ARTICLE

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Physiological Responses to 12-Km Loaded March Carrying a Machine Gun or a Rifle: Effect of Weapon Weight in Physically Fit Military Personnel

Respuestas fisiológicas a la marcha equipada de 12 km transportando una ametralladora MAG o un fusil: el efecto del peso del armamento en militares bien acondicionados

Abstract: The objective was to compare physiological responses, during a 12-km march following Brazilian Army protocols, between two groups carrying different loads (personal equipment plus machine gun and personal equipment plus rifle). Additionally, we investigated whether there is a correlation between load weight, in percentage of total body mass (%TBM), and those physiological responses. The following variables were analyzed: mean heart rate, heart rate variation, blood lactate variation and mean rating of perceived exertion. The personal equipment + machine gun group presented significantly higher median values for mean heart rate and heart rate variation. Furthermore, our data showed that load (%TBM) was positively and significantly correlated with all physiological variables assessed, except for blood lactate variation. Performing long-distance load carriage with a machine gun caused greater cardiovascular effort than carrying a rifle.

Keywords: military; weight-bearing; walking; physical exertion; physiological responses.

Resumen: El objetivo fue comparar las respuestas fisiológicas, durante una marcha de 12 km siguiendo los protocolos del Ejército Brasileño, entre dos grupos que transportaban diferentes cargas (equipo personal más ametralladora y equipo personal más fusil). Además, investigamos si existe una correlación entre el peso de la carga, en porcentaje de la masa corporal total (%MCT) y esas respuestas fisiológicas. Se analizaron las siguientes variables: frecuencia cardiaca media, variación de la frecuencia cardiaca, variación del lactato sanguíneo y percepción subjetiva del esfuerzo media. El grupo de equipo personal + ametralladora presentó medianas significativamente más altas para la frecuencia cardíaca media y la variación de la frecuencia cardíaca. Además, nuestros datos mostraron que la carga (%MCT) se correlacionó positiva y significativamente con todas las variables fisiológicas evaluadas, excepto con la variación del lactato sanguíneo. Realizar un transporte de carga de larga distancia con una ametralladora provocó un mayor esfuerzo cardiovascular que llevar un fusil. Además, las cargas más pesadas (% MCT) se correlacionan con una mayor respuesta cardiovascular y una mayor clasificación de percepción subjetiva del esfuerzo.

Palabras clave: militar; soporte de peso; caminata; esfuerzo físico; respuestas fisiológicas.

Lucas Vieira Coelho Dos Santos*
lucasvcoelhos@gmail.com

Adriane Mara de Souza Muniz*
adriane_muniz@yahoo.com.br

Bruno Trassi Fernandes Silva De Souza*
brunotrassi.eb@gmail.com

Ricardo Alexandre Falcão*
ricfal9@gmail.com

Verônica Pinto Salerno**
vpsalerno@yahoo.com.br

Luis Aureliano Imbiriba**
luis_aureliano@hotmail.com

Míriam Raquel Meira Mainenti*
miriam.mainenti@hotmail.com

* Exército Brasileiro.
Escola de Educação Física do Exército (EsEFEx).
Rio de Janeiro, Brasil.

** Universidade Federal do Rio de Janeiro.
Escola de Educação Física e Desportos (EEFD).
Rio de Janeiro, Brasil.

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1. INTRODUCTION

Military training and operations often depend on personal mobility. In these situations, soldiers carry their own equipment and supplies on their body, usually in backpacks and webbings, thus forming a load-carriage system (BIRREL; HOOPER; HASLAM, 2007; KNAPIK; REYNOLDS; HARMAN, 2004). Service members are thus required to maintain proper physical conditioning, as they may often find themselves in extreme situations where they must endure higher levels of fatigue than usually required from the population in general.

Among military preparation activities, marching training stands out, as it is one of the physical activities most required during military operations, representing about 60-70% of the Australian military tasks, for example (ORR, 2012). Lack of available motorized transport, tactical or terrain impositions and even military instruction or physical training are situations where troops are required to march (BRASIL, 2019). In addition, after marching, the troops must arrive at their stated destination on schedule and able to fight and fulfill the assigned mission.

Although terrain, weather conditions and psychological factors exert a considerable influence on marching (JOVANOVIĆ *et al.*, 2014; MCCORMICK; MEIJEN; MARCORA, 2015; VOLOSHINA, 2013), physiological factors should be given special attention, as physical fitness has a decisive relation to performance (KNAPIK *et al.*, 1990; KRAEMER *et al.*, 1987; SWAIN, 2011), and thus to the fulfillment of the task. Military personnel with platoon marching experience report there are more exhausting roles to be performed, due to the heavy load carried. Therefore, researches are being conducted to assess physiological responses of service members while carrying different loads (FAFUNDES *et al.*, 2017; HOLEWIJN, 1990; PAL *et al.*, 2009; PHILLIPS *et al.*, 2016; QUESADA *et al.*, 2000; STUEMPFLE; DRURY; WILSON, 2004), analyzing heart rate (HR), oxygen consumption (VO_2), rating of perceived exertion (RPE) and other physiological (ventilatory threshold, minute ventilation, respiratory exchange ratio, energy expenditure, inspiratory and expiratory mouth pressures, blood lactate, glucose concentration), biomechanical (electromyography activity, joint rotations and moments, isometric maximal voluntary contraction) and cognitive (correct responses, false alarms, sensitivity) variables (FAFUNDES *et al.*, 2017; FAGHY; BLACKER; BROWN, 2016; GILES, 2019; GRENIER *et al.*, 2012; HOLEWIJN, 1990; PAL *et al.*, 2009; PHILLIPS *et al.*, 2016; QUESADA *et al.*, 2000). However, study results still differ somewhat, with a set of studies not finding any effect of different loads on physiological responses (FAGHY; BLACKER; BROWN, 2016; FAGUNDES *et al.*, 2017; PHILLIPS, 2016) and another set that does (BORGHOLS; DRESEN; HOLLANDER, 1978; GILES, 2019; GRENIER *et al.*, 2012; PAL *et al.*, 2009; PIHLAINEN *et al.*, 2014), as described up below.

One of the first studies on this topic found that during a walk carrying weights of up to 30 kg, each extra kg of weight increased VO_2 by 33.5 milliliters per minute (ml/min), heart rate by 1.1 beats per minute (bpm) and pulmonary ventilation at 0.6 liters per minute (l/min) (BORGHOLS; DRESEN; HOLLANDER, 1978). Another study compared a 50-minute march at an average speed of 5.7 km/h while carrying 5.4 kg of equipment with the first 60 minutes of marching at an average speed of 5.4 km/h while carrying 24.4 kg of equipment, both on terrain with variable inclines (PIHLAINEN *et al.*, 2014). The study results showed significant increases in VO_2, $\%VO_2max$, HR and %HRmax when carrying 24.4 kg (PIHLAINEN *et al.*, 2014). Grenier *et al.* (2012) also identified a significant variation in mean HR (91 bpm to 139 bpm) depending on the load (23 kg or 47 kg) and the positive elevation change (240 m and 570 m) over the course of the 15-km march. Another study also found that walking speed interferes with HR (modified Harbor protocol), which increases according to speed and load (unloaded: 88.7 bpm at 3.5 km/h, 94.8 bpm at 4.5 km/h; with a 40-kg load: 114.4 bpm at 3.5 km/h, 127 bpm at 4.5 km/h) (PAL *et al.*, 2009). More recently, Giles *et al.* (2019) found a significant load carriage impact on %HR reserve, with values progressively increasing for load carriage conditions of 47.2 kg and 50.7 kg, compared with 8.8 kg.

Other studies, however, have found different results. Fagundes *et al.* (2017) found no significant differences in HR and RPE when varying the load from 0% to 15% of body mass both in maximal running tests and in a submaximal test at 90% of the ventilatory threshold. Phillips *et al.* (2016) also did not find significant HR variations when comparing loaded (25 kg; 189 bpm) and unloaded (187 bpm) maximal stress tests using the modified Balke protocol, despite a reduction in test duration in the loaded condition. Faghy, Blacker and Brown (2016) found no significant differences in blood lactate values when comparing 60-minute submaximal tests performed on a treadmill, with varying loads ranging from 0 to 20 kg.

In addition to this lack of consistency in findings, most studies carried out laboratory tests (FAGHY; BLACKER; BROWN, 2016; FAGUNDES *et al.*, 2017; HOLEWIJN, 1990; PHILLIPS *et al.*, 2016; PAL *et al.*, 2009; QUESADA *et al.*, 2000; STUEMPFLE, DRURY, WILSON, 2004) and did not vary the weight of weaponry, only of backpacks. However, weapons are usually carried during marches, training activities and military operations, and should be considered and assessed. The function which involves carrying a rifle has great importance for platoon tactical organization, as it is the most basic one and performed by most platoon soldiers, as well as carrying a machine gun, due to the firepower of this armament. Knowing the variations in physiological responses involved in each of the platoon duties will help to establish differentiated training activities aimed at developing a level of physical conditioning adequate to the effort required for loaded marching.

Therefore, the aim of this study was to compare physiological responses between a group of individuals carrying personal equipment (PE) plus a machine gun with another group carrying personal equipment plus a rifle during a 12-km march. In addition, we examined whether there is a correlation between the load carried, in percentage of total body mass (%TBM), and the physiological responses measured.

2. METHODS

2.1 Study design

An experimental study was carried out in which military service members were randomly assigned to two groups to perform a 12-km march: carrying either a rifle (lighter, control group) or a machine gun. Physiological responses were measured before, during and after marching.

2.2 Ethical aspects

The study research protocol was approved by the local ethics committee (CAAE: 83493618.1.0000.5235).

2.3 Sample

The sample consisted of 30 volunteer military officers (lieutenants and captains) serving in a Brazilian Army garrison in Rio de Janeiro (convenience sample). Inclusion criteria were as follows: participants should be military volunteers, male, aged between 20 and 32 years old (median: 26.50; 1st quartile: 25.00; 3rd quartile: 28.00 years old), in active service from 7 to 15 years (median: 8; 1st quartile: 7; 3rd quartile: 10 years), have achieved a minimum score of "Good" (B) in the Army Physical Fitness Test (APFT) and have signed the Free and Informed Consent Form (FICF). Were excluded from the study those who had just ended their period of assigned daily duties; with orthopedic, rheumatologic, respiratory or neurological conditions; with acute or chronic musculoskeletal pain; or who used medication that could alter the visual and vestibular systems. Health information was self-reported by participants and confirmed with their military organization's Health Section.

2.4 Test procedures

All participants performed a 12-km march in accordance with the Brazilian Army field manual (BRASIL, 2019). The march was divided into three 4-km stages, with a total duration of three hours. The first stage lasted 45 minutes (average speed of 5.3 km/h), followed by a 15-min rest period. The second and third stages were completed in 50 minutes each (average speed of 4.8 km/h), with a 10-min interval between them (BRASIL, 2019). The 12-km march was performed on a 1-km track, with the start and finish lines at the same place. Two persons at checkpoints located about 500 meters apart were tasked with monitoring the participants' average speed and alerting them to increase or reduce their pace.

All participants marched wearing personal equipment (PE), consisting of belt, suspenders, two 1-liter canteens filled with water, helmet and a large capacity backpack.

However, the sample was randomly divided into two equal groups of 15 participants, each group armed with a different weapon: one used a rifle simulator (4.7 kg) and the other a machine gun simulator (10.8 kg). Both simulators consisted of Mauser Model 1935 rifles with different loads attached to their centers in order to reach the approximate weight of the rifle and the machine gun.

Marching took place in the facilities of the Army's Physical Training Center (CCFEx), Rio de Janeiro. Three volunteers were selected each day between 17:00 and 22:00. Average temperature during marches was of 22.94 ± 1.93ºC and relative humidity was 79.61 ± 4.78%.

Volunteers showed up at the laboratory half an hour before marching for filling the anamnesis form (informing their last APFT score, length of service, age and presence or absence of pain or injury), signing the FICF and having total body mass (TBM, with and without the equipment), pre-effort lactate and resting heart rate measured. They were then randomly assigned to a group by drawing of lots. First we used 10 pieces of paper (10 days of data acquisition) with different sequences of three conditions (we collected data from three military officer per day). The distribution of rifle and machine gun in these sequences was organized in order to ensure a total of 15 individuals for each group. Then, we used simple pieces of paper in a small box with letters F and M, for rifle (F from "fuzil", rifle in Portuguese) and machine gun groups, respectively. After knowing which weapon would be used, we presented instructions on the sequence of activities, the route to be taken and safety rules.

Before marching, all participants ate a cereal bar containing 79 kilocalories and hydrated themselves with at least 200 milliliters of water. Each volunteer marched alone and to this end they started the march at intervals of about 20 minutes. During the rest periods, participants were allowed to remove the backpack and were fed a cereal bar and hydrated.

Heart rate was recorded continuously and perceived exertion was recorded at 0.5 km intervals (while marching) and at the end of the march. After marching, lactate was measured again. The assessments were performed by trained examiners who were working with the main output variables for, at least, six months. Furthermore, the heart rate monitor and the blood analyzer employed in this study are worldwide used and well respected for scientific purposes.

2.5 Instruments

Heart rate (HR) was measured with a V800 heart rate monitor (Polar, Finland), fitted with a Polar H7 strap. After marching, data (HR, distance covered, pace, among others) were transmitted via bluetooth for storage with the Polar Flow software (Polar, Finland). Lactate was measured by analyzing capillary blood with an Accutrend Plus monitor (Roche, Portugal). Perceived exertion was assessed using the modified Borg rating of perceived exertion (RPE), ranging from zero (no exertion) to ten (maximum exertion) (BORG, 1998); participants were given instruction on the scale before marching, which was later reinforced during data collection.

Participants' height was measured with a Professional Sanny stadiometer (American Medical do Brasil Ltda, Brazil) and their Total Body Mass (TBM) with a model 876 digital scale (Seca, Germany). Temperature and relative humidity were measured with a digital thermo-hygrometer (Incoterm, model TTH100, Brazil) at the beginning of each marching stage.

Data Analysis

Outcome variables were mean heart rate during the 12-km march excluding rest periods (Mean HR); heart rate variation (HR Var), calculated by subtracting the maximum value reached and the rest value; lactate variation (Lac Var = post-march value - pre-march value); and the average of all recorded values of RPE over the 12 km (Mean RPE).

The Shapiro-Wilk test was used to assess the normality of the data set. For descriptive statistics, the median was used [1st quartile; 3rd quartile], because most data have a non-parametric distribution. Statistical comparison of groups was performed using the independent samples Student's T test for Mean HR, age, TBM, height and total load carriage weight (parametric data), and the Mann-Whitney U test for HR Var, Lac Var and Mean RPE (nonparametric data). Categorical data of APFT scores were presented in absolute and relative frequency, and the two groups were compared using the chi-squared test.

Correlation between load (% of total body mass) and outcome variables were assessed using the Pearson test (r) for Mean HR and the Spearman test (rho) for HR Var, Lac Var and Mean RPE. The correlation coefficient (r/rho) was classified as: very strong for r values ≥ 0.90; strong for r between 0.6 (inclusive) and 0.9; regular for r between 0.3 (inclusive) and 0.6; and weak between 0 and 0.3 (CALLEGARI-JACQUES, 2003).

Statistical significance was set at $p < 0.05$, and the analyzes were performed using the SPSS software (version 27.0).

3. RESULTS

Sample characterization data are shown in Table 1. The groups were not different for age, total body mass, height nor Army physical fitness test scores (APFTS). They differed only in the conditions set for the purpose of this study, the total load carriage weight: PE + rifle = 24.7 [24.4; 24.8] kg and PE + machine gun = 30.7 [30.7-30.8] kg ($p < 0.001$).

Table 1– Characterization of the sample

	Total	PE + rifle	PE + machine gun	p value
Age (years)	26.50 (25.00 - 28.00)	27.00 (25.00 – 28.00)	26.00 (25.00 – 29.00)	1.00$^{\alpha}$
TBM (kg)	79.72 (73.96 - 85.88)	79.05 (74.15 – 85.85)	80.00 (69.55 – 86.00)	0.96$^{\alpha}$
Height (m)	1.77(1.71 - 1.82)	1.79 (1.70 – 1.87)	1.77 (1.71 – 1.81)	0.70$^{\alpha}$
APFTS (%)	E - 46.7% VG - 20.0% G - 33.3%	E - 53.3% VG - 20.0% G - 26.7%	E - 40.0% VG - 20.0% G - 40.0%	0.71$^{\beta}$

Source: the authors.

Subtitle: PE = Personal equipment, TBM = Total Body Mass, APFTS = Army physical fitness test score, E = Excellent, VG = Very good, G = Good. $^{\alpha}$p value for Student's T test; $^{\beta}$p value for chi-squared test.

Mean HR and HR Var data for only 26 of the 30 participants were used, due to the loss of data due to operational problems with the frequency meters.

Considering the sample as a whole, the following results were obtained: Mean HR = 117.19 (110.24 - 123.91) bpm; HR Var = 75.00 (59.75 - 81.25) bpm; LacVar = -0.35 (-0.83 - 0.30) mmol/L; Mean RPE = 2.38 (2.03 - 3.21). Comparisons between groups revealed that the PE + Machine Gun group showed higher Mean HR and HR Var (Graphic 1) compared with the PE + Rifle group. No difference was found for Lac Var, with values of PE + rifle = -0.40 [-0.80; 0.60] mmol/L and PE + machine gun: -0.30 [-0.90; 0.10] mmol/L (p = 0.983); and for Mean RPE, with values of 2.25 [2.00; 2.88] and 2.83 [2.33; 3.83], respectively (p = 0.065).

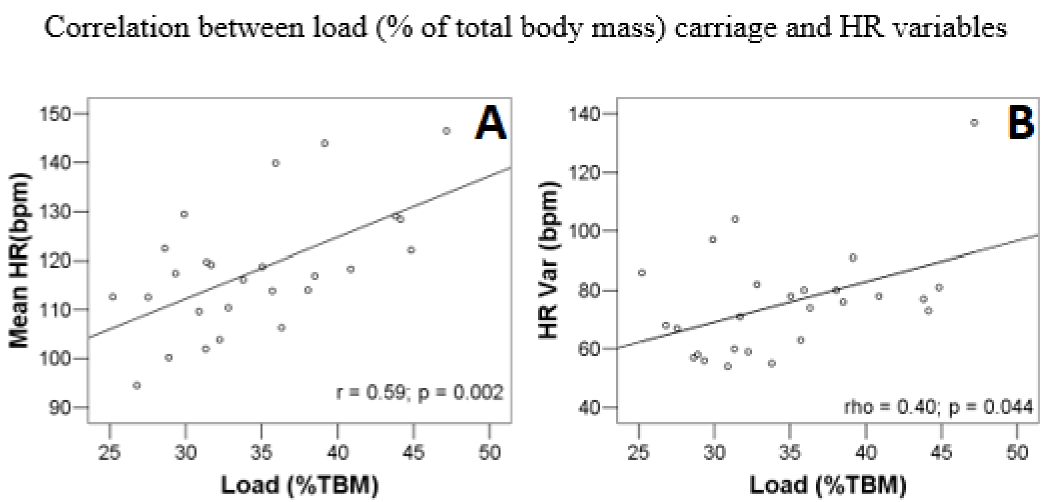
Graphic 1 – Box plot with median, quartiles (1st and 3rd), and minimum and maximum values for Mean HR (mean heart rate) and HR Var (heart rate variation)

Source: the authors.

Subtitle: A) Mean HR (mean heart rate) and B) HR Var (heart rate variation) for PE (personal equipment) + Rifle and PE + Machine Gun groups. * p < 0.05.

Except for Lac Var (rho = 0.15), all variables showed positive, regular and significant correlations with load (% of total body mass) (Graphics 2, 3).

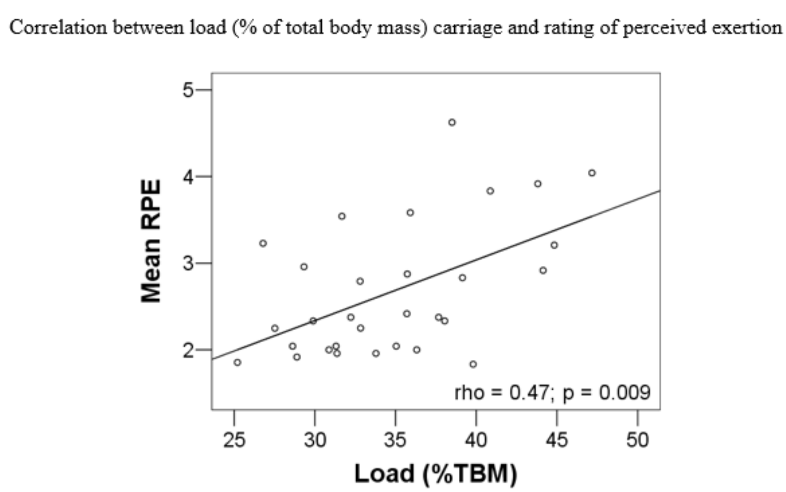
Graphic 2 – Scatter plot for load %TBM (% of total body mass), Mean HR (Mean heart rate) and HR Var (Heart rate variation)



Source: the authors

Subtitle: A) Mean HR (mean heart rate) and B) HR Var (heart rate variation). r = Pearson's correlation coefficient; rho = Spearman's correlation coefficient.

Graphic 3 – Scatter plot for load %TBM (% of total body mass) and Mean RPE (Mean rating of perceived exertion)



Source: the authors.

Subtitle: rho = Spearman's correlation coefficient; RPE = rating of perceived exertion; TBM = total body mass

4. DISCUSSION

This study aimed to compare physiological responses in a 12-km loaded march between two groups of participants: one carrying PE plus a machine gun and the other carrying PE plus a rifle. Additionally, we investigated whether there is a correlation between load carriage weight, in percentage of total body mass (% TBM) and physiological responses. Study results show that carrying the heaviest armament resulted in higher cardiovascular stress, with participants showing higher values for Mean HR and HR Var. With the exception of Lac Var, all variables showed a positive, regular and significant correlation with load carriage weight, as a percentage of total body mass.

The greater cardiovascular demands showed by the group that carried the heaviest load can be explained by the fact that physical activity increases the body's energy requirements, provoking several physiological responses aimed at meeting the increased metabolic demand (BRUM *et al.*, 2004). Cyclical activities such as marching cause an increase in the activity of the sympathetic nervous system (FORJAZ; TINUCCI, 2000), and as a result in heart rate (HR), stroke volume (SV) and cardiac output (CO) (FORJAZ *et al.*, 1998). According to Forjaz and Tinucci (2000), the greater the intensity of the exercise the greater the physiological responses, but these responses do not change during exercises performed at an intensity below the anaerobic threshold. Thus, holding and moving around with the additional weight of the machine gun requires greater CO, which can be achieved through greater HR and SV (MCARDLE; KATCH; KATCH, 2014), explaining the significantly greater values showed by the PE + machine gun group.

These results agree with those of Quesada *et al.* (2000), who identified that each 15% increase in load weight resulted in an increase in metabolic cost of about 5 to 6% when performing a 40-minute treadmill walk; however, the results differ from those of Fagundes *et al.* (2017), who found no significant difference in submaximal effort tests performed on a treadmill with loads ranging from 0 to 15% of body mass. Phillips *et al.* (2016) found no significant difference in Mean HR between groups carrying no load and a 25-kg load in incremental tests on the treadmill.

Grenier *et al.* (2012) found a variation of 81 bpm in a 4-hour march while carrying a 43-kg load for a simulated military mission, very similar to our results for the PE + machine gun group, which showed a median variation of about 80 bpm.

Unlike our Mean HR and HR Var results, lactate data indicate that differences in the weight carried do not significantly alter blood lactate levels, in agreement with the findings of Faghy, Blacker and Brown (2016), who also did not find significant differences in lactate levels. The likely cause for this result is that both groups performed a long-duration aerobic activity, which leads to a predominance of the oxidative system, resulting in a small concentration of lactate produced by the muscle (MCARDLE; KATCH; KATCH, 2014). The increase in blood lactate concentration is related to an increased lactate production in the muscles, which in turn is directly linked to the use of the lactic anaerobic system to generate enough energy for physical activity (MCARDLE; KATCH; KATCH, 2014).

The lactic anaerobic system is mainly used by the body in more intense physical activities, which require a large amount of energy in a short period of time (MCARDLE; KATCH; KATCH, 2014). Marching, for physically fit individuals, does not have the characteristics of these intense activities, and thus the energy system mostly used by the study participants was the aerobic system. In addition, because it requires greater CO, there is an increase in the blood flow, leading to a faster removal of lactate from the muscles and its transport to the liver to be converted into glucose. Therefore, it is understandable that there have been no major changes in lactate levels.

Perceived exertion data, in turn, showed no significant difference between the groups rifle and machine gun (p=0.065). However, when considering the relative load (a percentage of the individual's total body mass), it could be noted a positive significant correlation between load and RPE values. These results are in agreement with those of Quesada *et al.* (2000), who found a significant increase in RPE for loads equal to 30% of body mass (BM) in relation to 0%-BM and 15%-BM loads, possibly indicating that RPE increases for loads heavier than 30% of body mass.

A particularity of actual military operations is that, with respect to load carriage, all individuals carry similar absolute weight values, regardless of their body mass. This may cause smaller individuals to expend more energy, possibly generating more fatigue and greater risk of injury. To address this possibility, a correlation analysis was performed to assess the correlation between physiological responses and the weight of the load carried as a percentage of total body mass. Three of the four variables analyzed showed a positive and significant correlation with load (% of total body mass), confirming that a higher BM percentage load generates a greater physiological response.

One of the study limitations is that physiological responses were measured by simpler techniques compared with the direct measurement of oxygen consumption (VO_2) by gas-exchange analysis, which would allow energy expenditure estimation for a given physical activity (MCARDLE; KATCH; KATCH, 2014). This knowledge, however, would not be applicable to combat situations, with military personnel transporting their equipment on a foot march. To this end, heart rate measurement is a tool often used for estimating the intensity level of a physical activity. Another limitation was analyzing the load carried as a percentage of TBM and not of lean body mass. Using the latter in the analysis would allow distinguishing between individuals with the same body mass value but different body compositions. Percentage of body fat and lean body mass assessments should be added in future studies. This will make possible the analysis of load as a percentage of lean body mass or even specifically muscle mass, which will present a better data about muscle quality and function. It should be noted, however, that the troops' lean body mass values would hardly be available, and, on the other hand, TBM measurement is easy to perform, making this study's approach more realistic and applicable to large military contingents. Moreover, only the armament varied in weight, but machine gun ammunition is known to be heavier, adding to the backpack weight and further impacting the results.

One of the study's strengths was conducting the march outside the laboratory environment, with an uneven route and external climatic conditions, thus improving the study's external validity. Another highlight was using equipment provided by the Brazilian Army's supply chain, which allowed reproducing the same load-carriage conditions that Brazilian troops face in actual military operations, especially with regard to weight distribution, balance and comfort. The only exception was the boots used, which belonged to each participant, in order to ensure greater comfort and avoid possible foot injuries.

It is also worth mentioning that this study aimed to analyze physiological responses in conditions as close as possible to those of actual operations: the load was carried not only in the backpack but also distributed among helmet, armament, belt and suspenders. Finally, marching distance was greater than in most studies (BEEKLEY *et al.*, 2007; QUESADA *et al.*, 2000), so as to observe the behavior of the variables over a longer time period.

5. CONCLUSIONS

Performing long-distance load carriage with a machine gun caused a greater cardiovascular effort than load carriage with a rifle. Moreover, carrying heavier loads (%TBM) is correlated with greater cardiovascular responses and greater RPE values. Military personnel that usually carry a machine gun during operational marching should pay more attention to improving their aerobic training than those that usually carry a rifle. Another practical implication of this fact is that commanders should select soldiers with better aerobic conditioning to carry machine guns, since this weapon demands a greater effort of the cardiovascular system.

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AUTHORSHIP AND CONTRIBUTIONS

Lucas Vieira Coelho Dos Santos – writing (original draft, revision and edition)

Adriane Mara de Souza Muniz and Ricardo Alexandre Falcão – conceptualization, methodology and writing (revision)

Bruno Trassi Fernandes Silva De Souza – writing (original draft and revision)

Verônica Pinto Salerno and Luis Aureliano Imbiriba – writing (revision)

Míriam Raquel Meira Mainenti – conceptualization, methodology and writing (revision and edition)

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