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Factors associated with time of permanence in activity of military personnel wearing Personal Protective Equipment against Nuclear, Biological, Chemical and Radiological Agents

Factores asociados al tiempo de permanencia en servicio del personal militar que porta Equipos de Protección Individual contra Agentes Nucleares, Biológicos, Químicos y Radiológicos

Abstract: This study aimed to investigate the factors that can increase or decrease the time in which the military can remain in activity using Personal Protective Equipment (PPE) and provide assistance to decision-makers at the tactical level of what influences can be decisive for the time in the field. fulfillment of the different missions of Nuclear, Biological, Chemical and Radiological Defense (DefNBQR). A review of the literature, where the reviewed articles presented as influencing factors in the tolerance time, to a greater degree the state of hydration prior to the activity, the climate, the physical demand of the task and the type of PPE; and to a lesser extent aerobic condition, sex, body composition and acclimatization. The effectiveness of extra and intracorporeal cooling methods in prolonging time of the permanence was also observed.

Keywords: Personal Protective Equipment; Military Personnel; Work Performance.

Resumen: El objetivo de este artículo fue investigar los factores que pueden aumentar o disminuir el tiempo en que los militares pueden permanecer en actividad utilizando Equipos de Protección Personal (EPP), así como brindar asistencia a los tomadores de decisiones a nivel táctico cuyas influencias pueden ser determinantes para el tiempo en el cumplimiento de las diversas misiones de Defensa Nuclear, Biológica, Química y Radiológica (DefNBQR). Este análisis se trata de una revisión de la literatura cuyos artículos revisados presentaron como factores influenciadores en el tiempo de tolerancia, en mayor grado, el estado de hidratación previo a la actividad, el clima, la demanda física de la tarea y el tipo de EPP; y, en menor grado, la condición aeróbica, el sexo, la composición corporal y la aclimatación. También se observó la efectividad de los métodos de enfriamiento extra e intracorpóreo en la prolongación de la permanencia.

Palabras clave: Equipo de protección personal; militar; desempeño profesional.

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1 INTRODUCTION

The use of Nuclear, Biological, Chemical, and Radiological Agents (NBCR) dates back to the beginnings of warfare, such as the use of Greek fire by the Byzantine Navy in the 7th century. However, the use of chlorine gas during the First World War represented the start of employing chemical elements systematically as combat weapons. Thus, to deal with these various threats, the Brazilian Navy (MB) created, in 2011, the Nuclear, Biological, Chemical, and Radiological Defense System (SisDefNBQR-MB) (BRASIL, 2011).

Three basic requirements are established to deal with NBCR threats: early warning (ability to anticipate threats), protection (ability to protect oneself from the harmful effects of agents), and recovery (ability to mitigate the effects suffered due to the agent) (BRASIL, 2020). Addressing the physical performance of the military in combat with NBCR threats requires observing the protection requirement and seeking to reduce the physiological effects of NBCR agents on the military by using Personal Protective Equipment (PPE) (BRASIL, 2020).

However, combining body protection clothing with respiratory protection equipment reduces the combatant's capacity due to the physical wear and tear resulting from its use and causes a reduction in mobility (BRASIL, 2020). The North Atlantic Treaty Organization (NATO) considers that the use of PPE generates damage to physiological functions and causes other effects on the human body, which may result in an increase in the time to perform tasks and a reduction in the accuracy of their executions, leading to performance degradation (NORTH ATLANTIC TREATY ORGANIZATION, 2004).

MB adopts the classification of PPE for NBCR in four levels: level A is hermetically closed and fully encapsulated (including gloves and boots), presenting positive pressure and total facial protection. Furthermore, the supply of breathable air uses autonomous air cylinders or external air source, as long as it allows the maintenance of positive pressure; level B requires the same level of respiratory protection as level A but with a lower level of skin protection; level C is the average level of protection when less respiratory and skin protection is required; finally, level D is characterized by the lowest level of protection, without respiratory protection equipment (overalls or jackets and pants chemically resistant to partial splashes, with resistant gloves and boots, and goggles) (BRASIL, 2020).

Four main factors are considered when carrying out tasks involving such PPE: the time required to perform the task, level of clothing protection, weather conditions, and workload (NORTH ATLANTIC TREATY ORGANIZATION, 2004). However, there was a gap regarding the factors associated with the time wearing PPE in NBCR activities, particularly those related to the physical demands of the NBCR operator. Therefore, the objective of this article was to investigate the main factors associated with the time that the military can remain working with PPE.

2 METHOD

This article was a narrative review of the literature based on the recommendations of Sanra, with a systematic search carried out in February 2021 in electronic scientific

databases: Scopus, National Library of Medicine (Medline), and Web of Science (BAETHGE; GOLDBECK-WOOD; MERTENS et al., 2019). The factors associated with the time of use of the PPE were defined as independent variables, and the time of permanence or tolerance in activity using PPE as the dependent variable. The search descriptors were obtained from queries in the Health Sciences Descriptors (DeCS) and Medical Subject Headings (MeSH) databases, as shown in Chart 1.

Chart 1 – Descriptors used in the search in the databases.

DESCRIPTOR 1	DESCRIPTOR 2
nuclear, biological, and chemical (NBC) clothing OR NBC protective clothing OR chemical defense clothing OR Protective clothing ensembles OR Biological and chemical protective clothing OR Chemical protective ensemble OR Chemical protective mask OR Chemical protective equipment OR Chemical, Biological, Radiological, and Nuclear OR CBRN OR Hazmat clothing OR Hazmat suit OR CBRN suit OR Encapsulated clothing	Work performance OR Dehydration OR Heat OR Heat stress OR Water stress OR Physiological

Source: Prepared by the authors, 2022

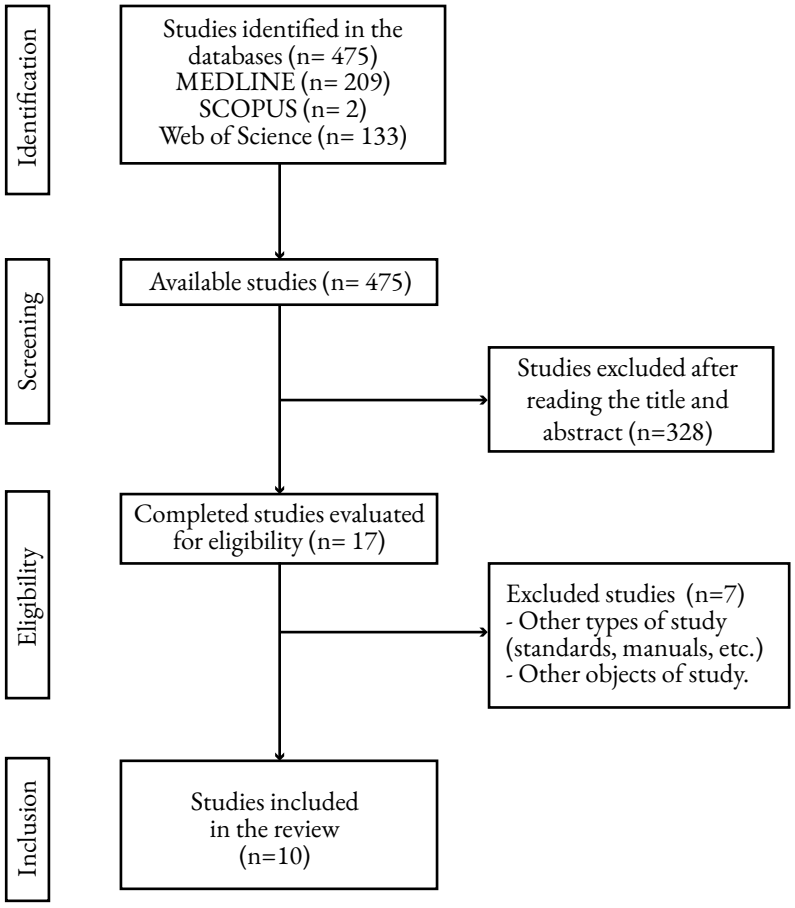
Analyzed articles investigated the length of stay as a study variable, including those assessing PPE levels from C to A of NBCR protection against physical wear and tear. A strategy based on analyses whose population was military and security forces was adopted to establish common parameters for the eligibility of articles, mentioning the exposure of officers to the use of NBCR protective clothing in activities with physical demand and resulted in the time spent in the activity. Studies carried out with a civilian population of a similar age group and body mass were included due to the few articles conducted with military personnel and security force agents. Finally, to standardize the presentation of the results, studies using the PPE classifications of the National Fire Protection Association (NFPA) or the Committee for the

Standardization of Products for the European Common Market had the results described in this article equivalently to the classification of PPE adopted in the MB.

3 RESULTS

Figure 1 presents the results of the search in the databases. We considered the articles that analyzed the use of NBCR PPE from level C to level A during some demanding physical activity and that, among their observations, presented the permanence time, i.e., computing and analyzing the time when the subjects remained using the protective clothing until reaching some physiological or volitional criterion established for the test interruption. The articles analyzed enabled us to obtain their characteristics, presented in Chart 2. Tables 1 and 2 show the tolerance times in minutes according to the Maximum Oxygen Consumption (VO_{2max}), measured in milliliters (mL) per kilo (Kg) per minute (min) reached during the NBCR activity and the PPE used in several studies.

Figure 1 – Literature search flowchart



Source: Prepared by the authors, 2022.

Chart 2 – Characteristics of the studies included in the review.

Author	Type of Protective Clothing	Sample	Condition for test end and final time count	Control group	Investigated factor (independent variable)	Exhibition	Average time of the group exposed to the investigated factor (min)	Average time of Control group (min)
MALEY *et al.* (2020)	Level A	n = 8 men Age: 24.0 ± 4.0 years Height: 180.2 ± 7.5 cm; BM: 77.1 ± 6.8 Kg %G: 13.8 ± 5.9 %	Rectal temperature> 39.0ºC; Heart Rate ≥ 90% of the maximum measured; Working time = 120.0 min Fatigue or nausea.	Use of PPE only	Cooling by outer clothing and/ or intra-body cooling	ICEPEAK Ice vest (P > 0.05)	48.0 (CI 95% = 39.0 to 58.0)	39.0 (CI 95% = 30.0 to 48.0)
						Full body clothing BCS-4 (P < 0.001)	62.0 (CI 95% = 53.0 to 70.0)	
						Cooling vest Kewl-Fit, Model 6626-PEV (P = 0.018)	46.0 (CI 95% = 36.0 to 56.0)	
						ICEPEAK Ice vest associated with prior ingestion of ice slurry (P < 0.001)	56.0 (CI 95% = 46.0 to 67.0)	
BACH *et al.* (2019)	Level C	n = 8 men Age: 23.6 ± 3.9 years; Height: 180.0 ± 7.0 cm; BM: 75.5 ± 6.4 Kg %G: 13.6 ± 5.2 %	Rectal temperature > 39.0 ºC Heart Rate ≥ 90.0% of the maximum measured; Working time = 120.0 min Fatigue or nausea	Use of PPE only	Cooling by outer clothing and/ or intra-body cooling	ICEPEAK Ice vest (p < 0.05)	107.0 ± 16.0	89.0 ± 19.0
						Full body clothing BCS-4 (P = 1.00)	93.0 ± 14.0	
						Cooling vest Kewl-Fit, Model 6626-PEV (P < 0.05)	109.0 ± 13.0	
						ICEPEAK Ice vest associated with prior ingestion of ice slurry (P < 0.005)	110.0 ± 9.0	

continue

Chart 2 – Continuation

Author	Type of Protective Clothing	Sample	Condition for test end and final time count	Control group	Investigated factor (independent variable)	Exhibition	Average time of the group exposed to the investigated factor (min)	Average time of Control group (min)
DENHAR-TOG *et al* (2017)	Level A	n = 40 men Age: 36.7 ± 8.3 years; BM: 84.7 ± 9.5 Kg	Rectal temperature > 39.0ºC Heart Rate > 90% of the maximum measured; Working time = 60 min Fatigue or nausea	Different Uniforms (A-F)	Type of Clothing, Climate, and Nature of the Task	Suit A	55.99	NR
						Suit B*	44.29	
						Suit C	50.98	
						Suit D	56.66	
						Suit E	54.66	
						Suit F**	41.78	
						Moderate climate (24ºC, 50% RH, 20ºC TBU)	53.92	
						Hot and humid (32ºC, 60% RH, 30ºC TBU)	40.44	
						Hot and dry (45ºC, 20% RH, 37ºC TBU)#	26.96	

continue

Chart 2 – Continuation

Author	Type of Protective Clothing	Sample	Condition for test end and final time count	Control group	Investigated factor (independent variable)	Exhibition	Average time of the group exposed to the investigated factor (min)	Average time of Control group (min)
JOVANOVI *et al* (2014a)	Level C	n =10 men (military) Age: 25.8 ± 2.4 years	Rectal temperature > 39,5ºC Measured Heart Rate > 190.0 bpm Working time = 45.0 min Fatigue or nausea	Group with PPE without cooling clothing	Cooling by outerwear	Group wearing cooling clothing	10.0 minutes longer on average than the control group	NR
MCLELLAN *et al*. (2013)	Level C	n = 4 men Age: 26.8 ± 4.4 years; Height: 177.0 ± 5.0 cm; BM: 77.1 ± 8.9 Kg; %G: 13.8 ± 5.9 %	Rectal temperature = 40ºC; Heart Rate > 95% of the maximum measured for 3 minutes; Working time = 190 min; Fatigue or nausea	Group with PPE and camouflaged	PPE embedded in the camouflage and with an opening for cooling	Group wearing PPE embedded in the camouflage and with an opening for cooling (Uniform A) (P < 0.05)	44.3 ± 21.9	33.3 ± 16.1
						Group wearing PPE embedded in the camouflage and with an opening for cooling (Uniform B) (P < 0.05)	47.0 ± 27.7	
CHEUNG and MCLELLAN (1998a)	Level C	n = 8 men Age: 15 to 40 years	Rectal temperature > 39,3ºC Heart Rate > 95% of the maximum measured for 3 minutes Working time = 240.0 min Fatigue or nausea	Moderately trained and pre-acclimatization hydrated subjects	Aerobic Capacity, Hydration Status, and Acclimatization	Moderately trained and post-acclimatization hydrated subjects (P > 0.05)	101.4 ± 11.4	96.6 ± 19.6
						Moderately trained and post-acclimatization hypo-hydrated subjects (P < 0.05)	78.3 ± 16..9	

continue

Chart 2 – Continuation

Author	Type of Protective Clothing	Sample	Condition for test end and final time count	Control group	Investigated factor (independent variable)	Exhibition	Average time of the group exposed to the investigated factor (min)	Average time of Control group (min)
				Highly trained and pre-acclimatization hydrated subjects	Aerobic Capacity, Hydration Status, and Acclimatization	Highly trained and post-acclimatization hydrated subjects (P > 0.05)	115.6 ± 18.4	114.5 ± 27.4
						Highly trained and pre-acclimatization hypo-hydrated subjects (P < 0.05)	100.9 ± 20.4	
MCLELLAN (1998)	Level C	n = 17 women and 13 men Age: 24.0 ± 4.0 years; Height: 180.2 ± 7.5 cm; BM: 77.1 ± 6.8 Kg %G: 13.8 ± 5.9 %	Rectal temperature > 39,3ºC Heart Rate > 95% of the maximum measured for 3 minutes Working time = 300.0 min Fatigue or nausea	Men	Sex	Women	114.4 ± 17.4 (P < 0.05)	142.9 ± 24.4

continue

Chart 2 – Continuation

Author	Type of Protective Clothing	Sample	Condition for test end and final time count	Control group	Investigated factor (independent variable)	Exhibition	Average time of the group exposed to the investigated factor (min)	Average time of Control group (min)
AOYAGI, *et al* (1998a)	Level B	n = 16 men Grupo 1: Age: 29.0 ± 2.0 years; Height: 1.79 ± 0.02 m; BM: 82.6 ± 3.3 Kg; %G: 18.1 ± 1.5% Grupo 2: Age: 28.0 ± 1.0 years; Height: 1.78 ± 0.01 m; BM: 83.8 ± 2.6 Kg; %G: 19.8 ± 1.5%	Rectal temperature > 39,3ºC Heart Rate > 95% of the maximum measured for 3 minutes Working time = 150 min Fatigue or nausea	Group 1	Acclimatization	Group 1 after 6-day Acclimatization	112.0 ± 6.0 (P < 0.05)	97.0 ± 4.0
				Group 2	Acclimatization	Group 2 after 12-day Acclimatization	120.0 ± 10.0 (P < 0.05)	108.0 ± 10.0
AOYAGI, *et al* (1998b)	Level B	n = 16 men Grupo 1: Age: 25.0 ± 1.0; Height: 1.76 ± 0.02 m; BM: 83.6 ± 3.8) Kg; Grupo 2: Age: 31.0 ± 1.0 years; Height: 1.76 ± 0.01 m; BM: 79.3 ± 4.1 Kg	Rectal temperature > 39,3ºC Heart Rate > 95% of the maximum measured for 3 minutes Working time = 120 min Fatigue or nausea	Group 1	Acclimatization and aerobic capacity	Group 1 after Acclimatization (P > 0.10)	49.0 ± 3.0	48.0 ± 2.0
				Group 2	Acclimatization and aerobic capacity	Group 2 after Acclimatization and Aerobic Training Program (P = 0.05 – 0.10)	52.0 ± 3.0	51.0 ± 2.0

continue

Chart 2 – Continuation

Author	Type of Protective Clothing	Sample	Condition for test end and final time count	Control group	Investigated factor (independent variable)	Exhibition	Average time of the group exposed to the investigated factor (min)	Average time of Control group (min)
CHEUNG and MCLELLAN (1998b)	Level C	n =8 men Age: 29.3 ± 6.4 Height: 178.0 ± 7.0 cm; BM: 75.6 ± 9.7 Kg. %G: 12.4 ± 2.8%.	Rectal temperature = 39,3 º C Heart Rate > 95% of the maximum measured for 3 minutes Working time	Previously hypo-hydrated subjects with water replacement during the work period	Hydration status in Light exercise	Previously hydrated group without water replacement during work period (P > 0.05)	93.1 ± 20.8	87.1 ± 14.2
						Previously hydrated group with water replacement during work period (P > 0.05)	106.50 ± 22.1	
				Previously hypo-hydrated subjects with water replacement during the work period	Hydration status	Previously hydrated group without water replacement during work period (P<0.05)	58.3 ± 11.1	53.3 ± 8.9
						Previously hydrated group with water replacement during work period (P > 0.05)	59.7 ± 9.5	

Subtitle: n = sample size; Kg = kilograms; cm = centimeters; PPE = Personal protective equipment; CI 95% = 95% confidence interval; ± = standard deviation; BM = body mass; bpm = beats per minute; %G: body fat percentage; * Significant reduction in PPE length of stay using suit B compared to A (P = 0.002) and E (P = 0.04); ** Significant reduction in PPE length of stay using suit F compared to A (P = 0.019), D (P = 0.014), and E (P = 0.0015). # Reduction in length of stay in hot and dry climates compared to moderate and hot humid climates (P < 0.001); NR = not reported.

Source: Prepared by the authors, 2022

Table 1 – VO_{2max} and tolerance time wearing Level B PPE

VO_{2max} (mL.Kg-1.min-1)		Tolerance time (min)		Author	PPE
Mean	Standard deviation	Mean	Standard deviation		
45.1	1.5	48.0	2.0	AOYAGI, MCLELLAN e SHEPHARD (1998)	Level B
45.7	2.1	49.0	3.0	AOYAGI, MCLELLAN e SHEPHARD (1998)	Level B
46.0	1.9	52.0	3.0	AOYAGI, MCLELLAN e SHEPHARD (1998)	Level B
46.3	2.3	47.0	2.0	AOYAGI, MCLELLAN e SHEPHARD (1998)	Level B
47.2	1.7	120.0	10.0	AOYAGI, MCLELLAN e SHEPHARD (1995)	Level B
48.1	1.8	112.0	6.0	AOYAGI, MCLELLAN e SHEPHARD (1995)	Level B
48.6	2.1	108.0	10.0	AOYAGI, MCLELLAN e SHEPHARD (1995)	Level B
49.5	2.2	97.0	4.0	AOYAGI, MCLELLAN e SHEPHARD (1995)	Level B

VO_{2max} = maximum oxygen consumption; PPE = personal protective equipment.

Source: Prepared by the authors, 2022

Table 2 – VO_{2max} and tolerance time in minutes wearing Level C PPE

VO_{2max} (mL.Kg-1.min-1)		Tolerance time (min)		Author	PPE
Mean	Standard deviation	Mean	Standard deviation		
46.0	2.9	96.6	19.6	CHEUNG e MCLELLAN (1998a)	Level C
48.4	4.9	145.2	26.7	MCLELLAN (1998)	Level C
59.8	2.8	114.5	27.4	CHEUNG e MCLELLAN (1998a)	Level C
51.6	4.0	89.0	19.0	BACH *et al*. (2019)	Level C

VO_{2max} = maximum oxygen consumption; PPE = personal protective equipment.

Source: Prepared by the authors (2022)

4 DISCUSSION

The analyzed results enabled us to relate the time a military person could remain operating in an environment with the presence of NBCR agents. In this case, the combatant's factors (aerobic capacity, sex, and hydration status) and external factors (climate of the

operating environment, type of work to be performed, and the type of PPE required for the task) were observed. In addition, it was also possible to relate this time to factors that can be inserted to prolong the military's ability to remain in military action, such as intra and extracorporeal cooling methods and acclimatization.

4.1 Aerobic Capacity

Aerobic capacity is undoubtedly a preponderant factor when physical exertion is required. However, this perception comes from the analysis of activities in which the subject can exchange heat with the environment, which is not the case when using equipment for protection that aims to contain the exchange of fluids between the person and the external environment. Thus, the analyzed studies sought to understand if this premise would also be valid for this type of activity.

When comparing subjects with a mean VO_{2max} of 46.1 ± 2.9 $mL.Kg^{-1}.min^{-1}$ with subjects with mean VO_{2max} of 59.8 ± 2.8 $mL.Kg^{-1}.min^{-1}$, researchers Cheung e McLellan (1998a) pointed out that, in addition to the more prolonged stay in activity using PPE, subjects had their tests interrupted after reaching the ethical limit of abdominal temperature (39.3ºC), in addition to those who had the test terminated at their request due to the perception of exhaustion.

Aoyagi, McLellan, and Shephard (1998), when analyzing subjects who went through a physical training program based on indoor running or on a treadmill in sessions of 30 to 45 min and three to four days a week, during eight weeks, reaching 60% to 80% of each one's initial VO_{2mas}, resulting in VO_{2max} increased from 39.9 ± 1.7 $mL.Kg^{-1}.min^{-1}$ to 46.3 ± 2.3 $mL.Kg^{-1}.min^{-1}$ found no significant increase in permanence time. However, they noted that the rectal temperature for trained subjects remained lower during the exercise with the PPE, which is a critical determinant in the permanence time. A possible explanation for this significant change in the permanence time of better-conditioned subjects is pointed out by the accumulation of sweat inside the clothes and the impossibility of effective heat exchange with the evaporation of sweat, which ends up overlapping the effect of training on aerobic capacity of subjects, maintaining high heart rate indices, which turns out to be the determining factor for the end of the exercise. Both tests used walking on a treadmill at 4.8 kilometers per hour (km/h) as an exercise, differing in the adopted inclination. Aoyagi, McLellan, and Shephard (1998) used a single inclination of 2%, while Cheung and McLellan (1998b) employed inclinations between 3 and 7%. Possibly, this variation of slopes and a more significant number of tests have led to a slight variation in the permanence time of the more conditioned subjects in the second study.

Jovanović *et al*. (2014a) support the importance of aerobic capacity when developing a test with military personnel and comparing them with results obtained by Nag *et al*. (1997), whose data indicated that men subject to work in which the abdominal temperature is 39º C manage to remain at work for 40 to 45 minutes, while in the tests by Jovanović *et al*. (2014a), a minimum number of military personnel completed the test before 45 minutes, establishing a relationship with the regularity in which the studied military personnel perform strenuous physical activities related to their profession.

While it is well known that better aerobic capacity promotes benefits for performing activities with physical demand (NINDL *et al*., 2017), evidence on how aerobic physiological indices are related to the length of stay is still scarce, therefore requiring further investigations.

4.2 Sex

Faced with the limitation of analyses that investigated differences between the sexes when wearing NBCR protective clothing, the study by McLellan (1998) stands out, founding a thermoregulatory disadvantage for women, which would influence the reduction of the length of stay for women. However, as the thermal advantage presented by men would be based on the amount of sweat they can produce and, consequently, offer greater regulatory efficiency, using PPE insulating evaporation could compensate for such differences, leading to a similar storage capacity of heat between men and women. Therefore, this article divided by the similarity of the percentage of fat associated with VO_{2max} and, with this division, the tolerance times became similar regardless of the sex of the participant.

Therefore, even though sex may influence due to differences in general body composition between female and male averages, such differences are minimized in the case of an exercise with no heat compensation with the PPE. Thus, with aspects related to body composition and aerobic capacity prevailing for the variation in the length of stay, men and women with similar indices of fat percentage and VO_{2max} seem to have identical tolerance times.

4.3 Hydration status

McLellan (1998), Jovanović *et al*. (2014a), and Aoyagi, McLellan, and Shephard (1998) observed an increase in the sweat rate during activity using NBCR PPE, which makes it possible to infer that there is indeed an increase in dehydration during this type of activity. Allied with this, due to the need to isolate, mainly, the airways from the environment, the consumption of water during operation in a contaminated environment is challenging, thus having the NBCR operator as the only opportunity for hydration the moments before starting work and during rest breaks in a decontaminated area.

Cheung and McLellan (1998a) then observed that the state of hypohydration at the beginning of the activity significantly increased the effects of thermal stress, even in acclimatized subjects. Likewise, those who had a normal state of hydration at the beginning of the exercise could remain active with PPE longer than those who were hypo-hydrated, regardless of the benefits of acclimatization and aerobic condition. Therefore, it is essential that when starting operations, subjects are in good hydration conditions. It is also possible to consider if hydration during the execution of the task brings about any effective gain in tolerance time, which, according to another study by Cheung e McLellan

(1998b), there is indeed this correlation when it occurs during the practice of light exercises with PPE. However, there is no determining effect on the lengthening of the permanence time when this hydration during activity occurs when carrying out high-intensity work. This investigation supported, therefore, the evidence that the hydration level before the exercise's beginning affects the operating time.

Thus, the importance of hydration is also highlighted during rest periods so that the person can return to activity with the necessary hydration level. Thus, the tolerance time is not reduced due to the hypohydration process. However, even if less evident, it is essential to avoid hyperhydration during rest. Analyzing several subjects wearing level A PPE in different climates and during other activities, Rubenstein *et al*. (2017) concluded that during rest periods after 60 minutes of activity, hydration with 0.7 liters (L) of water safely rehydrates 90% of operators and prevents under- and over-hydration for the subsequent work cycles. It is worth mentioning that the study also found that excessive rehydration (1.5 L at each rest cycle alternating with a 60-min work cycle) increases the risk of hyperhydration to 39% from the third work/rest cycle onward.

4.4 Operating environment climate and type of work to be performed

DenHartog *et al*. (2017) analyzed different workloads and weather conditions on tolerance time. Considering three climates and work intensities (moderate, hot, and humid, and hot and dry climates; and work – 127 $W.m^{-2}$, 205 $W.m^{-2}$ e 314 $W.m^{-2}$).

Considering that the workload increases when using NBCR PPE (Dorman; Havenith, 2009), predicting an inversely proportional relationship between workload and length of stay is possible. Therefore, DenHartog *et al*. (2017) showed a strong relationship between workload and tolerance time in inverse proportion.

Finally, it is worth confirming that the higher the region's temperature, the shorter the working time. Air humidity is assumed to have no direct influence on time due to the low or no exchange of fluids between the subject and the environment. However, the lack of studies in the literature on this specific relationship prevents confirming this assumption. Thus, according to DenHartog *et al*. (2017), the length of stay is inversely proportional to the work demand within the same climate.

However, due to some limitations in the article by DenHartog *et al*. (2017), age appeared as another possible factor influencing the length of stay. The age/tolerance time relationship was statistically verified, showing a minimal relationship of directly proportional variation, i.e., older subjects would endure longer in operation. However, as this research analyzed professional firefighters, it can be argued if people with more experience operating with PPE over the years have developed some physiological adaptation to withstand more extended periods under conditions of uncompensated thermal stress.

4.5 Type of PPE used

When the Armed Forces require levels C and B of protection, they use the layer system, i.e., when an NBCR threat is detected, the protective clothing, usually made of activated carbon, is placed on top of the combat uniform. From this conception, McLellan *et al*. (2013) compared the current system of layers to a combat uniform capable of filtering NBCR agents and which has ventilation openings (Protective Assault Uniform), requiring only the closure of these openings when detecting an NBCR threat for user's effective protection. When comparing these two protection systems, it was evident that the continuous use of a single combat uniform in activity, which allows a quick transition from a normal condition to an NBCR protection condition, significantly increases the time in the operation of the military personnel in a contaminated environment wearing the PPE. Thus, even if the soldier remains throughout the entire operation in a uniform with less gas exchange with the environment, the open parts of the uniform allow heat exchange with the environment. There is a significant benefit when the military needs NBCR protection. Although this advantage exists, in Brazil, this military technology is not yet available. In the case of a study with the Canadian military, this type of PPE would hardly be applicable in operations of our Armed Forces.

Level A protective clothing used in the armed forces is similar to that employed by fire departments and chemical industry companies, with greater commercial availability. DenHartog *et al*. (2017) investigated whether there are considerable differences between various level A clothing available on the market regarding tolerance time. The only difference noted occurred with one suit compared with the others in a moderately hot climate. Significant differences from this suit are a double layer of chemical protection (against one layer of the others) and its reflective aluminized outer layer. This clothing had reduced permanence time, as DenHartog *et al*. (2017) pointed out, which could result from its two layers increasing thermal stress and/or because it is an average climate, the aluminum layer prevented the exchange of heat from the clothing to the environment. In a hot environment, this suit did not present significant differences compared with the others, indicating the aluminized layer's efficiency in heat reflection.

Reflective clothing is usually used in services where there are fires combined with the release of NBCR agents, being more focused on the use of firefighters. However, concerning the armed forces, there is a latent need to check the importance of the number of protective layers in level A suits, considering that multi-layer clothing will tend to reduce the length of stay of military personnel in operation.

Finally, Xu *et al*. (2019) noted that improving the thermal properties of the fabrics currently used in military PPE can reduce thermal stress and increase the length of stay. However, even so, these advantages depend on the climate of the environment in which the operations are performed.

4.6 Cooling methods

Increasing body temperature is an intrinsic factor to exercise and becomes even more evident when heat exchange with the environment is reduced due to PPE. Thus, body cooling

can be a good alternative to reduce the effects of thermal stress resulting from operations with NBCR threat. Bach *et al*. (2019) and Maley *et al*. (2020) investigated three cooling suits and one associated with the intake of ice slurry by the subjects 30 minutes before the beginning of the exercise. The first study used level C PPE and the second level A PPE, with disagreement between the efficiency of the two suits concerning the length of stay in PPE. While the ice vest showed a significant improvement during tests with level C PPE, the same result was not observed in the test with level A PPE. On the other hand, the whole body suit with water perfusion improved the permanence time only when using the level A clothing.

When discussing this difference, it is essential to note that the ice vest differs from the whole body suit concerning the body surface area covered, area of effective contact with the body, storage temperature, and physical state of the cooling method. Level A clothing encapsulates the subject, isolates them from any gaseous exchange with the environment, limits breathing by the flow of the air valve attached to the cylinder, and restricts the amount of breathable air by the capacity of the cylinder. Thus, it presents, as a rule, a shorter time of permanence compared to level C clothing.

Therefore, for this suit, the water perfusion favors a greater heat exchange surface between the fluid and the body due to its fluid passing through small tubes throughout the body surface. It is more effective in maintaining the entire body refrigerated in a short time. When analyzing the use of level C, the average permanence times compared with level A are much longer, with time available for the entire fluid to have its temperature elevated and balanced with the body's high temperature, causing the subject to lose from then the benefit of external cooling. However, when analyzing the ice vest (stored at -18ºC), even if only the torso is refrigerated, the time the vest will spend absorbing heat from the person until it reaches thermal equilibrium will be much longer than that of the suit with water, thus benefiting the use of level C PPE. Despite these differences, it cannot be said that, in some way, specific cooling clothing is not suitable. Still, these characteristics must be considered when it is necessary to use cooling with different levels of PPE.

The method that demonstrated the most significant increase in tolerance time in both studies was the combination of an ice vest with the ingestion of 7.5 $g.Kg^{-1}$ of ice slurry at -2ºC (2.2% of carbohydrate), at the rate of 1.25 $g.Kg^{-1}$ every five minutes, 30 minutes before the beginning of the exercise. Jovanović *et al*. (2014b) pointed out, when studying cooling suits for PPE of the Serbian Armed Forces, that the use of these implements cooling the torso area causes the abdominal temperature to increase more slowly and the average skin temperature to be significantly lower. Thus, its use under NQBR protective clothing improves the military's physiological stability, contributing to confidence and efficiency in military missions against NBCR threats.

When analyzing the national military reality, it is emphasized that the ingestion of ice slurry can be performed quickly since machines for producing this type of food are available on the market or even using improvised means for its production, maintaining the proportion of ice/weight indicated in the studies. Regarding coolant clothing, even though it is not customary to use them in NBCR missions in the Marine Corps, the Marine Corps

Engineering Battalion currently has water perfusion cooling clothing to perform tasks to deactivate explosive devices with the use of the anti-bomb suit (EOD-9). Therefore, it is adaptable to the service with NBCR PPE.

4.7 Acclimatization

Operating using PPE for NBCR agents requires working at temperatures above average. Therefore, it is worth observing the influence of heat acclimatization by subjects and if there is a relationship with tolerance time. According to the acclimatization protocols specified in the results, three studies observed the relationship between acclimatization and length of stay.

Aoyagi, McLellan, and Shephard (1995) found a significant increase in the tolerance time in acclimatized subjects, contrary to their work (1998), which indicated that there was no variation in the length of stay for acclimatized subjects, similar to Cheung and McLellan (1998a). Analyzing these different perspectives, Cheung and McLellan (1998a) promoted the rehydration of the studied subjects in continuous intervals. Therefore, such continuous hydration may have overcome the beneficial effect of acclimatization. Comparing the two articles by Aoyagi, McLellan, and Shephard, it is clear that acclimatization helps reduce the physiological effects caused by thermal stress due to using PPE. However, there are still certain doubts regarding the direct impact on the length of stay, since in their conclusions, Aoyagi, McLellan, and Shephard (1998) found that the greater the effort required in the exercise, the smaller the effect of acclimatization in the prolongation of the tolerance time. This decrease is likely due to the higher sweating rate in high-intensity activities without heat exchange with the environment, making the temperature increase in the internal microclimate of the PPE sufficiently high to eliminate the physiological differences between acclimatized and non-acclimated subjects. Other investigations point to the advantages of acclimatization in situations of activities that result in thermal stress, helping to reduce heart rate, oxygen consumption, perception of exertion, and thermal sensation (Thake *et al*., 2009)

Thus, the acclimatization time of the study protocols can be assumed as insufficient for a physiological adaptation that effectively promoted the necessary acclimatization. However, Aoyagi, McLellan, and Shephard (1995) noted no significant physiological differences between the groups studied with acclimatizations of six and 12 days, as adaptations to heat occurred in the first days.

Therefore, further analyses would be needed to confirm the actual effectiveness of heat acclimatization in extending the length of stay, despite the already proven benefits. For the reality of the armed forces, it is possible to establish simple acclimatization protocols, similar to those pointed out in studies, to improve the performance of military personnel when there is enough time available preceding a specific mission for NBCR defense.

5 CONCLUSION

From all the data analyzed, it is possible to conclude that several important factors must be considered when the use of NBCR PPE is necessary, some more related to the time

spent in activity (aerobic capacity, sex, hydration status, climate of the operating environment, and type of activity performed) and others prolonging the tolerance time indirectly by acting on the subject's physiological adaptation and their perception of effort (intra and extracorporeal cooling and acclimatization). Thus, it is essential to highlight the initial state of hydration of the subject as a critical condition for the development of tasks since a dehydrated state will significantly reduce their permanence at work, suggesting intakes of 0.7 L of water every 60 minutes of the work cycle.

The type of task and the type of PPE also appear as factors that will influence the working time since the more significant the work intensity and the lower the permeability of the PPE to heat transfer between the subject and the environment, the lesser the influences of other factors will be, since the levels of sweat and its non-evaporation will cause the permanence times to be drastically reduced, regardless of different physiological and perceptual factors. Allied to these two factors is the operating environment, which, as the temperature increases, decreases the ability to remain active without; however, having a significant influence of humidity given the rare exchange of fluids between environment and subject.

Refrigeration methods, either with the help of cooling clothing or through the ingestion of ice slurry, proved to be effective in reducing thermal stress and consequent extension of the time spent in activity with PPE, thus being an efficient tool to increase the time of work of activity specialists, and therefore very important for tasks that require long exposure times to NBCR agents.

Finally, sex does not seem to influence the duration of PPE use. Although incipiently, subjects with better aerobic fitness and a lower fat percentage arguably performed better with PPE and more extended periods of permanence, which can be optimized if acclimatization occurs during activities conducted at high temperatures.

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