values of oxygen consumption and heart rate in all steps of the exercise when compared to the unloaded condition. Peak oxygen uptake and heart rate were significantly different between the two conditions. This study enables to enhance our understanding of the metabolic cost of load carriage, in a special forces team, and its impact in military readiness.

Keywords: Metabolic Cost · Military · Load Carriage · Non-parametric tests · Multiple Pairwise Comparisons

1 Introduction

Military missions are often comprised of heavy load carriage whilst marching in difficult terrains. Despite the fact that the load carried by soldiers has been increasing throughout history [1], the ability of carrying a load is a fundamental requirement for successful missions and safety in these populations to this day [2].

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Military assignments require not only a high level of technical competence, but also substantial physical demands for their performance. Thus, the physical performance of military personnel is not limited to the execution of military tasks, but also maintain their ability to execute them for prolonged periods, with the aim of consistent performance [3].

In the current battlefield scenarios, there is a growing trend towards conflicts in the urban environment, where the physical demands are significantly different. Combat in an urban environment is characterized by its asymmetrical nature, the unpredictability of confrontations and the fact that it is a constantly changing environment. Unlike conventional combat where both the terrain and the enemy are properly framed and defined this scenario requires a capacity for rapid response, agility, and resilience to face the challenges inherent to a dynamic and unpredictable system [4].

Therefore, the ability to carry a load is fundamental requirement in military settings and varies according to function and mission. This fact means that individuals rely on their personal mobility to transport the convenient equipment to the mission [5]. Additionally, the location of the load (upper body, hip, etc.) can affect walking efficiency, energy cost, subjective comfort and the biomechanics of the individual [5–7]. The prediction and evaluation of the metabolic cost of load carriage has been studied both in the laboratory [2, 8] and in operational settings [5–7], leading to the idea that the high physiological costs of carrying a load enhance the possibility of personal injury compromising health and safety and even mission success [2].

Logically with an increased metabolic cost comes increased physiological markers [1]. Although the relevance of cardiorespiratory parameters has shown relevant results [2, 8, 9], other studies have been more conservative regarding the usage of such parameters [10].

The Maximal Oxygen Uptake ($VO_{2máx}$) has been shown to reflect the individual maximal rate of energy expenditure and to be related with athletic performance [11]. Additionally the Lactate Threshold (LT) and the associated changes in gas changes reported by the Ventilatory Threshold (VT) have also been related to endurance performance [11–13]. In addiction the LT has been referred to be the exercise intensity where blood lactate concentration increases above resting levels [14].

Taking this into account, no previous studies were found that address both the Peak Oxygen Uptake (VO_{2peak}) and ventilatory parameters relation with different loading conditions in a special forces team in the Portuguese Army.

Thus, the purpose of this study was to measure and compare different physiological parameters such as VO_{2peak} and ventilation parameters associated with the LT and the between different loading conditions in a special forces team of the Portuguese Army.

This work is organized as follows: Sect. 2 describes the objectives and methods of this study regarding: soldiers conditions characterization, the protocol and derived variables and lastly the statistical methods. Section 3 refers to the analysis and discussion of the main results. The main conclusions and final remarks are described in Sect. 4.

2 Objectives and Methods

This research focuses on quantifying the metabolic cost of load carriage in a Portuguese special forces team. A graded protocol until exhaustion on a treadmill in a thermoneutral environment in two different conditions: Unloaded and Fully loaded for combat was performed.

A sample consisted of ten soldiers from the Portuguese Army's Commandos Battalion, who was undergoing preparation for their 13th deployment to the Central African Republic's theatre of operations.

All the participants were free from any injury or pain prior to the performance testing. After receiving a thorough explanation of the protocol, all gave their written informed consent to the study. The experimental protocol, the gas analysis and the blood analysis are described in detail below.

Considering the VO_{2peak} and the HR, BL concentration and rating of perceived exertion (RPE) as metabolic variables, for the Unload and Fully Loaded Groups, the aim is to analyse and compare whether there are significant differences in both conditions, assessing their impact on different metabolic capacities. Such an approach enables the definition of the VT and VO_{2peak} for each condition.

2.1 Soldiers' Conditions Characterization: Unloaded and Fully Loaded for Combat

Regarding collective material, the Assault Pack MIL-TEC backpacks were used, equipped with extra ammunition, offensive grenades and flashbang grenades, planning material, water, stretchers, first aid kit; Benelli Super Nova or Franchi SPAS-15 shotguns and the Grenade Launcher (LG) 40mm FN40GL-S Mk2.

Regarding weaponry, military personnel were equipped according to their specific combat role. All snipers are equipped with the Glock 17 Gen 5 FS pistol with two additional cartridges, the normal Snipers are equipped with the FN SCAR-L assault rifle with eight additional cartridges, the LMG Sniper with the FN Minimi 5,56 Mk ML plus eight ribbons, and the Special Sniper with the FN SCAR-H with Trijicon VCOG optical sight, eight more chargers. The personal protective equipment used includes the OPS-CORE helmet, the THOR ballistic vest and the THOR Anti-Fragmentation belt.

The total sum of the weight carried by the military in this study ranged between 25 kg and 35 kg, taking into account that this variation was due to the function performed by the soldier.

2.2 Experimental Protocol

All participants performed a graded protocol of until exhaustion on a treadmill TR1000 BM (BH Fitness; EXERCYCLE, S.L., Spain) in a thermoneutral environment in two different conditions: Unloaded and Fully loaded for combat. Previous to the incremental test the subjects performed a standardized warm-up consisting of 8 to 10 min of light running followed by active rest, followed by a 5-min rest. All tests were within at least 2 h after the subject's last meal. All subjects were asked to avoid the consumption of coffee and alcohol and physical activity (training) 24 h before the test.

The protocol consisted of a maximal continuous incremental exercise of two-minute steps the gradient was increased every second minute by 2° up to a gradient of 8°. Thereafter, the gradient of 8° was maintained and the walking speed was increased by 1 km/h every second min until the subjects were not able or willing to continue the test. VO_{2peak} and maximal aerobic velocity (MAV) were determined. VT with corresponding heart rate (HR) and speed were also determined. VO_{2peak} was considered when the athlete reached volitional exhaustion, was unable to maintain the required speed or was unable to sustain the given speed for at least one minute in the last stage. The VT was calculated by v-slope method (i.e., disproportioned increase in carbon dioxide uptake relative to oxygen uptake) [15].

2.3 Gas Analysis - Oxygen Consumption

Respiratory data were collected breath-by-breath using a PNOE metabolic cart which operates on a mode that continuously measures volume and determines expired gas concentrations simultaneously. The measurements of oxygen consumption are made by via an open-circuit indirect calorimetry technique by assessing pulmonary gas exchange at the mouth and the nose. The metabolic cart is comprised of an electrochemical O_2 analyzer and an infrared CO_2 analyzer.

Breath-by-breath oxygen uptake values were averaged over 5 s with peak oxygen uptake taken as the highest 30 s oxygen uptake value. HR was measured throughout the test (Polar H10, Kempele, Finland).

2.4 Blood Analysis

Blood samples were collected from the earlobe of the participants using a Lactate Pro 2 (AKRAY Europe-Netherlands). Prior to the collection the site was cleaned in order to remove any sweat or blood.

2.5 Statistical Methodology

The data was analyzed using various descriptive statistical methods, implemented using IBM SPSS Statistics 28 software. Statistical Inference techniques and probability models were considered to evaluate the metabolic capacities of soldiers and understand the impact that load can have in reducing maximal exercise tolerance.

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 5% [16].

Resorting to 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 [16].

Considering the Unloaded and Fully loaded groups, it was analysed if it provided different results of VO_{2peak}, HR and BL. The differences were also analysed considering the Unloaded and Fully loaded groups by step in the different variables.

3 Results Analysis and Discussion

The ten active-duty military personnel of a special forces team that constitute our sample are all male. These elite special forces team is specially trained for executing high-risk combat missions such as: direct combat, special reconnaissance, etc. All members had undergone intensive training in varied environments.

The participants were between 21 and 31 years old with an average of 24,7 years and a standard deviation (SD) of 3,5 years. Weight was between 68,8 kg and 96,8 kg, with an average of 77,12 kg and a SD of 8,5 kg; The height of the militaries ranged from 164 cm and 188 cm with an average of 175,8 cm and a SD of 7,88 cm. In terms of Body mass index, lies between 21,8 and 27,4 with an average of 25 kg/m^2 and a SD of 1,81 kg/m^2. Table 1 summarizes the mentioned main statistics.

Table 1. Table captions should be placed above the tables.

Statistics	Weight (Kg)	Height (cm)	Age (years)	Body mass index (kg/m^2)
Mean	77,1	175,8	24,7	24,9
Median	76,5	176,5	23,5	24,9
Std. Deviation	8,5	7,8	3,4	1,8
Range	28,6	24	10	5,6
Minimum	68,2	164	21	21,8
Maximum	96,8	188	31	27,4

3.1 Peak Oxygen Uptake

The VO_{2peak} by step is represented in Fig. 1 considering the two conditions, unloaded and fully loaded. It turns out that the VO_{2peak} was gradually higher in the Unloaded condition when comparing the two conditions. Furthermore, the oxygen consumption throughout the test was also higher in all steps of the exercise protocol (Fig. 1).

According to the study objective, and taking into account the null hypothesis, H0: The medians are the same across categories of Equipment, the Unloaded and Fully loaded groups, are compared in terms of VO_{2peak}. Resorting to Wilcoxon test, the null is rejected (p-value $< 0{,}001$), therefore significant different results of VO_{2peak} are provided depending on the equipment category (Fig. 2).

3.1.1 Peak Oxygen Uptake – Steps in Unload Group

Considering the non-parametric statistical test for the null hypotheses H0: The median value of the VO_{2peak} is the same across **categories (steps)** in **Unload** Group; this one is rejected (p-value $< 0{,}01$), and when we go through the pairwise comparisons between **categories (steps)** stands out that the steps 4 to 12 are significantly different from step 1 ($0{,}001 < p$-value $< 0{,}046$); steps 6 to 12 are significantly different from step 2, step 3

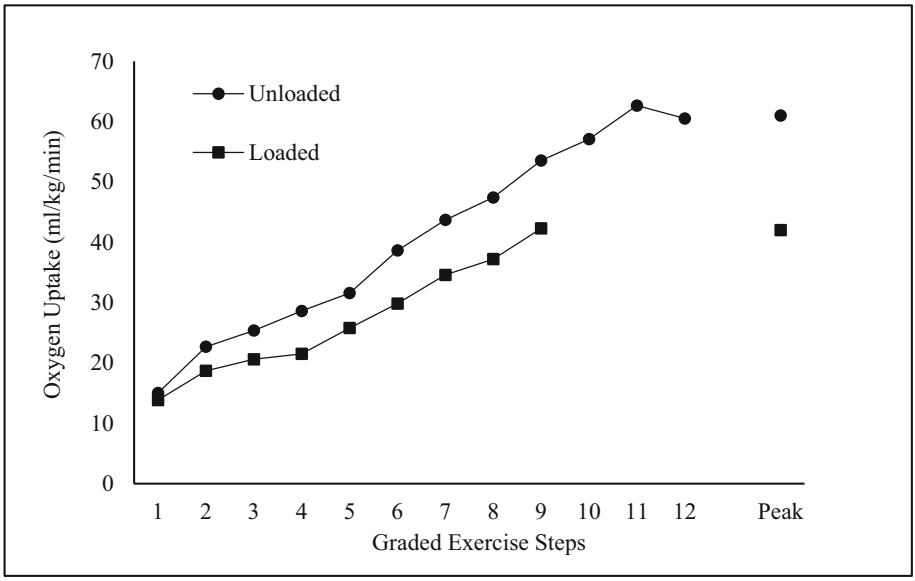

Fig. 1. Oxygen uptake during the graded exercise protocol in both conditions

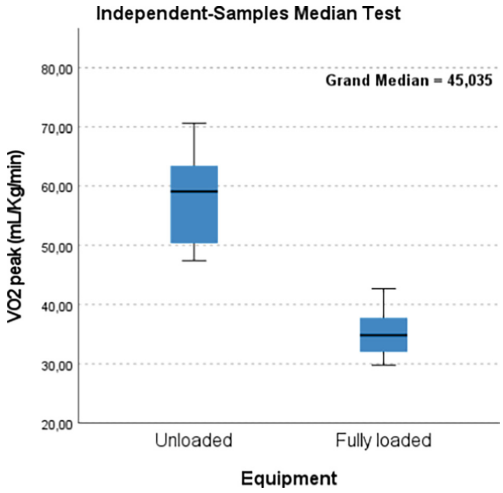

Fig. 2. Boxplot relative to VO_{2peak} across categories of Equipment.

and from step 4 (0,001 < p-value < 0,040); steps 8 to 12 are significantly different from step 5 (0,001 < p-value < 0,014), and steps 9 to 12 are significantly different from step 6 (0,001 < p-value < 0,032) (Fig. 3).

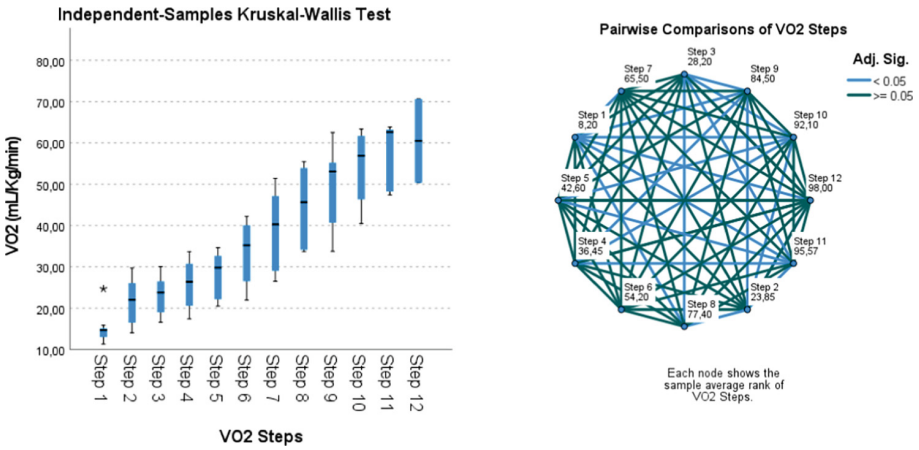

Fig. 3. Boxplot relative to VO_{2peak} across categories (steps) in Unload Group (left) and pairwise comparisons between steps (right).

3.1.2 Peak Oxygen Uptake – Steps in Load Group

Performing the non-parametric statistical test across **categories (steps)** in **Load** Group, for the null hypotheses H0: The median value of the VO_{2peak} is the same across **categories (steps),** is also rejected (p-value $< 0{,}01$), and when we carry out comparisons between **categories (steps)** stands out that the steps 4 to 9 are significantly different from step 1 ($0{,}001 < p\text{-value} < 0{,}016$), steps 5 to 9 are significantly different from step 2 ($0{,}001 < p\text{-value} < 0{,}007$), steps 6 to 9 are significantly different from step 3 and from step 4 ($0{,}001 < p\text{-value} < 0{,}002$), and step 7 are significantly different from step 5 (p-value $= 0{,}04$) (Fig. 4).

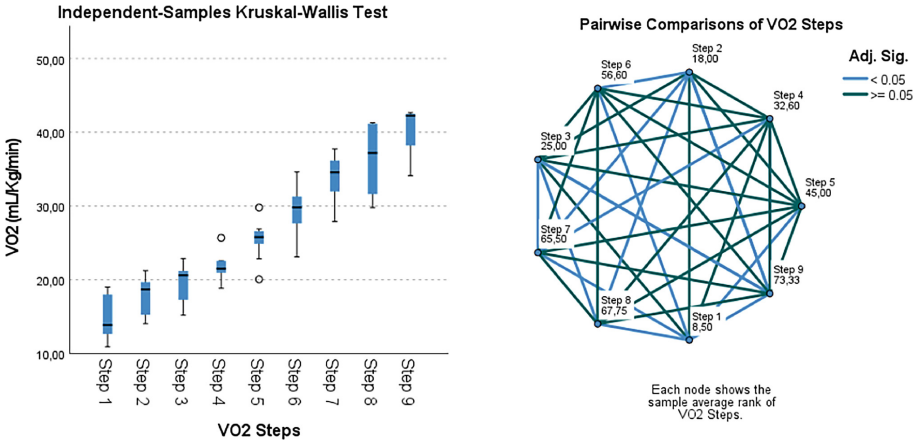

Fig. 4. Boxplot relative to VO_{2peak} across categories (steps) in Load Group (left) and pairwise comparisons between steps (right).

3.2 Heart Rate During Treadmill Exercise

The HR during treadmill exercise by step is represented in Fig. 5 considering the two conditions, unloaded and fully loaded. It turns out the Maximal Heart Rate was reached 3 steps earlier in the Loaded condition.

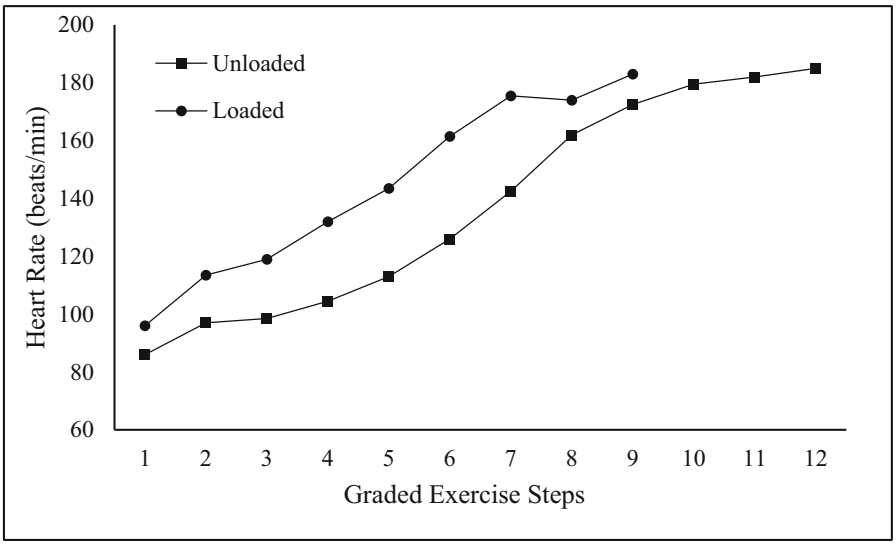

Fig. 5. Heart Rate during the graded exercise protocol in both conditions**.**

Following the aim of the investigation for the second metabolic variable under analysis, and taking into account the null hypothesis, H0: The medians are the same across categories of Equipment, the Unloaded and Fully loaded groups, are compared in terms of HR, in each common step during the graded exercise protocol. When the Wilcoxon test is applied, the null is rejected from step 2 (inclusive) (0,011 < p-value < 0,029), therefore from this level significant different results of heart rate are provided depending on the equipment category.

3.2.1 Heart Rate During Treadmill Exercise – Steps in Unload Group

For the null hypotheses H0: The median value of the HR is the same across **categories (steps)** in **Unload** Group, when going through the non-parametric statistical test, the hypothesis is rejected (p-value < 0,01), and when we go through the pairwise comparisons between **categories (steps)** stands out that the steps 5 to 12 are significantly different from step 1 (0,001 < p-value < 0,043), steps 6 to 12 are significantly different from step 2 (0,001 < p-value < 0,025), steps 7 to 12 are significantly different from step 3 and from step 4 (0,001 < p-value < 0,035), steps 8 to 12 are significantly different from step 5 (0,001 < p-value < 0,003), steps 9 to 12 are significantly different from step 6 (0,001 < p-value < 0,032), steps 10 and 11 are significantly different from step 7 (0.04 < p-value < 0,045) (Fig. 6).

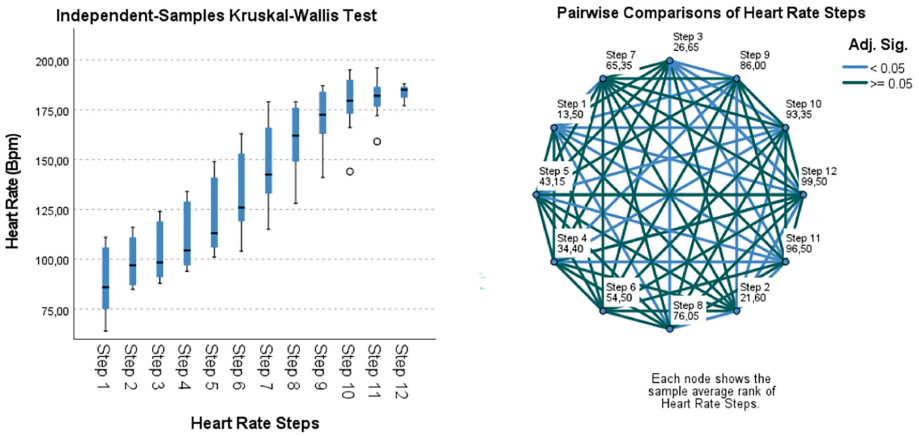

Fig. 6. Boxplot relative to Heart rate across categories (steps) in Unload Group (left) and pairwise comparisons between steps (right).

3.2.2 Heart Rate During Treadmill Exercise – Steps in Load Group

The Kruskal-Wallis non-parametric statistical test applied between **categories (steps)** in **Load** Group, for the null hypotheses H0: The median value of the HR is the same across **categories (steps),** is also rejected (p-value $<$ 0,01), and when we take effect comparisons between **categories (steps)** stands out that the steps 4 to 9 are significantly different from step 1 (0,001 $<$ p-value $<$ 0,049), steps 3 to 9 are significantly different from step 2 (0,001 $<$ p-value $<$ 0,007), steps 6 to 9 are significantly different from step 3 (0,004 $<$ p-value $<$ 0,021), and steps 7 and 9 are significantly different from step 4 (0,012 $<$ p-value $<$ 0,023) (Fig. 7).

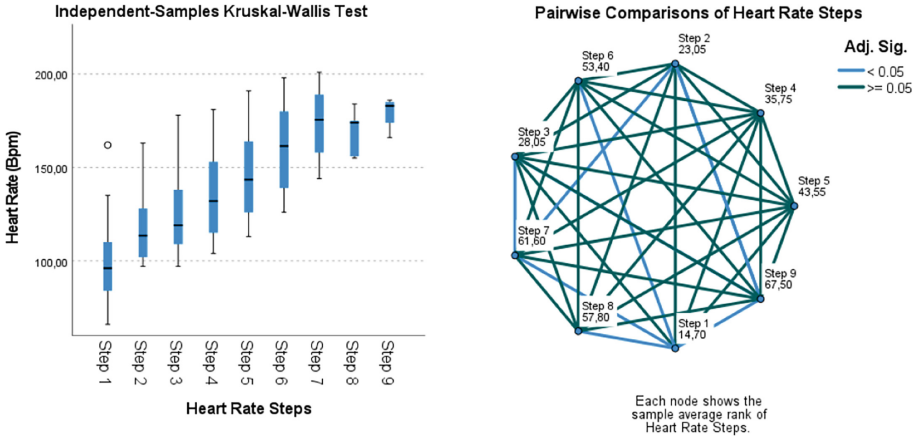

Fig. 7. Boxplot relative to Heart rate across categories (steps) in Load Group (left) and pairwise comparisons between steps (right).

3.3 Blood Lactate (mmol/l)

The step at which the blood lactate increases above resting levels is identical, the peak value for BL concentration for the Unloaded Condition occurs three steps prior to the Loaded Condition (Fig. 8).

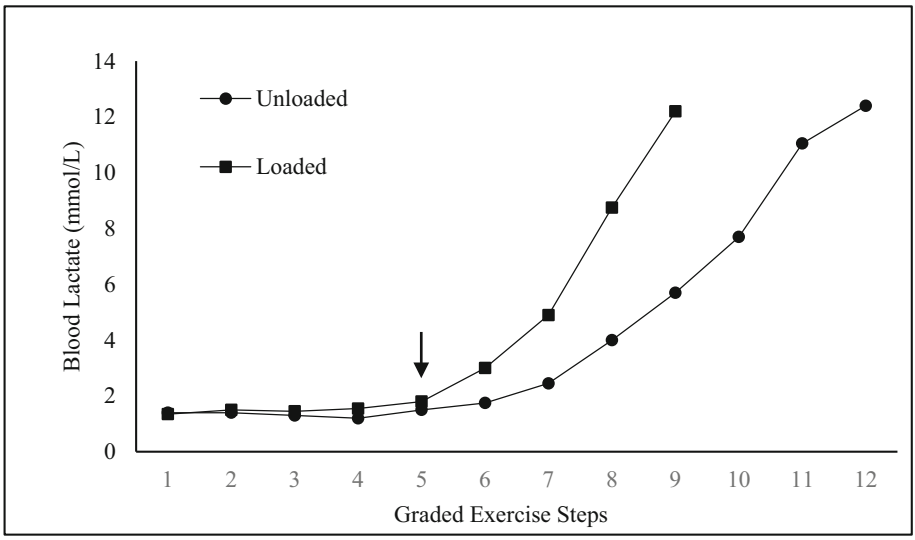

Fig. 8. Blood lactate concentration during the graded exercise protocol in both conditions (The vertical arrow represents the Lactate Threshold for both conditions).

From the perspective of the metabolic variable aimed at measuring BL concentration and given the null hypothesis, H0: The medians are the same across categories of Equipment, the Unloaded and Fully loaded groups, in each common step during the graded exercise protocol, through the Wilcoxon test, H0 is rejected from step 7 (0,007 $<$ *p*-value $<$ 0,001), and so significant differences emerged between the two groups in respect of blood lactate, from this level upwards.

3.3.1 Blood Lactate (mmol/l) – Steps in Unload Group

Considering the non-parametric statistical test for the null hypotheses H0: The median value of the BL is the same across **categories (steps)** in **Unload** Group; this one is rejected (*p*-value $<$ 0,000), and when we go through the pairwise comparisons between **categories (steps)** stands out that the steps 7 to 12 are significantly different from step 3 and from step 4 (0,024 $<$ *p*-value $<$ 0,001), the steps 8 to 12 are significantly different from step 6 and step 7 (0,017 $<$ *p*-value $<$ 0,001) (Fig. 9).

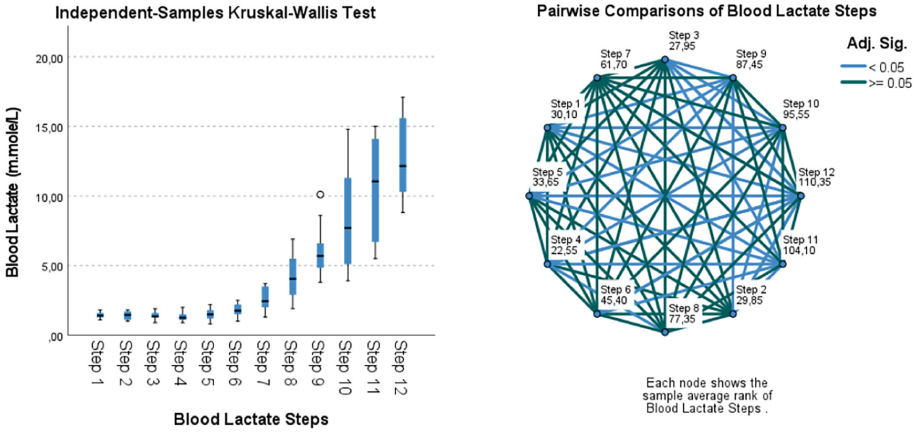

Fig. 9. Boxplot relative to Blood Lactate across categories (steps) in Unload Group (left) and pairwise comparisons between steps (right).

3.3.2 Blood Lactate (mmol/l) – Steps in Load Group

The Kruskal-Wallis non-parametric statistical test applied between **categories (steps)** in **Load** Group, for the null hypotheses H0: The median value of the BL is the same across **categories (steps),** is also rejected (p-value $< 0{,}001$), and when we take effect comparisons between **categories (steps)** stands out that the steps 7 to 9 are significantly different from step 1 to step 4 ($0{,}001 < p$-value $< 0{,}02$), steps 8 and 9 are significantly different from step 5 ($0{,}001 < p$-value $< 0{,}038$) (Fig. 10).

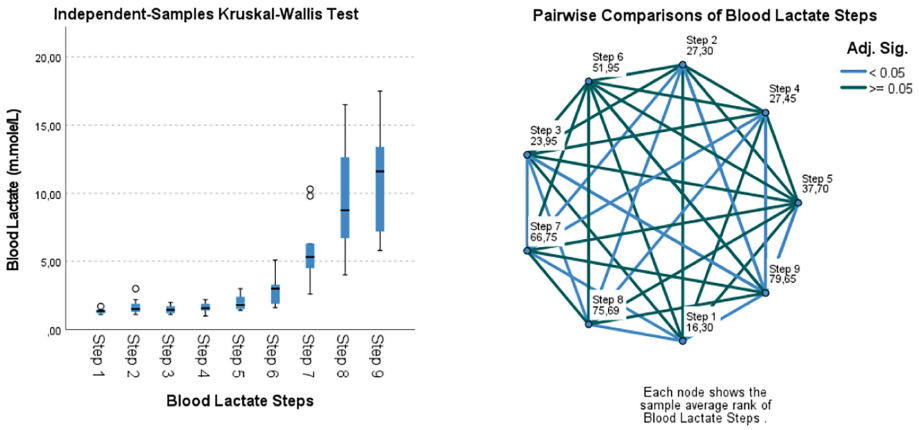

Fig. 10. Boxplot relative to Blood Lactate across categories (steps) in Load Group (left) and pairwise comparisons between steps (right).

4 Conclusions and Final Remarks

Changes in exercise tolerance caused by thoracic load carriage have been reported previously by several authors [9, 17, 18]. Although some authors have found no significant differences neither in VO_{2peak} nor in cardiorespiratory parameters (as long as the load is not excessive), thoracic load carriage may alter cardiopulmonary function [17].

This lends support to the possibility that cardiopulmonary function limits exercise with load carriage, but the point of work intolerance is perhaps reached earlier and at lower external work rates. According to Taylor [1] perhaps this (homeostatic) failure affects primarily less critical functions (hence the increased BL and HR) aiming to preserve pulmonary function.

This study was conducted with the aim of creating, implementing and analysing a suitably designed protocol, in order to quantify the metabolic cost of load carriage in a Portuguese special forces team combined with identification of differences in important metabolic variables in two conditions, Load vs Unload.

First, considering the Unloaded and Fully loaded groups, it was analysed if it provided different results of VO_{2peak}, HR and BL. It is important to emphasise that VO_{2peak} is significantly different between the two conditions, Load vs. Unload, but this difference is just registered in the metabolic variables related to HR and BL from a specific level. More specifically, from step 2 in heart rate, and from step 7 in BL.

Second, taking into account that higher differences were detected across categories (steps), when considering the conditions groups separately, an analysis is performed, which enables the definition of the VT, VO_{2peak} and BL threshold for each condition. Pairwise comparisons between steps are characterized and related to the physiological thresholds.

The RPE, another important metabolic variable, which was documented in the course of the protocol implemented, for the Unload and Fully Loaded Groups remains pending and will be considered in future analysis.

However, the conducted work up until now is considered to be a valuable contribution to the scientific community in the field of Human Performance, in comprehension the influence of load carriage on Portuguese special forces team performance, in particular and, on military missions' performance, in general. This study enables to enhance our understanding of the metabolic cost of load carriage, in a special forces team, and its impact in military readiness.

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