Prolonged Physical Effort Affects Cognitive Processes During Special Forces Training

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Abstract. This study aimed to investigate the effects of strenuous physical exertion on biomarkers of muscle damage, on physical and mental fatigue, and on cognitive processes. Seventeen military (males 24–40 years old) were tested cognitively at six time points, while they were progressively exhausted over the course of 102 h of continued operations. Three types of variables were analyzed: biomarkers of muscle damage [serum levels of creatine kinase (CK) and lactate dehydrogenase (LDH)], reported physical fatigue (PF) and mental fatigue (MF), and cognitive processes [(verbal reasoning (VR), numerical reasoning (NR) and spatial reasoning (SR) and short-term memory (STM)]. The results revealed significant increases in CK, LDH, PF and MF. On the other hand, we found significant decreases in VR, NR, SR and STM, which were negatively correlated MF. Our results show additional evidences about the impact of strenuous physical exertion on muscle damage, physical and mental fatigue, and cognitive processes.

Keywords: Strenuous physical exertion · Physical fatigue · Mental fatigue · Cognitive processes · Continued operations

1 Introduction

Continued operations is a common type of military operation prevalent in ground warfare involving continuous individual performance for periods longer than twenty-four hours. The soldiers must work steadily for long periods without rest, and are typically unaware of their next opportunity for sleep, feed and hydration, working instead until an objective is reached [1–3]. This type of operation entails continuous physical and mental workload that result in fatigue, which may collectively lead to poor performance, accidents, and decrease of mission effectiveness [4–7].

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A critical issue for military authorities in Brazil is the identification of parameters that indicate the intensity of military training and how physical exertion can interfere with the cognitive performance of military enrolled in training with high physical and psychological demands [8–10]. In order to accomplish this goal, since 2012 the Special Operations Instruction Center has developed the project entitled Biomedical Research in Commandos Actions, which aims, among other objectives, to evaluate the impact of strenuous physical exertion on muscle damage, how it is related with physical and mental fatigue, and how the fatigue can affect cognitive processes [7].

Strenuous physical exertion can cause muscle damage that is a dysfunction in the cell membrane, which allows the migration of the intracellular content into the extracellular environment and into the systemic circulation [11–15]. Muscle damage can be identified from apparent histological changes and from quantification of specific serum levels of muscle enzymes such as creatine kinase (CK) and lactate dehydrogenase (LDH), which serve as indicators of increased of permeability or destruction of muscle cells. Thus, biomarkers of muscle damage have been used to screen overtraining and fatigue [12, 16–19].

It is well known that high levels of fatigue and stress can negatively affect cognitive functions needed for decision-making [20–24]. For example, errors are likely to occur in cognitive functions such as: attention, memory formation and memory recall [23, 25–28], in decision processes that underlie perception, attention such as signal detection and executive functioning [29, 30] such as set shifting and categorization [30] or operant conditioning [31].

In such a context, by employing biomarkers of skeletal muscle damage, this study aims to examine the effects of strenuous physical exertion on physical and mental fatigue, which can in turn affect the cognitive processes during 102 h of Special Forces training. We hypothesized that during continued operations there would be an increase in biomarkers of muscle damage, which would be positively associated with the levels of physical and mental fatigue. On the other hand, we also hypothesized that cognitive performance would significantly decrease, and would be negatively correlated with biomarkers of muscle damage, physical fatigue and mental fatigue.

2 Methods

Participants were requested to complete 102 h of the Leadership Development Exercise (LDE), while variables of interest (biomarkers of muscle damage, subjective perceptions of physical and mental fatigue, and performances on cognitive tests) were recorded. All variables of interest were collected in six different time points: Baseline (BL) - 6:00 am first activity of the LDE, 24 h (24 h), 48 h (48 h), 72 h (72 h), 96 h (96 h), and 102 h after LDE had begun (102 h). The data collection procedures included taking a blood sample and filling out the Clinical Subjective Parameters Questionnaire (CSPQ), followed by the completion of a cognitive test. Each data collection at each time point lasted approximately 45 min. The first five collections were performed at the beginning of each day at 6:00 am. The sixth test routine was conducted at 12:00 am at the end of LDE. Subjects were not permitted unallowed to rest, sleep, eat or hydrate themselves over the course of the LDE.

Subjects. Seventeen subjects (all men, age range = 24–40 years, mean = 28.7 and standard deviation = 4.19), enrolled in the 2013 Command Actions Course of the Brazilian Army, participated in the present study. All subjects were right-hand dominant and right-eye dominant without a history of neurological or psychiatric disorders or psychotropic medications at the time of their participation in the study. Prior to testing, all participants gave their written informed consent in accordance with the protocol approved by Special Operations Instruction Center Institutional Review Board, and were also informed that they were free to withdraw from the study at any time. Before beginning the LDE, all participants were evaluated by a medical committee.

Leadership Development Exercise. The LDE is a field military exercise conducted in the context of 102 h of continued operations, which was developed with the purpose of enabling military performance evaluation over the course of one week of intense physical and mental activity. The LDE is divided into three stages: 48 h Rest Time (RT), Leader Reaction Test Preparation (LRTP - 96 h) and Leader Reaction Test (LRT - 6 h) [8]. The participants were instructed to eat, hydrate, prepare their equipment, and rest as must as possible (at least 7 h of sleep) per evening 48 h prior to base line (BL). During LRTP, the participants performed patrols and typical military activities in a continued operations context during four cycles of 24 h, which involve studies of tactical situations, planning tactical missions, an approach march (about 20 km), mission performance, orientation, transposition of watercourses, shooting and obstacle courses, and a return march to base (about 20 km). During the LRT, subjects must perform 12 workshops that simulate combat, which requires them to demonstrate effective attributes of leadership, selflessness, courage, adaptability, self-confidence, cooperation, decision, emotional balance, objectivity, persistence and resistance. While the activities were performed, combat stressors were progressively applied, according Table 1.

Blood Sampling. Blood samples were collected by qualified professionals linked to the Clinical Analysis Laboratory of the Doctrine and Research Division (DRD) of the Especial Operations Instruction Center. An 8-ml blood sample was collected from the antecubital vein at each sample time, using a winged cannula attached to a

Table 1. Combat Stressors applied during Leadership Development Exercise.

Combat Stressors	Time Points					
	BL	**24 h**	**48 h**	**72 h**	**96 h**	**102 h**
Water restriction (l)	Free	2.0	1.0	0.5	0.0	0.0
Food restriction (cal)	Free	2,500.0	1,000.0	500.0	0.0	0.0
Sleep allowed (hr)	Free	2.0	1.0	0.5	0.0	0.0
Weight carried (kg)	0.0	30.0	35.0	40.0	45.0	0.0
Physical effort**	Rest	4	5	6	7	8
Mental effort**	Rest	4	5	6	7	8

*48 h to rest from 6:00am on Saturday until 6:00am on Monday (Base line day).
**Adapted from 0-10 Borg Rating of Perceived Exertion Scale [32]. The numbers mean: Somewhat strong (4), Strong (5, 6), Very strong (7, 8).

vacutainer (Becton Dickinson Rutherford, N. J.). A fresh venous puncture was used for each sample. The blood sample was collected into 8 ml Serum Clot Activator with gel Separator Blood Collection Tube clotting tubes with separator gel (VACUETTE®). After clot retraction, the gel tubes were centrifuged at 3000 rpm for 15 min to separate the serum for determination of the measures of interest. Serum levels of CK and LDH were determined by using the automated analyzer Vitros250® (Ortho Clinical Diagnostics - Johnson & Johnson), using Johnson & Johnson kits by dry-chemistry method.

Subjective Measures. We investigated the subjective clinical parameters using the Clinical Subjective Parameters Questionnaire (CSPQ) developed by the DRD. The CSPQ is divided into seven (7) parts, which had to be answered in 5 min. In order to assess the levels of physical fatigue (PF) and mental fatigue (MF) accumulated in the preceding 24 h, we used the fourth part of CSPQ (P4). The measurement scale was adapted from 1-10 Borg Rating of Perceived Exertion Scale [32] and the subjects were required to indicate their levels of PF and MF checking one value that could vary between: Nothing at all (0), Very, very weak (0.5), Very weak (1), Weak (2), Moderate (3), Somewhat strong (4), Strong (5, 6), Very strong (7, 8, 9), Very, very strong (10). The different verbal expressions were then placed where they belonged according to their ratio properties. When using this scale, subjects were allowed to use decimals but they could not go beyond 10.

Cognitive Test. Cognitive processes were investigated using the Cognitive Tests (CT) developed by DRD. The CT is divided into seven questions (Q) in a total of 80 scores: two for verbal reasoning (VR - 20 scores), two for numerical reasoning (NR - 20 scores), two for spatial reasoning (SR - 20 scores) and a for short-term memory (STM - 20 scores). VR was evaluated in questions 1 and 4 (Q1 and Q4). In Q1, VR was tested by analysis of four words, which had to be compared to one another. The subject was asked to indicate the different word among the four according to the following criteria: spelling, size, context or meaning. In Q4, the subjects were told to read a sentence and evaluate ten claims about the sentence, stating whether these claims were true or false depending on the statement in the sentence. NR was evaluated in questions 2 and 3 (Q2 and Q3). In Q2 the subject had to fill two gaps, one related to an arithmetic progression and another referring to a geometric progression. In Q3, the participants filled gaps related to mathematical operations in the following order: addition, multiplication, division and subtraction. Questions 5 and 6 (Q5 and Q6) evaluated SR. In Q5, the object was to understand the logical sequence in which black squares were presented on a 10×10 white square board, while the black squares changed their positions from the first board to the second board. The subjects were asked to fill the gaps into a third board on their respective logical future positions. In Q6, the participants marked with a circle the different crosses symbols on a 30×30 crosses board. Question 7 (Q7) assessed STM. In Q7, the subjects were required to memorize a sequence of 20 characters (12 numbers and 8 letters) for one minute, turn the page, and wait for one minute until the command was given to fill in the answer sheet. The CT took 15 min to complete.

Statistical analysis. The Shapiro-Wilk test was employed to verify the hypothesis of normal distribution of frequencies. Since the data were not normally distributed, we used the Friedman ANOVA test to determine whether there were significant differences among the measures of interest (serum levels of CK and LDH, PF and MF, VR, NR, SR and STM) as a function of the severity of military training conditions imposed by the LDE. The Wilcoxon tests were applied post hoc to determine nature of the significant differences. The Spearman Rank Correlation Coefficient tests were applied to determine correlations among biomarkers of muscle damage physical and mental fatigue, as well as among cognitive performances and physical and mental fatigue. Significance was established at the $p < 0.05$ level. Analysis of all data was conducted using the SPSS for Windows (version 20).

3 Results

Muscle damage and physical and mental fatigue. We found significant differences in serum levels of CK ($\chi^2 = 66.714$, $p < 0.001$) and LDH ($\chi^2 = 76.529$, $p < 0.001$) as well as PF ($\chi^2 = 79.288$, $p < 0.001$), MF ($\chi^2 = 81.096$, $p < 0.001$) among the six time points of test. The descriptive measures of CK, LDH, PF and MP are shown respectively in the Figs. 1 and 2.

In order to evaluate which time point were different from each other, we applied the Wilcoxon test (see Table 2).

Serum levels of CK were different among all time points of test compared to baseline (BL < 24 h, BL < 48 h, BL < 72 h, BL < 96 h, BL < 102 h). CK increased on

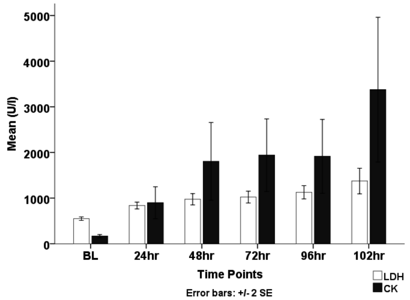

Fig. 1. Serum levels of CK and LDH during 102 h of strenuous physical exertion.

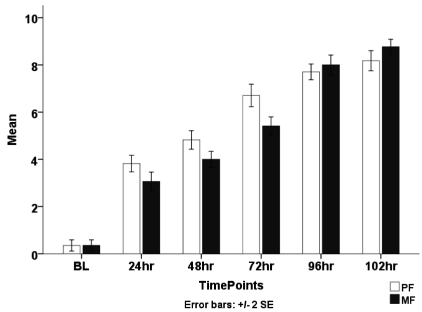

Fig. 2. Reported physical and mental fatigue during 102 h of strenuous physical exertion.

Table 2. Differences in serum levels of creatine kinase, lactate dehydrogenase, physical and mental fatigue as a function of time points of test.

Time points			CK			LDH			PF			MP		
			Dif	**Z**	***p***	**Dif**	**Z**	***p***	**Dif**	**Z**	***p***	**Dif**	**Z**	***p***
24 h	–	**BL**	731.41	-3.621	<0.001**	287.88	-3.622	<0.001**	3.47	-3.729	<0.001**	2.71	-3.671	<0.001**
48 h	–	**BL**	1,637.24	-3.621	<0.001**	425.53	-3.621	<0.001**	4.47	-3.647	<0.001**	3.65	-3.671	<0.001**
72 h	–	**BL**	1,773.53	-3.621	<0.001**	473.18	-3.621	<0.001**	6.35	-3.690	<0.001**	5.06	-3.695	<0.001**
96 h	–	**BL**	1,747.76	-3.621	<0.001**	577.65	-3.621	<0.001**	7.35	-3.782	<0.001**	7.65	-3.716	<0.001**
102 h	–	**BL**	3,208.76	-3.621	<0.001**	825.24	-3.621	<0.001**	7.82	-3.684	<0.001**	8.41	-3.779	<0.001**
48 h	–	**24 h**	905.82	-3.479	0.001**	137.65	-3.574	<0.001**	1.00	-2.506	0.012*	0.94	-2.388	0.017*
72 h	–	**24 h**	1,042.12	-3.621	<0.001**	185.29	-3.574	<0.001**	2.88	-3.697	<0.001**	2.35	-3.714	<0.001**
96 h	–	**24 h**	1,016.35	-3.290	0.001**	289.76	-3.574	<0.001**	3.88	-3.782	<0.001**	4.94	-3.711	<0.001**
102 h	–	**24 h**	2,477.35	-3.621	<0.001**	537.35	-3.621	<0.001**	4.35	-3.687	<0.001**	5.71	-3.649	<0.001**
72 h	–	**48 h**	136.29	-1.207	0.227	47.65	-2.817	0.005*	1.88	-3.231	0.001**	1.41	-3.096	0.002**
96 h	–	**48 h**	110.53	-1.112	0.266	152.12	-2.817	0.005*	2.88	-3.648	<0.001**	4.00	-3.656	<0.001**
102 h	–	**48 h**	1,571.53	-2.627	0.009**	399.71	-3.621	<0.001**	3.35	-3.646	<0.001**	4.76	-3.666	<0.001**
96 h	–	**72 h**	-25.76	-1.538	0.124	104.47	-2.485	0.013*	1.00	-3.314	0.001**	2.59	-3.703	<0.001**
102 h	–	**72 h**	1,435.24	-2.059	0.039*	352.06	-3.621	<0.001**	1.47	-3.119	0.002**	3.35	-3.652	<0.001**
102 h	–	**96 h**	1,461.00	-3.006	0.003**	247.59	-3.622	<0.001**	0.47	-1.730	0.084	0.76	-2.517	0.012*

* Differences are significant at the 0.05 level (2-tailed).
** Differences are significant at the 0.01 level (2-tailed).

average of 1,085.84 % among the time point. CK increased significantly until the first 48 h of the LDE, remained relatively stable up to 96 h (48 h = 72 h = 96 h) and increased again by the end of the LDE (102 h > 96 h, 102 h > 72 h, 102 h > 48 h, 102 h > 24 h, 102 h > BL). CK was positively correlated with PF ($r_s = 0.726$, $p < 0.001$) and with MF ($r_s = 0.687$, $p < 0.001$). Serum levels of LDH were also different among all time points of test compared to baseline (BL < 24 h, BL < 48 h, BL < 72 h, BL < 96 h, BL < 102 h). LDH increased on average of 94.17 % among the time points and were different from each other in all time points of test (BL < 24 h < 48 h < 72 h < 96 h, < 102 h). LDH was positively correlated with PF ($r_s = 0.761$, $p < 0.001$) and with MF ($r_s = 0.725$, $p < 0.001$).

Reported physical fatigue levels were different in all time points compared to baseline (BL < 24 h, BL < 48 h, BL < 72 h, BL < 96 h, BL < 102 h). As expected, physical fatigue levels increased progressively until the first 96 h remaining high until the end of the LDE (BL < 24 h < 48 h < 72 h < 96 h = 102 h). Similarly, mental fatigue levels were different in all time points compared to baseline (BL < 24 h, BL < 48 h, BL < 72 h, BL < 96 h, BL < 102 h), increasing progressively until the end of the LDE (BL < 24 h < 48 h < 72 h < 96 h < 102 h). PF was positively correlated with MF ($r_s = 0.969$, $p < 0.001$).

Cognitive processes. As expected, we found significant differences in all subcomponents of the cognitive tests [VR ($\chi^2 = 82.728$, $p < 0.001$), NR ($\chi^2 = 82.072$, $p < 0.001$), NR ($\chi^2 = 81.955$, $p < 0.001$), e STM ($\chi^2 = 84.019$, $p < 0.001$)] among the six time points of test (Fig. 3).

In order to evaluate which time point were different from each other, we applied the Wilcoxon test (see Table 3).

VR performances were different in all time points of test compared to baseline (BL < 24 h, BL < 48 h, BL < 72 h, BL < 96 h, BL < 102 h), decreasing progressively until the end of the LDE (BL < 24 h < 48 h < 72 h < 96 h < 102 h). RV decreased on

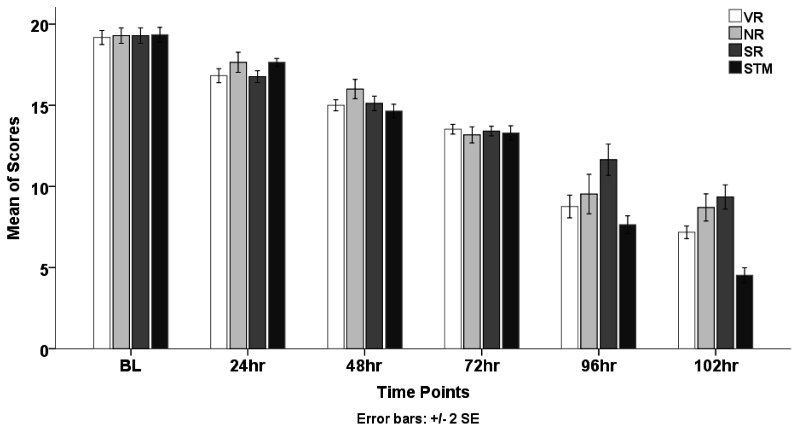

Fig. 3. Performance on verbal reasoning, numerical reasoning, spatial reasoning and short-term memory tasks during 102 h of strenuous physical exertion.

Table 3. Differences in cognitive processes as a function of time points of test

Time points			VR			NR			SR			STM		
			Dif	Z	*p*	Dif	Z	*p*	Dif	Z	*p*	Dif	Z	*p*
24 h	–	**BL**	2,35	-3,695	<0.001**	1,65	-3,742	<0.001**	2,53	-3,654	<0.001**	1,71	-3,624	<0.001**
48 h	–	**BL**	4,18	-3,672	<0.001**	3,29	-3,714	<0.001**	4,18	-3,641	<0.001**	4,71	-3,644	<0.001**
72 h	–	**BL**	5,65	-3,655	<0.001**	6,12	-3,779	<0.001**	5,88	-3,695	<0.001**	6,06	-3,651	<0.001**
96 h	–	**BL**	10,41	-3,632	<0.001**	9,76	-3,641	<0.001**	7,65	-3,646	<0.001**	11,71	-3,652	<0.001**
102 h	–	**BL**	12,00	-3,652	<0.001**	10,59	-3,688	<0.001**	9,94	-3,638	<0.001**	14,82	-3,671	<0.001**
48 h	–	**24 h**	1,82	-3,453	0.001**	1,65	-3,276	0.001**	1,65	-3,223	0.001**	3,00	-3,650	<0.001**
72 h	–	**24 h**	3,29	-3,689	<0.001**	4,47	-3,703	<0.001**	3,35	-3,676	<0.001**	4,35	-3,658	<0.001**
96 h	–	**24 h**	8,06	-3,642	<0.001**	8,12	-3,644	<0.001**	5,12	-3,634	<0.001**	10,00	-3,652	<0.001**
102 h	–	**24 h**	9,65	-3,649	<0.001**	8,94	-3,658	<0.001**	7,41	-3,647	<0.001**	13,12	-3,658	<0.001**
72 h	–	**48 h**	1,47	-3,473	0.001**	2,82	-3,487	<0.001**	1,71	-3,568	<0.001**	1,35	-3,289	0.001**
96 h	–	**48 h**	6,24	-3,650	<0.001**	6,47	-3,650	<0.001**	3,47	-3,421	0.001**	7,00	-3,640	<0.001**
102 h	–	**48 h**	7,82	-3,651	<0.001**	7,29	-3,703	<0.001**	5,76	-3,633	<0.001**	10,12	-3,657	<0.001**
96 h	–	**72 h**	4,76	-3,647	<0.001**	3,65	-3,324	0.001**	1,76	-2,834	0,005**	5,65	-3,652	<0.001**
102 h	–	**72 h**	6,35	-3,711	<0.001**	4,47	-3,711	<0.001**	4,06	-3,640	<0.001**	8,76	-3,654	<0.001**
102 h	–	**96 h**	1,59	-3,119	0,002**	0,82	-1,474	0,140	2,29	-3,482	<0.001**	3,12	-3,658	<0.001**

* Differences are significant at the 0.05 level (2-tailed).
** Differences are significant at the 0.01 level (2-tailed).

average of 17.25 % among the time points, being more evident in 102 h (62.58 % lower than BL). VR was negatively correlated with MF (r_s = -0.919, $p < 0.001$).

NR performances were different in all time points of test compared to baseline (BL < 24 h, BL < 48 h, BL < 72 h, BL < 96 h, BL < 102 h). NR decreased progressively until 96 h, remaining low until the end of the LDE (BL < 24 h < 48 h < 72 h < 96 h = 102 h). NR decreased on average of 14.37 % among the time points of test, being more evident in 102 h (54.88 % lower than BL). NR was negatively correlated with MF (r_s = -0.903, $p < 0.001$).

SR performances were also different in all time points of test compared to baseline (BL < 24 h, BL < 48 h, BL < 72 h, BL < 96 h, BL < 102 h), decreasing on average of 13.41 % until the end of the LDE (BL < 24 h < 48 h < 72 h < 96 h < 102 h), being also more evident in 102 h (51.52 % lower than BL). SR was negatively correlated with MF (r_s = -0.919, $p < 0.001$).

STM performances were also different in all time points of test compared to baseline (BL < 24 h, BL < 48 h, BL < 72 h, BL < 96 h, BL < 102 h), decreasing progressively until the end of the LDE (BL < 24 h < 48 h < 72 h < 96 h < 102 h). STM was the most affected by LDE, decreasing on average of 23.66 % among the time points, being also more evident in 102 h (76.60 % lower than the BL). STM also was negatively correlated with MF (r_s = -0.930, $p < 0.001$).

4 Discussion

The aim of this study was, through biomarkers of skeletal muscle damage, to evaluate the effects of 102 h of strenuous physical exertion on subjective perceptions of physical and mental fatigue, and on important cognitive processes that may affect decision-making such as verbal reasoning, numerical reasoning, spatial reasoning and short-term memory.

Biomarkers of muscle damage were assessed in order to describe the impact of strenuous physical activity on skeletal muscles and to investigate the relationship of such measure with the subjective perception of physical and mental fatigue of the subjects over the military training days. The post exercise increase of CK and LDH activity is widely documented and regarded by many researchers as a specific biomarker of muscle damage [12, 16–19, 33]. Analyses of serum levels CK and LDH showed a significant and gradual increase in the muscle damage during all time points of the LDE. The type of physical activity performed during the LDE (long marches on land with great variability of elevations, transposition of obstacles and watercourses) makes the military to perform concentric and eccentric contractions against a constant resistance. This exhaustive physical exercise combined with excess weight transported (backpacks, weapons and ammunition), lack of rest and impossibility of post-exercise recovery, increase the intensity of the extravasation of enzymes from skeletal muscle into blood circulation. Considering the normal serum levels of CK on plasma (55-170 U/l) is important to report that after 48 h serum levels of CK reached 10 times the reference levels and by the end of the LDE 19 times. It means that after 48 h all subjects were affected by rhabdomyolysis [34–36]. It is a fact that the combination and accumulation of lack of hydration, nutrition and rest, combined with strenuous physical exercise intensified muscle damage, but analysis of the collaboration of each type of stressor for onset of rhabdomyolysis still need to be performed. The serum levels CK and LDH also were positively correlated with PF and MF. It reinforces the value of this type of screening to have better adjusts in the levels of physical and mental effort in order to improve the learning during the military training.

The levels of PF and MF were partly consistent with the levels of planned physical and mental effort. During the first 72 h, the levels of PF and MF were in accordance with the planning, but the reported PF and MF at 96 h were a point higher than expected. At the end of LDE (102 h), the levels of PF were in accordance with the requirements, but the MF levels were still a point higher than expected. This probably occurred because after 72 h the participants were not allowed to sleep and the cumulative effect of sleep deprivation may have emphasized even more the perception of fatigue. Fatigue is known to result in less accurate performance, increased error rates, and to significant alter judgment capabilities [37, 38]. Due to these high levels of mental fatigue, the subject is affected by the decrease in attention, concentration and short term memory, planning and organizing of ideals, which negatively impact the performance on cognitive tasks with high demands [39, 40].

In order to evaluate the effects of mental fatigue caused by strenuous physical effort in decision-making processes in combat, we use questions related to cognitive processes that are typically used in military tactical planning, such as VR, NR, SR and STM. Our results show that both VR, NR, SR and STM decreased during de all time points and also were negatively correlated with the reported MF. MF can cause lapses of attention and decrease the focus of attention, which directly affects the cognitive load to the extent that the perception, concentration and working memory will be negatively affected [6, 20–22, 24, 41–44]. We assume that the workload is a result of the proportion of time required to process the information available for the resolution of questions in relation to the time available for decision-making. With less information available (perceived or processed), the subjects take longer to evaluate and decide. With less time to decide increases the possibility of making mistakes or even not answer the question (by not having enough time to analyze and answer the question or simply disengage).

Our results indicate that the participants showed poor performances in complex questions compared with simple questions. For instance, in the VR questions the subjects revealed a high difficulty to decide whether a statement was true or false in relation to the sentences (as in Q4), suggesting that some important information may have been lost throughout the process that includes reading the sentences, understand them and compare the statements with the preestablished rule. On the other hand, when the important information to answer the question remained visually available (as in Q1) they were able to identify a different word in the group, but faced high difficulty to justify their choices. The more complex mathematical operations (multiplication, division, arithmetic and geometric progressions) also showed more response errors than simple mathematical operations (addition, and subtraction).

Regarding the SR, the subjects showed worse performance on questions related with spatial logic reasoning (as Q5) than questions of simple visuo-spatial localization (such as Q6). This may indicate that the visuo-spatial localization process and visual discrimination seems to be less affected by fatigue than the processing of the visuo-spatial information. It may occur because spatial logic tasks require the maintenance of relevant information in working memory, while the simple spatial localization tasks do not so much require working memory [43, 44].

The STM was the most affected by fatigue among other cognitive processes. At the end of LDE, subjects were able to remember only 13.40 % of the sequence of letters and numbers. When they could remember two or three letters and numbers in sequence, generally they were in the first positions of the answer sheet. This probably occurred since the subjects were progressively fatigued and it took them longer to memorize the sequences. Due to their state of fatigue, letters and numbers were forgotten while as the time elapsed. Thus, the subjects had to return to the beginning of the sequence in order to recall them, which further decreased the time to memorize the other parts of the sequence. In fact, when the letters and numbers placed in the middle and the end of the sequence were recalled, the subjects could rarely fill them in their respective positions. It also should not be denied that the subjects simply disengaged from the task due to fatigue.

In summary, the results revealed additional evidences about the impact of strenuous physical activity on biomarkers of muscle damage and on physical and mental fatigue. Such biomarkers could be used as screening to better estimate the physical and mental states of military while conducting military training with high physical demands. In the same direction, we present additional evidence on the impact of mental fatigue on important cognitive processes related to decision-making. Specifically for the Special Forces training, this type of screening can provide accurate feedback about the physical and mental fatigue states, in real time, to assist in adjusting levels of physical effort required during military training in order to improve learning conditions and also prevent the occurrence of accidents. In future studies we propose the performance of logistic regression and multifactorial analysis to check how much each of the independent variables contributes to the variability in cognitive performance. In addition, we propose to evaluate the specificity of combat stressors such as lack of nutrition, hydration, sleep deprivation and level of physical exertion in order to predict the mental fatigue levels and cognitive performance.

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