# Tactical Operations in Extreme Heat

*Improving Mission Performance and Reducing Heat Illness*

Rory O'Brien, MS, CSCS, PES
Guardian Strength and Conditioning

## Introduction

Extreme heat, and the various pathologies which can accompany it, remains one of the foremost risk factors for tactical operators. Structural and wildland firefighters are an obvious population that encounters extreme heat in the course of operations, not only due to direct heat but also the added weight and thermal load of protective gear (McEntire et al., 2013). Law enforcement and military personnel also encounter severe heat, which is further compounded by the wearing of body armor and various other equipment (Caldwell et al., 2011; Ashworth et al., 2020; Parsons et al., 2019; Bach et al., 2013; Larsen et al., 2011). Due to the additional loads which these tactical athletes must carry (added to the often extended exercise, time, and exertion in operations), they are at an increased risk of heat illness when compared to competitive and recreational athletes. For this reason, it is essential to investigate the various physiological risks inherent with physical exertion in extreme heat and examine proven methods of improving heat acclimation and tolerance for tactical athletes. This research article will also explore how these methods, many from the sports sphere, can be adapted for and utilized in the training programs and operational deployments of tactical athletes to improve mission performance in the heat and reduce the risk of heat illness.

## Exercise Physiology Considerations in Extreme Heat

Homeostasis, or the proper physiological balance within an organism, remains the essential principle which medical and exercise professionals must seek to uphold in patients and athletes. For athletes in tactical operations, such as military, law enforcement, and firefighting personnel, this need is multiplied due to various factors which differentiate tactical operations from sporting events, such as:

- the life-or-death nature of tactical operations
- the wearing of protective equipment, adding weight and thermal load to body
- the lack of rules and regulations governing behavior of opponents
- the unpredictable nature of operations, especially regarding:

- time spent in an "event"
- changing metabolic demands of exertion
- extreme levels of exertion
- last minute changes in mission parameters, locations, and weather

Various aspects of exercise in the extreme heat and its associated effects on the human body can bring mild to severe to life-threatening dangers to homeostasis (Racinais et al., 2015; Périard et al., 2015). These dangers include: general hyperthermia, dehydration and hypovolemia, electrolyte imbalance, and various forms of heat illness. One of the primary homeostatic needs of the human body, and especially for tactical athletes, is therefore thermoregulation and maintenance of a proper balance of fluids and electrolytes. Due to the factors listed above, thermal load is often increased in tactical athletes compared to the general population, or even compared to elite athletes. High levels of exertion, when combined with the wearing of protective gear and elevated ambient temperatures, can increase heat strain in tactical athletes (Cheuvront et al., 2008; Caldwell et al., 2011).

During exercise in the extreme heat, the need for homeostatic balance becomes exacerbated. As ambient temperature, core body temperature, and exercise intensity increase, the body must utilize sweating to help dissipate heat (Périard et al., 2021). As the brain recognizes an elevated core temperature, cutaneous vasodilation occurs in order to bring heat to the skin via the blood. Sweat glands are activated, and the heat from the blood is transferred to sweat due to the proximity of capillary beds to the sweat glands. Due to water's high specific heat, sweat is able to absorb a relatively large amount of heat, which is then removed from the body as sweat leaves pores. It can then be evaporated from the skin, which assists the body in dissipating heat and preventing core temperature from reaching dangerous levels.

Though heat dissipation via sweating is of immense importance during exercise in the heat, this does present its own risks to homeostasis, namely the loss of and altered balance of body fluid and electrolytes. A loss of fluids and electrolytes which exceeds those replaced during or soon after activity can have highly detrimental effects on the body (Hosey & Glazer, 2004). In order to maintain proper functioning, the body must both maintain adequate levels of fluid and electrolytes and maintain a balance between these fluids and electrolytes. This is why rehydration and replenishment of electrolytes lost in sweat is essential when exercising in extreme heat. The body must maintain normovolemia, and in order to do so, one must offset sweat losses. In order to perform at a high level in extreme heat, the body must continue to cool itself via sweating and simultaneously maintain blood volume. Strategies to improve hydration levels in training and operations will be explored later in this research article. As Caldwell et al. (2011) have demonstrated, sweating increases with the wearing of body armor, which makes hydration of even greater importance for tactical operators.

The role that the cardiovascular system plays in sweating should not be overlooked, as heat transfer through blood vessels is considered the most important heat-exchange pathway in the body (González-Alonso, 2012). Thermoregulation does indeed create a number of cardiovascular demands and creates unique challenges for heart and blood vessels, both in hot and cold environments. During exercise in the extreme heat, there exist two “competitive” demands within the cardiovascular system: first, bringing oxygen and energy nutrients to working muscles, and second, the need to increase peripheral vascular flow to dissipate heat and prevent a severely elevated core temperature (McArdle et al., 2005), which can lead to heat illness.

During intense exercise, the cardiovascular system must increase its activity in order to supply working skeletal muscles with energy nutrients and oxygen. Since this is a necessary function and exercise cannot continue without elevated heart rate and circulation, temperature regulation is often secondary to circulatory regulation and blood flow (McArdle et al., 2005), which can lead to a very increased core temperature. Though this creates unique challenges for operations in extreme heat, it demonstrates the importance of a holistic understanding of not only the physiological threats of operations in extreme heat, but also the importance of training strategies and interventions which can mitigate many of these threats.

## Major Factors Affecting Heat Tolerance

Certain fitness parameters have been demonstrated to have a significant impact on heat tolerance, supporting the notion that operators with higher fitness levels may indeed be less prone to developing heat illnesses and therefore able to continue toward mission objectives. are: aerobic capacity and VO2 max, body fat percentage, sweat composition, and sweating rate. An exploration of each of these follows.

Endurance training has long been known to confer multiple beneficial adaptations supporting both general health and human performance in sport and tactical occupations (Hughes et al., 2018; Ashworth et al., 2020; Parsons et al., 2019). These benefits, according to Baechle & Earle (2008), include:

- increased maximal cardiac output
- increased stroke volume
- decreased resting and submaximal heart rate
- improved sweat composition
- increased sweat rate
- increased VO2 max

Endurance training, and therefore improved aerobic capacity and VO2 max, have also been specifically shown in multiple studies to have a beneficial impact on heat tolerance during exercise. After finding a significant connection between higher VO2 max and heat tolerance, Lisman et al. (2014) concluded that low aerobic fitness could be addressed as a preventative measure for exercise-induced heat illnesses.

An Australian study by Alele et al. (2021) confirmed this finding, as their research demonstrated that subjects with lower aerobic capacities were less heat tolerant than their more aerobically-fit counterparts. Périard et al. (2021) also concluded that athletes with greater levels of aerobic fitness are already better suited to heat-exercise tolerance. Based upon these data, it is prudent for the practitioner to assist tactical athletes in developing a high level of aerobic capacity. However, since strength and power capabilities are essential in tactical athletes, it is advisable to utilize interval training methods as the majority of a tactical athlete's endurance programming, as these can improve VO2 max as well - if not better - than steady-state endurance training (MacInnis & Gibala, 2017, Rowan et al., 2012) while more effectively maintaining strength and power capabilities.

A direct connection between higher body fat percentages and heat intolerance was not seen by Lisman et al. (2014), but was seen by Alele et al. (2021). They reported that higher body fat percentages were indeed significant predictors of heat intolerance. Considering that low to moderate body fat percentages are well-known for being indicators of higher fitness levels, this should be a goal in tactical performance training. The indication that lower body fat percentages can also assist in the expression of heat tolerance may assist trainers and instructors in achieving buy-in from operators when presenting the new approaches to tactical strength and conditioning which are characteristic of programs such as the US Army's Holistic Health and Fitness (H2F) initiative.

As discussed in a previous section, sweating plays a major role in assisting the body to thermoregulate when exercising in extreme heat: in order to dissipate heat, water in sweat carries heat from the body's circulation outside of the body via pores in the skin, from which it then evaporates to the environment. Contained in sweat are both fluids and electrolytes such as sodium, potassium, and chloride. Highly-trained athletes and untrained (or less trained) individuals both will sweat when exposed to heat; what may not be apparent to the layperson, however, are the differences in both sweat composition and sweating rate between these two groups.

Through training, highly-trained athletes (especially endurance athletes) achieve thermoregulatory adaptations which assist the body in elevated levels of performance and decreased risks of heat illness. Among these are the ability to attain an increased rate of sweating (which can cool the body to a greater extent) and a decreased amount of electrolytes lost through sweat. In other words, endurance training in general, as well as controlled hyperthermic training, will improve both the sweating rate and sweat composition in athletes, helping lead to improved heat tolerance (Baker, 2017; Périard et al., 2015; Racinais, 2015). For sports scientists and other practitioners, sweat loss testing can be a very useful tool to estimate sweat rate and sodium concentration in sweat (Baker, 2017). This can provide data that can in turn assist sports scientists and coaches to guide fluid and electrolyte replacement strategies for the operators that they train.

## Heat Acclimation and Acclimatization

Acclimation and acclimatization are often used synonymously in the literature regarding adaptations to the heat. For example, after a search was performed on the National Library of Medicine online database (*PubMed*) for "human heat acclimation", the same results, in the same order, were achieved by searching "human heat acclimatization". However, some biologists (Filatova et al., 2019; Nakajima et al., 2020) differentiate acclimation and acclimatization in that acclimation refers to shorter-term adaptations which assist in thermoregulation (obtained in controlled conditions), with acclimatization referring to longer-term thermoregulatory adaptations which occur in response to being in a specific environment itself.

Heat acclimation could refer to soldiers in a cold environment who are preparing for deployment to a hot environment. They implement additional endurance training and sauna exposure in their overall training program to assist in heat tolerance. Heat acclimatization then, could occur when they then deploy and have been exercising and operating in a hot environment for a few weeks. In both of these examples, the operators have improved their heat tolerance, although actual exposure to a hot climate improves heat tolerance better than does heat acclimation training strategies in a non-hot climate (McGarr et al., 2014). Regardless of the exact definitions used for acclimation and acclimatization, it is clear that greater levels of heat tolerance can be achieved by tactical operators through heat-stress training and exposure to hot climatic conditions.

Below are highlighted specific physiological effects of acclimatization that can be achieved through training and heat exposure (McArdle et al., 2005), all of which will lead to improved physiological responses in the body:

- increased cutaneous blood flow
- more effective distribution of cardiac output
- decreased threshold for the initiation of sweating
- more effective distribution of sweat over skin surface
- decreased concentration of electrolytes in sweat
- increased sweat output

## Methods for Improving Heat Tolerance

Since the mid-twentieth century, there has existed an interest in the physiology of military operations in extreme heat, though this field of study has grown significantly since the beginning of American and allied involvement in Afghanistan and Iraq post September 11th (Ashworth et al., 2020; Parsons et al., 2019). Novel strategies are emerging which can assist not only members of the military, but law enforcement and firefighting personnel as well, to improve mission performance in extreme heat and reduce the risk of heat illness. These strategies are separated into three categories in this research article: a.) active training strategies, b.) passive training strategies, and c.) in-training and in-mission strategies.

### Active Heat Acclimation Strategies

Perhaps the first emphasis to make when discussing active training strategies that can assist with heat acclimation is the importance of seriously challenging the body's thermoregulatory capabilities in order to truly trigger adaptations (Ravanelli et al., 2019). Without a great enough training stimulus, the body will not achieve the desired adaptations making it more capable of elite performance in extreme heat. Active training stimuli that can trigger heat-tolerant adaptations include: an elevated core temperature for a prolonged period of time, elevated heart rate, and exposure to high ambient temperatures in training. Below is a summary of much of the scientific data gathered around active training strategies to achieve heat tolerance combined with an exploration of how this data can be used to inform tactical training approaches.

Heat acclimation training can improve multiple physiological measurements in both hot and cool environments (Lorenzo et al., 2010), and heat-stressed cycling even improved running performance in team sport athletes (Gale et al., 2021). This demonstrates that the body undergoes wide-ranging benefits from heat-stress training, even if that training does not exactly mimic the exercise to be later performed. Applying this data to a tactical training environment, we can intuit that a military unit, currently stationed in a cold climate and preparing for deployment to a hot climate, could utilize heat-stressed indoor cycling to assist in heat acclimation for the imminent deployment.

James et al. (2017) found that when compared to normothermic training, heat-stress training induced improvements in heat acclimation in only five days. This demonstrates, together with Stone et al. (2022) and Chalmers et al. (2014), that athletes have a capacity for short-term heat acclimation (STHA). Especially for special operations forces, which may have to deploy with little to no notice to a hot climate, this finding is important, as these units can utilize proven strategies for developing short-term heat acclimation. Heat acclimation benefits garnered through training can even be maintained for a month by performing heat-stressed training every five days (Pryor et al., 2019); this data can be useful as well for special operations forces awaiting a probable call-up. When operators arrive in theater, however, it is still advisable to undergo intentional heat-stress training when possible in order to expedite full heat acclimation. Indeed, Charlot et al. (2017) found that <60 minute daily moderate intensity training sessions after arriving in a hot climate for five days improves heat acclimation when compared to only performing general outdoor military duties.

As mentioned in a previous section, interval training for endurance has been demonstrated to have certain advantages over steady-state training. Overreaching through high-intensity interval training (HIIT), however, needs to be avoided, as this will negatively affect performance in the heat when short-term heat acclimation is necessary (Reeve et al., 2019; Schmitt et al., 2018). Practitioners should carefully monitor rate of perceived exertion (RPE), hydration levels, sweat loss and sweat composition, and heart rate recovery to ensure that overreaching and overtraining symptoms are avoided.

Although multiple studies have addressed the effects of endurance training on heat acclimation, no studies could be found exploring the effect that heat-stressed resistance training can have on heat acclimation and/or heat tolerance. However, Doma et al. (2019) discovered that in already heat-acclimatized men, resistance training does not negatively affect thermoregulatory measures. This is an important finding, considering the importance of strength and power capabilities in tactical occupations, as overemphasizing endurance training over strength and power training could lead to decreases in mission-specific performance. Due to the ability of multiple modes of HIIT to improve VO2 max (Astorino et al. 2017), an exploration of the effect that resistance training-based HIIT could have on heat tolerance is advisable and may add valuable training recommendations for tactical operators seeking both heat tolerance and the maintenance of strength and power capabilities.

**Passive Heat Acclimation Strategies**

Tactical operations and training are inherently metabolically taxing, making it necessary to properly frame strength and conditioning sessions around job-specific tactical training such as defensive tactics, firearms training, or scuba training. If strength and conditioning sessions are not structured to complement job-specific operations and training, tactical athletes run the risk of overreaching and overtraining, which can greatly diminish both mission performance and health outcomes (Jensen et al., 2019). Extra endurance training sessions, in order to favor heat acclimation, may actually be detrimental to operator health if performed in addition to normal job-specific training and strength and conditioning programs. Methods of triggering adaptations that favor heat acclimation while simultaneously aiding recovery, then, could assist tactical operators in preventing overtraining symptoms. For this reason, passive heat acclimation strategies are explored below.

Passive heat acclimation strategies are those which do not involve exertion, but which still expose the body to higher-than-normal ambient temperatures; this is in order to prompt heat acclimation adaptations or assist the body in improving thermoregulatory processes. Passive heat acclimation strategies can and should be utilized in addition to active strategies, such as those explored in the previous section, as this combination is effective (Stephenson et al., 2019). These strategies can even elicit larger thermal adaptations than conventional short-term exercise heat acclimation (McIntyre et al., 2021). It is important to note, however, that for complete acclimatization, exposure to the actual heat being trained for is still needed (McGarr et al., 2014).

One form of passive heat acclimation that has been shown to be very effective is post-exercise hot water immersion (HWI). Zurawlew et al. (2019) found that post-exercise HWI performed for six days both reduced thermal strain and improved exercise performance in the heat. This strategy helped subjects retain heat acclimation adaptations for at least two weeks after the initial six day HWI period. A strategy related to post-exercise HWI was investigated by Mee et al. (2018), who discovered that *pre*-exercise exposure to a hot sauna elicited many beneficial adaptations favoring heat acclimation, including reductions in thermoregulatory, cardiovascular, and perceptual strain. Both of these strategies may be beneficial for short pre-deployment periods in military populations.

An additional passive strategy to assist in heat tolerance for subsequent exercise in the heat is pre-cooling. This strategy may take the form of ice/ice-water ingestion or cooling via cold materials being placed on the body. Pre-cooling strategies may have benefits for heat tolerance in subsequent exercise in the heat (Zimmerman et al., 2018) and may be especially beneficial for unacclimatized persons (Schmitt et al., 2017). When planned training or missions occur in extreme heat, these strategies may prove beneficial for not only military personnel, but for law enforcement and firefighters as well.

### Strategies for Heat Stress Mitigation During Training and Operations

Though the above strategies - both active and passive - to increase heat tolerance and improve heat acclimation are important, they do not replace the need for heat stress mitigation strategies during training and operations. Without in-training and in-mission interventions, even the most heat-acclimatized and otherwise healthy individuals can suffer severe heat illness (Department of the Army, 2012). For example, elite special operators could spend months preparing for deployment to an extremely hot climate, with all of the benefits of a full human performance staff comprised of medical doctors, exercise physiologists, strength and conditioning specialists, and more. Yet, if these soldiers do not utilize mitigation strategies to assist their bodies in maintaining homeostasis throughout operations in the heat, they could easily fall prey to severe - and even life-threatening - heat illness. Due to the importance of these strategies to the maintenance of homeostasis and mission performance, the principal strategy is introduced below: hydration/nutrition.

Rehydration is an essential strategy to prevent heat illness and improve performance (Department of the Army, 2012; Périard et al., 2021). Due to the large amounts of fluid loss that are intrinsic to sweating, it is essential that persons exercising, competing, or operating in extreme heat replenish fluid at regular intervals. However, since electrolytes are also lost in sweat, rehydration with water only is cautioned against (Gotlin, 2020). Instead, rehydration with a drink containing both water and electrolytes is a key strategy during exercise in the heat. While fluid and electrolytes are of utmost importance, a combination of carbohydrates and protein can further improve exercise performance in the heat (Cathart et al., 2011).

## Conclusion

Training and operations in extreme heat introduce a number of physiological dangers to tactical athletes. For this reason, it is of utmost importance that preparing for the rigors of heat stress be a fundamental element of the overall training programs for military, law enforcement, and firefighting personnel. Through a combination of active and passive strategies, tactical operators can indeed prepare their bodies - and minds - for the inherently strenuous nature of extreme heat. During training and missions, hydration and nutrition strategies are essential, though can be combined with active cooling strategies including the wearing of cooling vests, fanning and spraying with water, and cold water ingestion (Périard et al., 2021).

An investigation of the role that resistance training and concurrent training can play in increasing thermoregulatory abilities for tactical operators is warranted, due to the need for both strength and endurance capabilities in this population. In conclusion, tactical operators, due to the nature of their work, are often at increased risk for heat illness compared to sport athletes, and for this reason it is essential that training to increase heat tolerance be a fundamental portion to tactical strength and conditioning programs.

## References


Alele, F. O., Malau-Aduli, B. S., Malau-Aduli, A. E. O., & J Crowe, M. (2021). Individual Anthropometric, Aerobic Capacity and Demographic Characteristics as Predictors of Heat Intolerance in Military Populations. Medicina (Kaunas, Lithuania), 57(2), 173. https://doi.org/10.3390/medicina57020173

Alhadad, S. B., Tan, P. M. S., & Lee, J. K. W. (2019). Efficacy of Heat Mitigation Strategies on Core Temperature and Endurance Exercise: A Meta-Analysis. *Frontiers in physiology*, *10*, 71. https://doi.org/10.3389/fphys.2019.00071

Aljaroudi, A. M., Kadis, D. S., Bhattacharya, A., Strauch, A., Quinn, T. D., & Williams, W. J. (2020). Effect of continuous cooling on inhibition and attention while wearing firefighter's PPE in a hot environment. *Journal of occupational and environmental hygiene*, *17*(5), 243–252. https://doi.org/10.1080/15459624.2020.1726933

Ashworth, E. T., Cotter, J. D., & Kilding, A. E. (2021). Impact of elevated core temperature on cognition in hot environments within a military context. *European journal of applied physiology*, *121*(4), 1061–1071. https://doi.org/10.1007/s00421-020-04591-3

Astorino, T. A., Edmunds, R. M., Clark, A., King, L., Gallant, R. A., Namm, S., Fischer, A., & Wood, K. M. (2017). High-Intensity Interval Training Increases Cardiac Output and V̇O2max. *Medicine and science in sports and exercise*, *49*(2), 265–273. https://doi.org/10.1249/MSS.0000000000001099

Bach, A. J. E., Maley, M. J., Minett, G. M., & Stewart, I. B. (2018). Occupational cooling practices of emergency first responders in the United States: A survey. *Temperature (Austin, Tex.)*, *5*(4), 348–358. https://doi.org/10.1080/23328940.2018.1493907

Baechle, T. R., & Earle, R. W. (2008). *Essentials of strength training and conditioning*. Human Kinetics.

Baker L. B. (2017). Sweating Rate and Sweat Sodium Concentration in Athletes: A Review of Methodology and Intra/Interindividual Variability. *Sports medicine (Auckland, N.Z.)*, *47*(Suppl 1), 111–128. https://doi.org/10.1007/s40279-017-0691-5

Barwood, M. J., Thelwell, R. C., & Tipton, M. J. (2008). Psychological skills training improves exercise performance in the heat. *Medicine and science in sports and exercise*, *40*(2), 387–396. https://doi.org/10.1249/mss.0b013e31815adf31

Benjamin, C. L., Sekiguchi, Y., Armstrong, L. E., Manning, C. N., Struder, J. F., Butler, C. R., Huggins, R. A., Stearns, R. L., Lee, E. C., & Casa, D. J. (2022). The efficacy of weekly and bi-weekly heat training to maintain the physiological benefits of heat acclimation. *Journal of science and medicine in sport*, *25*(3), 255–260. https://doi.org/10.1016/j.jsams.2021.10.006

Benjamin, C. L., Sekiguchi, Y., Struder, J. F., Szymanski, M. R., Manning, C. N., Grundstein, A. J., Lee, E. C., Huggins, R. A., Armstrong, L. E., & Casa, D. J. (2021). Heat Acclimation Following Heat Acclimatization Elicits Additional Physiological Improvements in Male Endurance Athletes. *International journal of environmental research and public health*, *18*(8), 4366. https://doi.org/10.3390/ijerph18084366

Boffey, D., Harat, I., Gepner, Y., Frosti, C. L., Funk, S., & Hoffman, J. R. (2019). The Physiology and Biomechanics of Load Carriage Performance. *Military medicine*, *184*(1-2), e83–e90. https://doi.org/10.1093/milmed/usy218

Burgomaster, K. A., Howarth, K. R., Phillips, S. M., Rakobowchuk, M., Macdonald, M. J., McGee, S. L., & Gibala, M. J. (2008). Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. *The Journal of physiology*, *586*(1), 151–160. https://doi.org/10.1113/jphysiol.2007.142109

Caldwell, J. N., Engelen, L., van der Henst, C., Patterson, M. J., & Taylor, N. A. (2011). The interaction of body armor, low-intensity exercise, and hot-humid conditions on physiological strain and cognitive function. *Military medicine*, *176*(5), 488–493. https://doi.org/10.7205/milmed-d-10-00010

Cathcart, A. J., Murgatroyd, S. R., McNab, A., Whyte, L. J., & Easton, C. (2011). Combined carbohydrate-protein supplementation improves competitive endurance exercise performance in the heat. *European journal of applied physiology*, *111*(9), 2051–2061. https://doi.org/10.1007/s00421-011-1831-5

Chalmers, S., Esterman, A., Eston, R., Bowering, K. J., & Norton, K. (2014). Short-term heat acclimation training improves physical performance: a systematic review, and exploration of physiological adaptations and application for team sports. *Sports medicine (Auckland, N.Z.)*, *44*(7), 971–988. https://doi.org/10.1007/s40279-014-0178-6

Chatterjee, T., Bhattacharyya, D., Pramanik, A. *et al.* Soldiers' load carriage performance in high mountains: a physiological study. *Military Med Res* 4, 6 (2017). https://doi.org/10.1186/s40779-017-0113-x

Cheuvront, S. N., Goodman, D. A., Kenefick, R. W., Montain, S. J., & Sawka, M. N. (2008). Impact of a protective vest and spacer garment on exercise-heat strain. *European journal of applied physiology*, *102*(5), 577–583. https://doi.org/10.1007/s00421-007-0632-3

Doma, K., Nicholls, A., Gahreman, D., Damas, F., Libardi, C. A., & Sinclair, W. (2019). The Effect of a Resistance Training Session on Physiological and Thermoregulatory Measures of Sub-maximal Running Performance in the Heat in Heat-Acclimatized Men. *Sports medicine - open*, *5*(1), 21. https://doi.org/10.1186/s40798-019-0195-y

Ely, B. R., Ely, M. R., & Cheuvront, S. N. (2011). Marginal effects of a large caffeine dose on heat balance during exercise-heat stress. *International journal of sport nutrition and exercise metabolism*, *21*(1), 65–70. https://doi.org/10.1123/ijsnem.21.1.65

Travers, G., González-Alonso, J., Riding, N., Nichols, D., Shaw, A., & Périard, J. D. (2021). Exercise Heat Acclimation With Dehydration Does Not Affect Vascular and Cardiac Volumes or Systemic Hemodynamics During Endurance Exercise. *Frontiers in physiology*, *12*, 740121. https://doi.org/10.3389/fphys.2021.740121

Filatova, T. S., Abramochkin, D. V., & Shiels, H. A. (2019). Thermal acclimation and seasonal acclimatization: a comparative study of cardiac response to prolonged temperature change in shorthorn sculpin. *The Journal of experimental biology*, *222*(Pt 16), jeb202242. https://doi.org/10.1242/jeb.202242

Gale, R. M., Etxebarria, N., Pumpa, K. L., & Pyne, D. B. (2021). Cycling-based repeat sprint training in the heat enhances running performance in team sport players. *European journal of sport science*, *21*(5), 695–704. https://doi.org/10.1080/17461391.2020.1759696

Gibson, O. R., Willmott, A. G., James, C. A., Hayes, M., & Maxwell, N. S. (2017). Power Relative to Body Mass Best Predicts Change in Core Temperature During Exercise-Heat Stress. *Journal of strength and conditioning research*, *31*(2), 403–414. https://doi.org/10.1519/JSC.0000000000001521

Goforth, C., Lisman, P., & Deuster, P. (2014). The physiological impact of body armor cooling devices in hot environments: a systematic review. *Military medicine*, *179*(7), 724–734. https://doi.org/10.7205/MILMED-D-13-00398

González-Alonso J. (2012). Human thermoregulation and the cardiovascular system. *Experimental physiology*, *97*(3), 340–346. https://doi.org/10.1113/expphysiol.2011.058701

Guy, J. H., Deakin, G. B., Edwards, A. M., Miller, C. M., & Pyne, D. B. (2015). Adaptation to hot environmental conditions: an exploration of the performance basis, procedures and future directions to optimise opportunities for elite athletes. *Sports medicine (Auckland, N.Z.)*, *45*(3), 303–311. https://doi.org/10.1007/s40279-014-0277-4

Haroutounian, A., Amorim, F. T., Astorino, T. A., Khodiguian, N., Curtiss, K. M., Matthews, A. R. D., Estrada, M. J., Fennel, Z., McKenna, Z., Nava, R., & Sheard, A. C. (2021). Change in Exercise Performance and Markers of Acute Kidney Injury Following Heat Acclimation with Permissive Dehydration. *Nutrients*, *13*(3), 841. https://doi.org/10.3390/nu13030841

Havenith G. (1999). Heat balance when wearing protective clothing. *The Annals of occupational hygiene*, *43*(5), 289–296.

Heled, Y., Peled, A., Yanovich, R., Shargal, E., Pilz-Burstein, R., Epstein, Y., & Moran, D. S. (2012). Heat acclimation and performance in hypoxic conditions. *Aviation, space, and environmental medicine*, *83*(7), 649–653. https://doi.org/10.3357/asem.3241.2012

Hosey, R. G., & Glazer, J. L. (2004). The ergogenics of fluid and electrolyte balance. *Current sports medicine reports*, *3*(4), 219–223. https://doi.org/10.1249/00149619-200408000-00008

Hughes, D. C., Ellefsen, S., & Baar, K. (2018). Adaptations to Endurance and Strength Training. *Cold Spring Harbor perspectives in medicine*, *8*(6), a029769. https://doi.org/10.1101/cshperspect.a029769

James, C. A., Richardson, A. J., Watt, P. W., Willmott, A. G., Gibson, O. R., & Maxwell, N. S. (2017). Short-term heat acclimation improves the determinants of endurance performance and 5-km running performance in the heat. *Applied physiology, nutrition, and metabolism = Physiologie appliquee, nutrition et metabolisme*, *42*(3), 285–294. https://doi.org/10.1139/apnm-2016-0349

Jensen, A. E., Arrington, L. J., Turcotte, L. P., & Kelly, K. R. (2019). Hormonal balance and nutritional intake in elite tactical athletes. *Steroids*, *152*, 108504. https://doi.org/10.1016/j.steroids.2019.108504

Kirby, N. V., Lucas, S. J. E., & Lucas, R. A. I. (2019). Nine-, but Not Four-Days Heat Acclimation Improves Self-Paced Endurance Performance in Females. *Frontiers in physiology*, *10*, 539. https://doi.org/10.3389/fphys.2019.00539

Knapik, J. J., & Epstein, Y. (2019). Exertional Heat Stroke: Pathophysiology, Epidemiology, Diagnosis, Treatment, and Prevention. *Journal of special operations medicine : a peer reviewed journal for SOF medical professionals*, *19*(2), 108-116.

Kuennen, M., Gillum, T., Dokladny, K., Bedrick, E., Schneider, S., & Moseley, P. (2011). Thermotolerance and heat acclimation may share a common mechanism in humans. *American journal of physiology. Regulatory, integrative and comparative physiology*, *301*(2), R524–R533. https://doi.org/10.1152/ajpregu.00039.2011

Larsen, B., Netto, K., & Aisbett, B. (2011). The effect of body armor on performance, thermal stress, and exertion: a critical review. *Military medicine*, *176*(11), 1265–1273. https://doi.org/10.7205/milmed-d-10-00470

Lee, B. J., Miller, A., James, R. S., & Thake, C. D. (2016). Cross Acclimation between Heat and Hypoxia: Heat Acclimation Improves Cellular Tolerance and Exercise Performance in Acute Normobaric Hypoxia. *Frontiers in physiology*, *7*, 78. https://doi.org/10.3389/fphys.2016.00078

Lee, J. K., Yeo, Z. W., Nio, A. Q., Koh, A. C., Teo, Y. S., Goh, L. F., Tan, P. M., & Byrne, C. (2013). Cold drink attenuates heat strain during work-rest cycles. *International journal of sports medicine*, *34*(12), 1037–1042. https://doi.org/10.1055/s-0033-1337906

Lisman, P., Kazman, J. B., O'Connor, F. G., Heled, Y., & Deuster, P. A. (2014). Heat tolerance testing: association between heat intolerance and anthropometric and fitness measurements. *Military medicine*, *179*(11), 1339–1346. https://doi.org/10.7205/MILMED-D-14-00169

Lorenzo, S., Halliwill, J. R., Sawka, M. N., & Minson, C. T. (2010). Heat acclimation improves exercise performance. *Journal of applied physiology (Bethesda, Md. : 1985)*, *109*(4), 1140–1147. https://doi.org/10.1152/japplphysiol.00495.2010

MacInnis, M. J., & Gibala, M. J. (2017). Physiological adaptations to interval training and the role of exercise intensity. *The Journal of physiology*, *595*(9), 2915–2930. https://doi.org/10.1113/JP273196

Marshall, H. C., Ferguson, R. A., & Nimmo, M. A. (2006). Human resting extracellular heat shock protein 72 concentration decreases during the initial adaptation to exercise in a hot, humid environment. *Cell stress & chaperones*, *11*(2), 129–134. https://doi.org/10.1379/csc-158r.1

McArdle, W. D., Katch, F. I., & Katch, V. L. (2005). *Essentials of exercise physiology*. Lippincott Williams & Wilkins.

McCleave, E. L., Slattery, K. M., Duffield, R., Saunders, P. U., Sharma, A. P., Crowcroft, S., & Coutts, A. J. (2019). Impaired Heat Adaptation From Combined Heat Training and "Live High, Train Low" Hypoxia. *International journal of sports physiology and performance*, *14*(5), 635–643. https://doi.org/10.1123/ijspp.2018-0399

McDermott, B. P., Casa, D. J., Ganio, M. S., Lopez, R. M., Yeargin, S. W., Armstrong, L. E., & Maresh, C. M. (2009). Acute whole-body cooling for exercise-induced hyperthermia: a systematic review. *Journal of athletic training*, *44*(1), 84–93. https://doi.org/10.4085/1062-6050-44.1.84

McDermott, B. P., Anderson, S. A., Armstrong, L. E., Casa, D. J., Cheuvront, S. N., Cooper, L., Kenney, W. L., O'Connor, F. G., & Roberts, W. O. (2017). National Athletic Trainers' Association Position Statement: Fluid Replacement for the Physically Active. *Journal of athletic training*, *52*(9), 877–895. https://doi.org/10.4085/1062-6050-52.9.02

McEntire, S. J., Suyama, J., & Hostler, D. (2013). Mitigation and prevention of exertional heat stress in firefighters: a review of cooling strategies for structural firefighting and hazardous materials responders. *Prehospital emergency care*, *17*(2), 241–260. https://doi.org/10.3109/10903127.2012.749965

McGarr, G. W., Hartley, G. L., & Cheung, S. S. (2014). Neither short-term sprint nor endurance training enhances thermal response to exercise in a hot environment. *Journal of occupational and environmental hygiene*, *11*(1), 47–53. https://doi.org/10.1080/15459624.2013.816429

McIntyre, R. D., Zurawlew, M. J., Oliver, S. J., Cox, A. T., Mee, J. A., & Walsh, N. P. (2021). A comparison of heat acclimation by post-exercise hot water immersion and exercise in the heat. *Journal of science and medicine in sport*, *24*(8), 729–734. https://doi.org/10.1016/j.jsams.2021.05.008

Mee JA, Peters S, Doust JH, Maxwell NS. Sauna exposure immediately prior to short-term heat acclimation accelerates phenotypic adaptation in females. J Sci Med Sport. 2018 Feb;21(2):190-195. doi: 10.1016/j.jsams.2017.06.024. Epub 2017 Jul 4. PMID: 28739443.

Mikkelson, C.J., Junge, N., Piil, J., Morris, N., Oberholzer, L., Siebenmann, C., Lundby, C., Nybo, L., (2019). Prolonged Heat Acclimation and Aerobic Performance in Endurance Trained Athletes. *Frontiers in Physiology* 10: 1372. http://doi.org/10.3389/fphys.2019.01372

Mitchell, K. M., Cheuvront, S. N., King, M. A., Mayer, T. A., Leon, L. R., & Kenefick, R. W. (2019). Use of the heat tolerance test to assess recovery from exertional heat stroke. *Temperature (Austin, Tex.)*, *6*(2), 106–119. https://doi.org/10.1080/23328940.2019.1574199

Nakajima, A., Okada, M., Ishihara, A., & Yamauchi, K. (2020). Modulation of plasma protein expression in bullfrog (Rana catesbeiana) tadpoles during seasonal acclimatization and thermal acclimation. *General and comparative endocrinology*, *290*, 113396. https://doi.org/10.1016/j.ygcen.2020.113396

Oberholzer, L., Siebenmann, C., Mikkelsen, C. J., Junge, N., Piil, J. F., Morris, N. B., Goetze, J. P., Meinild Lundby, A. K., Nybo, L., & Lundby, C. (2019). Hematological Adaptations to Prolonged Heat Acclimation in Endurance-Trained Males. *Frontiers in physiology*, *10*, 1379. https://doi.org/10.3389/fphys.2019.01379

Périard, J. D., Eijsvogels, T. M. H., & Daanen, H. A. M. (2021). Exercise under heat stress: thermoregulation, hydration, performance implications, and mitigation strategies. *Physiological reviews*, *101*(4), 1873–1979. https://doi.org/10.1152/physrev.00038.2020

Périard, J. D., Houtkamp, D., Bright, F., Daanen, H. A. M., Abbiss, C. R., Thompson, K. G., & Clark, B. (2019). Hyperoxia enhances self-paced exercise performance to a greater extent in cool than hot conditions. *Experimental physiology*, *104*(9), 1398–1407. https://doi.org/10.1113/EP087864

Périard, J. D., Racinais, S., & Sawka, M. N. (2015). Adaptations and mechanisms of human heat acclimation: Applications for competitive athletes and sports. *Scandinavian journal of medicine & science in sports*, *25 Suppl 1*, 20–38. https://doi.org/10.1111/sms.12408

Pryor, J. L., Pryor, R. R., Vandermark, L. W., Adams, E. L., VanScoy, R. M., Casa, D. J., Armstrong, L. E., Lee, E. C., DiStefano, L. J., Anderson, J. M., & Maresh, C. M. (2019). Intermittent exercise-heat exposures and intense physical activity sustain heat acclimation adaptations. *Journal of science and medicine in sport*, *22*(1), 117–122. https://doi.org/10.1016/j.jsams.2018.06.009

Pyke, A. J., Costello, J. T., & Stewart, I. B. (2015). Heat strain evaluation of overt and covert body armour in a hot and humid environment. *Applied ergonomics*, *47*, 11–15. https://doi.org/10.1016/j.apergo.2014.08.016

Racinais, S., Alonso, J. M., Coutts, A. J., Flouris, A. D., Girard, O., González-Alonso, J., Hausswirth, C., Jay, O., Lee, J. K., Mitchell, N., Nassis, G. P., Nybo, L., Pluim, B. M., Roelands, B., Sawka, M. N., Wingo, J., & Périard, J. D. (2015). Consensus recommendations on training and competing in the heat. *British journal of sports medicine*, *49*(18), 1164–1173. https://doi.org/10.1136/bjsports-2015-094915

Racinais, S., Moussay, S., Nichols, D., Travers, G., Belfekih, T., Schumacher, Y. O., & Periard, J. D. (2019). Core temperature up to 41.5ºC during the UCI Road Cycling World Championships in the heat. *British journal of sports medicine*, 53(7), 426–429. https://doi.org/10.1136/bjsports-2018-099881

Ravanelli, N., Coombs, G., Imbeault, P., & Jay, O. (2019). Thermoregulatory adaptations with progressive heat acclimation are predominantly evident in uncompensable, but not compensable, conditions. *Journal of applied physiology (Bethesda, Md. : 1985)*, *127*(4), 1095–1106. https://doi.org/10.1152/japplphysiol.00220.2019

Reeve, T., Gordon, R., Laursen, P. B., Lee, J. K. W., & Tyler, C. J. (2019). Impairment of Cycling Capacity in the Heat in Well-Trained Endurance Athletes After High-Intensity Short-Term Heat Acclimation. *International journal of sports physiology and performance*, *14*(8), 1058–1065. https://doi.org/10.1123/ijspp.2018-0537

Rehrer N. J. (2001). Fluid and electrolyte balance in ultra-endurance sport. *Sports medicine (Auckland, N.Z.)*, *31*(10), 701–715. https://doi.org/10.2165/00007256-200131100-00001

Rowan, A.E., Kueffner, T.E., Stavrianeas, S. (2012). Short Duration High-Intensity Interval Training Improves Aerobic Conditioning of Female College Soccer Players. *International Journal of Exercise Science* 5(3) : 232-238.

Schmit, C., Duffield, R., Hausswirth, C., Brisswalter, J., & Le Meur, Y. (2018). Optimizing Heat Acclimation for Endurance Athletes: High- Versus Low-Intensity Training. *International journal of sports physiology and performance*, *13*(6), 816–823. https://doi.org/10.1123/ijspp.2017-0007

Schmit, C., Le Meur, Y., Duffield, R., Robach, P., Oussedik, N., Coutts, A. J., & Hausswirth, C. (2017). Heat-acclimatization and pre-cooling: a further boost for endurance performance?. *Scandinavian journal of medicine & science in sports*, *27*(1), 55–65. https://doi.org/10.1111/sms.12629

Sekiguchi, Y., Benjamin, C. L., Lee, E. C., Struder, J. F., Manning, C. N., Morrissey, M. C., Szymanski, M. R., Stearns, R. L., Armstrong, L. E., & Casa, D. J. (2022). Effects of Heat Acclimation Following Heat Acclimatization on Whole Body Heat Exchange in Trained Endurance Athletes. *International journal of environmental research and public health*, *19*(11), 6412. https://doi.org/10.3390/ijerph19116412

Sekiguchi, Y., Benjamin, C. L., Manning, C. N., Struder, J. F., Armstrong, L. E., Lee, E. C., Huggins, R. A., Stearns, R. L., Distefano, L. J., & Casa, D. J. (2022). Effects of Heat Acclimatization, Heat Acclimation, and Intermittent Exercise Heat Training on Time-Trial Performance. *Sports health*, *14*(5), 694–701. https://doi.org/10.1177/19417381211050643

Shetty, V. B., Smith, G., Paramalingam, N., Roby, H. C., Davis, E. A., Jones, T. W., & Fournier, P. A. (2021). Antidiuretic hormone and the activation of glucose production during high intensity aerobic exercise. *Metabolism open*, *11*, 100113. https://doi.org/10.1016/j.metop.2021.100113

Stephenson, B. T., Tolfrey, K., & Goosey-Tolfrey, V. L. (2019). Mixed Active and Passive, Heart Rate-Controlled Heat Acclimation Is Effective for Paralympic and Able-Bodied Triathletes. *Frontiers in physiology*, *10*, 1214. https://doi.org/10.3389/fphys.2019.01214

Stone, B. L., Ashley, J. D., Skinner, R. M., Polanco, J. P., Walters, M. T., Schilling, B. K., & Kellawan, J. M. (2022). Effects of a Short-Term Heat Acclimation Protocol in Elite Amateur Boxers. *Journal of strength and conditioning research*, *36*(7), 1966–1971. https://doi.org/10.1519/JSC.0000000000004233

Travers, G., González-Alonso, J., Riding, N., Nichols, D., Shaw, A., & Périard, J. D. (2021). Exercise Heat Acclimation With Dehydration Does Not Affect Vascular and Cardiac Volumes or Systemic Hemodynamics During Endurance Exercise. *Frontiers in physiology*, *12*, 740121. https://doi.org/10.3389/fphys.2021.740121

Tyler, C. J., Reeve, T., Hodges, G. J., & Cheung, S. S. (2016). The Effects of Heat Adaptation on Physiology, Perception and Exercise Performance in the Heat: A Meta-Analysis. *Sports medicine (Auckland, N.Z.)*, *46*(11), 1699–1724. https://doi.org/10.1007/s40279-016-0538-5

Waldron, M., Fowler, R., Heffernan, S., Tallent, J., Kilduff, L., & Jeffries, O. (2021). Effects of Heat Acclimation and Acclimatisation on Maximal Aerobic Capacity Compared to Exercise Alone in Both Thermoneutral and Hot Environments: A Meta-Analysis and Meta-Regression. *Sports medicine (Auckland, N.Z.)*, *51*(7), 1509–1525. https://doi.org/10.1007/s40279-021-01445-6

Zhang, S., & Zhu, N. (2021). Exercise heat acclimation causes human responses and safety performance improvements. *Journal of thermal biology*, *100*, 103042. https://doi.org/10.1016/j.jtherbio.2021.103042

Zimmermann, M., Landers, G., Wallman, K., & Kent, G. (2018). Precooling With Crushed Ice: As Effective as Heat Acclimation at Improving Cycling Time-Trial Performance in the Heat. *International journal of sports physiology and performance*, *13*(2), 228–234. https://doi.org/10.1123/ijspp.2016-0766

Zurawlew, M. J., Mee, J. A., & Walsh, N. P. (2019). Post-exercise Hot Water Immersion Elicits Heat Acclimation Adaptations That Are Retained for at Least Two Weeks. *Frontiers in physiology*, *10*, 1080. https://doi.org/10.3389/fphys.2019.01080