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Heat Stress Control Mechanisms in Military Operations

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Abstract:

Heat-related illnesses are a problem for a lot of troops in the world. Thus, this work aimed to analyze the thermal stress control mechanisms applicable to troops in military operations. For this reason, it was chosen to address the following topics: basic aspects of thermoregulation in hot environments, and heat stress control mechanisms in military operations (adaptation to heat; rest, hydration, and replenishment of hydro-electrolytes; immersion cooling; and personal cooling systems). It can be concluded that some operational situations can impose thermal stress on the military beyond normal thermoregulatory capacity, requiring adequate intervention to dissipate body heat and maintain work capacity over time.

Keywords:

adaptation to heat, heat-related illness, immersion cooling, personal cooling systems

1 Introduction

Whether in training or in real employment, military operations involve a wide spectrum of activities that contribute to demanding physical performance [1]. In addition to typical military activities, other complementary activities such as the guarantee of law and order; fighting fires, and managing other disasters and natural hazards also demand high energy and metabolic expenditure, raising body temperature and heat stress [2].

Heat-related illnesses are a problem that runs through the history of military troops and reaches the present day with high incidence rates. Authors report extreme heat-related illness incidence rates of 0.2 to 3.1 per 1 000 person-years in UK military personnel [3]. In the United States, in 2017, the rate of cases of stress stroke in the

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armed forces was 58 % higher than in 2013, and the troops most affected by it were the Marine Corps and the Army [4]. This is because, in many cases, there was no control of individual differences, such as fitness, acclimation status, morphology, and body composition [3]. Military personnel works in very peculiar situations that increase the risk of heat-related illness, such as higher physical exertion due to a heavy burden (from 30 kg to 50 kg), sleep deprivation, lack of acclimatization to the region of operations, dehydration, etc. [4].

In this sense, knowledge of strategies for preventing and mitigating the risk of developing heat-related illness becomes fundamental for adequately managing this risk, preventing casualties, and maintaining the troops' combat power. Thus, this work aimed to analyze the heat stress control mechanisms applicable to soldiers in military operations. Therefore, it was chosen to address the following topics: basic aspects of thermoregulation in hot environments, and the heat stress control mechanisms in military operations (adaptation to heat; rest, hydration, and replacement of hydro-electrolytes; immersion cooling; and clothing with individual cooling systems).

2 Basic Aspects of Thermoregulation in Hot Environments

During military operations, with the increase in body heat production due to physical demands or thermal stress, the primary heat dissipation mechanism becomes the evaporation of sweat. Sweat increases heat loss by evaporating fluids at the skin level, cooling the skin surface [3, 4].

Heat dissipation by evaporation of sweat is proportional to the area of the skin effectively exposed, the moisture gradient between the skin and the environment, and the permeability of the uniform to water vapor. Thus, in very humid climates or when clothing with low water vapor permeability is worn, sweat evaporation rates are reduced, and heat dissipation is lower [3, 5].

Thermoregulatory changes impact the cardiovascular system, altering heart rate (HR), core temperature, and blood pressure (BP), especially during physical activity or in hot environments. Changes in blood flow from the skin to the muscles during physical activity and, in the opposite direction, seeking to dissipate heat in hot environments, cause changes in the blood volume of body compartments, which can alter HR and BP, especially in moments of postural changes [6].

In the same vein, high rates of sweating or dehydration can decrease plasma volume and essential minerals, imposing an extra effort on the cardiovascular system to maintain cardiac output and blood pressure [7]. In the absence of adequate hydration, this process can lead to the loss of body fluids and essential minerals due to excessive sweating, which will raise the skin temperature dramatically depending on the environment and the clothes used [5].

Anthropometric characteristics play an important role in human thermoregulation. In any type of thermal environment, body surface area greatly influences thermoregulation capacity (heat loss) [8]. In addition to the body surface area, we can mention the subcutaneous fat layer that acts as a barrier to the dissipation of heat produced in the body [9].

The variation in the relative thermal conductivity of body tissues (lean tissue, fat, and bone) determines part of each body's ability to thermoregulate. Adipose tissue has a lower specific heat capacity (2.51 kJ/kg·K) compared to lean tissue (3.65 kJ/kg·K) [8]. In this sense, it is to be expected that individuals with greater adiposity would present more significant changes in core temperature for a given change in body heat content. In the same sense, subjects with the same muscle mass, and different subcutaneous fat layers, have different skin temperatures, with lower skin temperatures in those who are more obese [10].

3 Heat Stress Control Mechanisms

When it comes to the military operational environment, commanders at different hierarchical levels can make use of the following mechanisms or strategies to control heat stress: providing time before the mission to acclimate the troops to the climate of the operational environment, providing supplies for hydration and replacement of hydro electrolytes, adequate management of rest time, provision of structures for immersion cooling (hands and forearms), and provision of clothing with individual cooling systems [11].

3.1 Adaptation to Heat

Heat adaptation contributes in several ways to improving the operational performance of the military. On the biological side, adaptation to heat enhances the performance of tasks with physical demands and helps prevent heat-related illnesses; on the psychological/cognitive side, it improves cognitive processes and decision-making under heat stress [2].

Heat adaptation is usually developed by controlling the workload under the climatic conditions to which adaptation is desired. Control of the physiological parameters of the troop during the process of adaptation to heat must be exercised to avoid undesirable outcomes. The main physiological parameters used in this process are heart rate and perceived exertion [2]. Authors [2, 12] recommend that the troop have a standardized workload with constant intensity and individualized approaches to the military who need it.

The time of exposure to heat and the duration of the adaptation process will always depend on the availability of the troops and the urgency of the operational mission. However, it is possible to mention some references used by the United Kingdom's defense forces for the acclimatization of physically active soldiers, which comprise a period of 8 days of adaptation to the heat: 1st day – rest, food and hydration; from the 2nd to the 4th day – a gradual increase in gait activity time (6 km/h) using light clothes, on the 5th and 6th days – a gradual increase in gait activity time (6 km/h) using combat uniform and personal equipment, on the 7th and 8th days – gradual increase in gait activity time (6 km/h) using combat uniform and personal equipment with an overload of 10 kg [2].

It is well known that military personnel must maintain high levels of physical fitness. This also helps with the heat adaptation process, as heat-related illnesses are reported at lower rates in well trained military personnel than in those with lower physical fitness [13, 14]. In this sense, the North Atlantic Treaty Organization (NATO) recommends monitoring soldiers with less physical conditioning in the processes of adaptation to heat, as they can be considered a risk group for heart-related illnesses [15]. This is explained by the indirect relationship between VO_2max (maximal oxygen uptake) and the number of days required for acclimatization [14].

3.2 Rest, Hydration, and Replacement of Hydro-Electrolytes

Rest, hydration and hydro-electrolyte replacement are measures to control heat stress widely used by athletes at all levels. As a tactical athlete, the military must also use these strategies. Rest works by lowering metabolic activity and reducing body heat production [3, 4].

On the other hand, hydration helps in the dissipation of heat by convection of the liquid in the different body tissues. To enhance the dissipation of body heat, you can opt for the ingestion of ice paste, which is a drink that can contain only a mixture of ice particles and liquid water but can also be enriched with hydro electrolytes necessary for proper functioning of human physiology. By adding ice to drinks, the heat exchange is increased as the ice absorbs a more significant amount of thermal energy in the change of physical state to liquid water [16].

Replacement of hydro electrolytes aims to prevent symptoms of dehydration caused by water loss during sweating. Hydro electrolytes help control the decrease in plasma volume and increase in osmolarity and plasma sodium concentration. The dehydration framework reduces the cardiovascular response, aerobic capacity, and the ability to redistribute blood flow to the skin, which directly affects hypothalamic sensitivity to sweating. In this sense, it is recommended the addition of carbohydrates and electrolytes in adequate amounts to the volumes of liquids used in the moments of hydration [17].

3.3 Immersion Cooling

Another resource to combat heat stress is the immersion of the extremities. This can be an effective method of reducing core temperature [18]. Immersion cooling is as effective as the more significant the temperature gradient of the immersed body surface and the water temperature; that is, the greater the temperature difference, the greater the cooling rate [19].

The operationalization of this strategy involves choosing the ideal temperature of the water and the anatomical region to be immersed. After analyzing several studies [18, 20, 21], it can be recommended that the hands and forearms be immersed in water at a temperature of 10 ℃ due to the higher rate of heat transfer and ease factors related to shoe removal and operational readiness.

3.4 Personal Cooling Systems

Personal cooling systems are a technological resource developed to minimize the effects of heat on military personnel who operate under great thermal stress and/or use special clothing for specific activities such as decontamination of environments with chemical, bacteriological or radiological agents. These garments can work by different heat exchange mechanisms. Clothes with personal cooling systems can be air-cooled, ice-cooled, liquid-cooled, or they may be made of phase change materials. Each type of clothing may best suit a specific type of operational application[16, 22].

Of the available systems, liquid-cooled clothing is considered the most beneficial by the military because of the more significant heat transfer potential of circulating water than air or ice and its general compatibility for use in an environment contaminated by chemical bacteriological or radiological. In liquid-cooled clothing, tubes circulate the cold liquid inside the dress, and heat from the skin is transferred to the liquid. Thus, the skin temperature is kept low, and consequently, the core temperature is maintained. Unlike the previously mentioned immersion cooling mechanism, which uses the hand and forearm areas, due to the ease of immersion of the same, without the need to remove the combat uniform, the cooling vests are aimed at the torso region because they are typically used in situations where the military is wearing special clothing. The trunk region offers a large surface area for heat extraction (about 20-25 % of the body surface area [16].

Regardless of the operating principle of clothing with individual cooling systems, its use imposes an extra weight on the military's equipment since they need a battery, a structure to drive the cooling principle (pipes for circulating air, liquid, ice, or phase change materials) and the refrigeration principle itself. In addition, the time of efficient use of the clothing is limited to the battery life that powers the system (around 4 hours) [16, 22].

4 Conclusions

The military must be prepared to act in any situation and operational environment. The type of operational task can impose thermal stress on the military beyond normal thermoregulatory capacity, requiring adequate intervention to dissipate body heat and maintain work capacity over time. The increased availability and use of heat stress control mechanisms can improve work performance and reduce the risk of heat-related illness in military operations.

Training and continuing education of military and troop leaders are recommended. Everyone can analyze the operational and tactical situation, deciding on the use of the most appropriate thermal stress control mechanism for each type of task / operating condition.

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References

[1] OLIVEIRA de, R.M., E.B. NEVES, S.E. da ROSA, R.A. MARSON, R.G. de SOUZA VALE, J.J.M. MORGADO, W. de ASSIS LACERDA, Jr., R.S.P. SOEIRO and R. de ALKIM MOREIRA NUNES. Effect of 6 Months of Physical Training on the Physical Fitness of Young Brazilian Army Cadets. *Healthcare,* 2021, **9**(11), 1439. DOI 10.3390/healthcare9111439.

[2] PARSONS, I.T., M.J. STACEY and D.R. WOODS. Heat Adaptation in Military Personnel: Mitigating Risk, Maximizing Performance. *Frontiers in Physiology,* 2019, **10**, 1485. DOI 10.3389/fphys.2019.01485.

[3] BULLER, M.J., S.K. DELVES, A.L. FOGARTY and B.J. VEENSTRA. On the Real-Time Prevention and Monitoring of Exertional Heat Illness in Military Personnel. *Journal of Science and Medicine in Sport,* 2021, **24**(10), pp. 975-981. DOI 10.1016/j.jsams.2021.04.008.

[4] NYE, N.S. and F.G. O'CONNOR. Exertional Heat Illness Considerations in the Military. In: ADAMS, W. and J. JARDINE, ed. *Exertional Heat Illness*. New York: Springer, 2020, pp. 181-209. ISBN 978-3-030-27804-5.

[5] JOVANOVIĆ, D., R. KARKALIC, S. ZEBA, M. PAVLOVIĆ and S.S. RADAKOVIĆ. Physiological Tolerance to Uncompensated Heat Stress in Soldiers: Effects of Various Types of Body Cooling Systems. *Vojnosanitetski Pregled,* 2014, **71**(3), pp. 259-264. DOI 10.2298/vsp120731045j.

[6] NEVES, E.B., R.M. CUNHA, C. ROSA, N.S. ANTUNES, I.M.V. FELISBERTO, J. VILAÇA-ALVES and V.M. REIS. Correlation between Skin Temperature and Heart Rate During Exercise and Recovery, and the Influence of Body Position in These Variables in Untrained Women, *Infrared Physics & Technology,* 2016, **75**, pp. 70-76. DOI 10.1016/j.infrared.2015.12.018.

[7] SCHLADER, Z.J., T.E. WILSON and C.G. CRANDALL. Mechanisms of Orthostatic Intolerance During Heat Stress. *Autonomic Neuroscience,* 2016, **196**, pp. 37-46. DOI 10.1016/j.autneu.2015.12.005.

[8] CRAMER, M.N. and O. JAY. Biophysical Aspects of Human Thermoregulation During Heat Stress. *Autonomic Neuroscience,* 2016, **196**, pp. 3-13. DOI 10.1016/j.autneu.2016.03.001.

[9] SALAMUNES, A.C.C., A.M.W. STADNIK and E.B. NEVES. The Effect of Body Fat Percentage and Body Fat Distribution on Skin Surface Temperature with Infrared Thermography. *Journal of Thermal Biology,* 2017, **66**, pp. 1-9. DOI 10.1016/j.jtherbio.2017.03.006.

[10] NEVES, E.B., A.C.C. SALAMUNES, R.M. de OLIVEIRA and A.M.W. STADNIK. Effect of Body Fat and Gender on Body Temperature Distribution. *Journal of Thermal Biology,* 2017, **70**(Part B), pp. 1-8. DOI 10.1016/j.jtherbio.2017.10.017.

[11] ASHWORTH, E.T., J.D. COTTER and A.E. KILDING. Methods for Improving Thermal Tolerance in Military Personnel Prior to Deployment. *Military Medical Research,* 2020, **7**(1), pp. 1-17. DOI 10.1186/s40779-020-00287-z.

[12] DAANEN, H.A.M., S. RACINAIS and J.D. PÉRIARD. Heat Acclimation Decay and Re-Induction: A Systematic Review and Meta-Analysis. *Sports Medicine,* 2018, **48**(2), pp. 409-430. DOI 10.1007/s40279-017-0808-x.

[13] STACEY, M.J., I.T. PARSONS, D.R. WOODS, P.N. TAYLOR, D. ROSS and S.J. BRETT. Susceptibility to Exertional Heat Illness and Hospitalisation Risk in UK Military Personnel. *BMJ Open Sport & Exercise Medicine,* 2015, **1**(1), 000055. DOI 10.1136/bmjsem-2015-000055.

[14] GARRETT, A.T., N.J. REHRER and M.J. PATTERSON. Induction and Decay of Short-Term Heat Acclimation in Moderately and Highly Trained Athletes. *Sports Medicine,* 2011, **41**, pp. 757-771. DOI 10.2165/11587320-000000000-00000.

[15] *Management of Heat and Cold Stress Guidance to NATO Medical Personnel* [online]. Brussels: NATO, 2013 [viewed 2022-01-09]. ISBN 978-92-837-0182-8. Available from: https://apps.dtic.mil/sti/pdfs/ADA602345.pdf

[16] LEE, J.K.W., R.W. KENEFICK and S.N. CHEUVRONT. Novel Cooling Strategies for Military Training and Operations. *Journal of Strength &*

Conditioning Research, 2015, **29**(Suppl 11), pp. S77-S81. DOI 10.1519/jsc.0000000000001086.

[17] MACHADO-MOREIRA, C.A., A.C. VIMIEIRO-GOMES, E. SILAMI-GARCIA, and L.O.C. RODRIGUES. Exercise Fluid Replacement: Is Thirst Enough? *Revista Brasileira de Medicina do Esporte* [online], 2006, **12**(6), pp. 361-364 [viewed 2022-01-30]. Available from: https://www.scielo.br/j/rbme/a/7QD5xyBKdjsGf7KRqqkKGCK/?format=pdf&lang=en

[18] DEGROOT, D.W., R.P. GALLIMORE, S.M. THOMPSON and R.W. KENEFICK. Extremity Cooling for Heat Stress Mitigation in Military and Occupational Settings. *Journal of Thermal Biology,* 2013, **38**(6), pp. 305-310. DOI 10.1016/j.jtherbio.2013.03.010.

[19] LIVINGSTONE, S.D., R.W. NOLAN and S.W. CATTROLL. Heat Loss Caused by Immersing the Hands in Water. *Aviation, Space, and Environmental Medicine,* 1989, **60**(12), pp. 1166-1171. ISSN 0095-6562.

[20] GIESBRECHT, G.G., C. JAMIESON and F. CAHILL. Cooling Hyperthermic Firefighters by Immersing Forearms and Hands in 10 °C and 20 °C Water, *Aviation, Space, and Environmental Medicine,* 2007, **78**(6), pp. 561-567. ISSN 0095-6562.

[21] SELKIRK, G.A., T.M. McLELLAN and J. WONG. Active Versus Passive Cooling During Work in Warm Environments While Wearing Firefighting Protective Clothing. *Journal of Occupational and Environmental Hygiene,* 2004, **1**(8), pp. 521-531. DOI 10.1080/15459620490475216.

[22] MORRISSEY, M. and F. WANG. Air and Water Perfusion-Based Personal Cooling Systems (PCSs) to Protect against Heat Stress in Protective Clothing. In: WANG, F. and C. GAO, ed. *Protective Clothing*. Amsterdam: Elsevier, 2014, pp. 296-315. ISBN 978-1-78242-032-3.