Heat Tolerance Testing: A Historical Perspective

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Abstract

Assessing individual heat tolerance is a critical component of occupational and military medicine, particularly for determining safe return to duty after exertional heat illness. This review provides a comprehensive historical perspective on the evolution of Heat Tolerance Testing (HTT), tracing its development from early 20th-century deep-mining safety protocols to contemporary military applications. We examine the transition from rudimentary thermal metrics to sophisticated functional assessments, focusing on the Israel Defense Forces (IDF) protocol, which is currently the most widely validated and used screening protocol. The discussion highlights the physiological rationale for clamping metabolic and environmental conditions to identify thermoregulatory impairment. Furthermore, the review addresses modern challenges and emerging frontiers in HTT, including the disproportionate failure rates among female personnel and the necessity for sex-specific criteria that account for aerobic fitness and hormonal fluctuations. We also explore recent evidence suggesting that physiological recovery does not always coincide with cognitive and affective readiness, suggesting that brief neurocognitive and affective evaluations be considered for integration into standard protocols. By synthesizing decades of research, this review underscores the role of HTT results not as a standalone diagnostic test but as one supportive tool in a multi-modal clinical decision-making process. Ultimately, refining these assessments is essential to enhance force health protection and ensure operational readiness in increasingly heat-stressed environments.

Keywords: Tolerance to heat, Heat stroke, Heat stress, RTD, HTT.

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Introduction

Soldiers, elite and recreational athletes, and occupational laborers regularly perform stressful physical activities in warm to hot environments, sometimes wearing heavy equipment. This heat stress markedly affects exercise performance and produces physiological strain that may progress to exertional heat illness. It is therefore unsurprising that the human ability to work in a hot climate has been investigated for almost 250 years. Probably the first study in a climatic chamber was carried out by Blagden, who reported in 1775 the sense of fatigue and increased pulse rate of an associate exposed in a heated room to temperatures of 32 °C to 127 °C [1]. However, systematic testing of an individual's tolerance to heat did not begin until the twentieth century and intensified after World War II.

Predicting an individual's tolerance to heat, as a surrogate decision-making tool for return to duty or returning to play, particularly after recovery from exertional heat illness, is relevant in sports, occupational, and military environments. Such a functional test can also help identify clinical situations that might hamper physiological responses under heat stress. Adolph and colleagues proposed that "tolerance to heat can be evaluated by seeing at what temperature and humidity a man can carry on a set kind of work. Preferably, the work would be done in a steady state, metabolic state" [2]. In short, the thermoregulatory response is assessed by clamping metabolic rate and environmental conditions and then following the physiological responses. Later, the American College of Sports Medicine adopted a general recommendation for undergoing a structured heat tolerance test before an athlete returns to play, but without specifying a definitive protocol [3,4]. Hence, for nearly a century, practical quantitative or semi-quantitative tests designed to evaluate the thermoregulatory response to exercise-heat stress have been proposed. This review traces the development of those tests from the early deep-mining protocols to the assessments in current military use, sets out the physiological rationale that underlies them, and examines two questions that remain unresolved: whether criteria derived from young male populations are appropriate for women, and whether physiological recovery is a sufficient basis for a return-to-duty decision.

Earlier studies

Probably, the first heat tolerance test (HTT) was conducted by Dreosti in the early 1930s, studying gold miners in South Africa [5]. Dreosti aimed to identify individuals particularly susceptible to heatstroke, thereby preventing them from facing life-threatening conditions in the mines, and to determine the number of days required to acclimate workers before descending into the mines. The exercise-heat test he used was conducted in a climatic chamber, where the unclothed workers performed two 30-min bouts of shoveling rocks under conditions of 35 °C and 100% relative humidity (RH) with no access to drinking water; the exercise-heat exposure was followed by a 1-h cooling-down period at approximately 27 °C and 22% RH, during which drinking water was allowed [5]. Workers whose body temperature rose more steeply during the test and who also had lower cooling rates were deemed less tolerant to heat. Consequently, he determined that the most reliable measurement for assigning an effective heat acclimation protocol was the final core temperature recorded after the HTT. Workers with a final core temperature below 38.1 °C were considered heat tolerant (HT) and assigned only four acclimation sessions before commencing mining work. Those individuals whose final core temperature exceeded 38.9°C were categorized as heat intolerant (HI) and subsequently assigned to a comprehensive 14-day heat-acclimation protocol [5].

During World War II, extensive research focused on studying the thermoregulatory and cardiovascular responses of military personnel during heat acclimation, on the assumption that even individuals with lower heat tolerance would ultimately adapt [6-10]. Consequently, the emphasis on detecting susceptibility to heat to minimize the risk of heat illness was not as pronounced during that period.

In the early 1950s, Wyndham and coworkers introduced a modified HTT to screen the population of gold miners [11]. Men dressed in shorts performed 4 h of continuous work at an oxygen uptake (VO_2) of approximately 1.0 L/min (block stepping, 12 steps/min) under conditions of 34 °C and 85% RH, which closely matched the working conditions in the mines [12,13]. A notable distinction between Dreosti's test and the one developed by Wyndham et al. was the inclusion of cardiovascular and

sweat rate parameters as additional indicators of strain, in addition to body temperature alone.

Scott and colleagues [14] and Bean and Eichna [8] reported a marked decrease in the orthostatic response associated with symptoms of thermal stress in the 1940s. Subsequently, Brown and colleagues (1959) proposed evaluating impaired circulatory adaptation in individuals exposed to increasing environmental heat stress by examining their orthostatic response [15].

Later studies

Extensive work on assessing heat tolerance has been done since the 1970s. Following the earlier studies of the orthostatic response during heat stress, Shvartz et al. (1977) demonstrated that heat tolerance, as determined by an HTT consisting of 3 h of stepping on a 30-cm-high bench at 39.4 °C and 50% RH, was a determining factor in orthostatic tolerance [16]. Shvartz and colleagues also concluded that in approximately 83% of cases, physically fit and heat-acclimated individuals exhibited a superior orthostatic response compared with unfit and poorly acclimated individuals [16]. Similarly, Hori and Ihzuka (1979) showed that the fall in systolic blood pressure in an orthostatic test in a hot environment is a useful indicator of the degree of adaptability to such an environment [17]. Years later, Schiffmann et al. showed that HI individuals used a larger part of their cardiovascular reserve during an HTT, indicating greater cardiovascular strain in the heat [18]. Nevertheless, although orthostatic responses were initially considered a potential means of assessing cardiovascular adaptability to exercise-heat exposure, this approach has proven limited and has since been abandoned.

Concurrently, Shvartz and colleagues (1977) explored the feasibility of predicting heat tolerance by a composite score based on heart rate (HR) and rectal temperature (Tre) responses to exercise at room temperature [19]. They concluded that HI individuals exhibited scores lower than 35 and that a 15-min bench-stepping exercise at an average workload of 80 W (24 steps/min) at 23 °C correlated strongly with 3 h of bench stepping (40 W, 12 steps/min) in the heat (39.3 °C, 50% RH) [19]. This test was ultimately discarded, but it further supported the potential of these physiological parameters for predicting an individual's heat tolerance.

A set of indices to assess the physiological strain induced by heat load was presented by Hori and colleagues, who proposed using a combination of the relative rise in rectal temperature, relative water loss, and relative salt loss, using as the critical values of these three factors those associated with heat stroke (40.6 °C), water-depletion heat exhaustion (7% of body weight), and salt-depletion heat exhaustion (0.75 g (44 mmol) per kg of body weight). While the authors argued that, from a theoretical point of view, the set of indices they proposed reflects heat strain and heat tolerance, they concluded that “from a practical point of view, the application of experimental data in a quadratic equation appears rather complicated” [20].

During the 1970s, field commanders in the Israel Defense Forces (IDF) asked for a means of returning to duty soldiers who had recovered from heatstroke or heat exhaustion. Such a test was required to be simple, reproducible, and quantitative. Shapiro and colleagues of the IDF Medical Corps adopted a protocol based on the tests developed by Wyndham et al. and Shvartz et al., with slight modifications [21]. Since then, every soldier in the IDF who recovers from exertional heat stroke (EHS) or heat exhaustion undergoes an HTT as part of the return-to-duty protocol.

In the late 1980s, the IDF HTT underwent several important modifications. Stepping on a bench was replaced by walking on a treadmill at 5 km/h (1.39 m/s) on a 2% incline, which was found to be more convenient and of equivalent work intensity (30-40% of VO2max for young, fit individuals). Additionally, the test duration was shortened to 2 h; it had been noted that Tre would either plateau during the second hour (indicating an adequate thermoregulatory response) or continue to increase (suggesting an impaired thermoregulatory response) [22]. In this revised HTT, individuals are classified as HT if their Tre is <38.5 °C and their HR is <150 bpm, with both variables tending to plateau during the second hour of the test [22]. Over the last decade, researchers have developed auxiliary indices to objectively evaluate HTT results, especially in borderline cases. Consequently, heat intolerance would be defined if any of the following criteria are met: (a) no tendency of body core temperature to plateau - the increase in rectal

temperature during the second hour of the test (60-120 min) is >0.45 °C [23]; (b) the ratio Tre-to-HR at the end of the test (the average over the last 5 min) is <0.279 °C/bpm [24]; (c) the probability of heat tolerance, which uses an algorithm to provide a standardized, objective interpretation of the HTT results, yields a value <0.5 [25]. For practical reasons, the IDF HTT does not account for the time of year or for the patient's acclimatization state. While IDF HTT is widely used in laboratories and clinics, several modified versions have been developed over the years to suit specific needs. For example, the US Naval Health Research Center (NHRC) protocol requires participants to walk slightly faster (5.3 km/h, 1.47 m/s) on a treadmill at a greater incline (4%) [26]. As Butler and colleagues observe, no validity study has yet established the effectiveness or utility of the NHRC protocol.

Other military-oriented HTTs have been developed. Unlike the IDF HTT, which is a functional test, these are more military-task oriented. The UK Army heat tolerance assessment test is conducted on a treadmill in an environmental chamber set at 34 °C and 44% RH [27]. Patients begin the test wearing military clothing and carrying a 15-kg rucksack, walking at 60% of their VO2max. At 30 min into the test, the rucksack and jacket are removed, and at 45 min the T-shirt is also removed. The individual then continues walking for a total of 60-90 min. Patients are considered HT if their Tre plateaus [27]. This test is physically more demanding than the IDF test. Another test, proposed by the French military medical service, involves an 8-km track run in full combat gear [28]. Ambient conditions are not controlled in this test, and the authors could not establish its validity.

Although most published HTTs have focused on testing military personnel, there have been suggestions for occupational HTTs as well. For example, Kenney and colleagues developed a test for nuclear power station workers [29]. The test consists of 15-20 min of exercise while wearing a vapor-barrier suit, followed by measurement of the recovery heart rate 5 min after the end of exercise. From this heart rate, a physiological limit (in minutes) can be predicted with 95% confidence. For the most intense work-heat conditions encountered in nuclear power stations. A test consisting of 40 min of walking in full firefighting protective clothing at a metabolic heat production of 6 W/kg in an environment of 50 °C and 10% RH has also been assessed for validity and reliability [30]. Further work is needed to determine whether a fixed workload or a body-weight-corrected workload is more appropriate for an HTT.

Cognitive function

Heat tolerance testing focuses on the physiological ability to cope with exercise-heat stress. However, heat stress also affects cognitive function, including decision-making, attention span, memory, and overall performance [31,32]. Two questions follow. The first is whether the HTT, as it is currently performed, can distinguish cognitively heat-tolerant from heat-intolerant individuals; the second is whether cognitive function tracks the physiological categorization. Integrating cognitive testing into the physiological assessment might capture a complex interplay between body and mind. While this idea is appealing, supporting evidence is currently limited, and further studies are needed. In a recent preliminary study, Erez and colleagues (2025) reported that during the HTT, those individuals who were subsequently classified as physiologically HI showed greater cognitive and affective impairment than their HT counterparts [33]. Accordingly, those preliminary data indicate that achieving physiological recovery does not necessarily signify full cognitive or emotional readiness for duty, suggesting possible integration of brief neurocognitive and affective evaluations into the HTT.

Sex differences and heat tolerance test

The standard HTT criteria are based on extensive experience with young, healthy men. When these uniform criteria and absolute workloads are applied to women, women are more likely to fail the test. Retrospective data indicate a 67% rate of heat intolerance in women compared with 26% in men [34]. This disproportionate failure rate may largely reflect the test's absolute workload, which elicits greater relative cardiovascular and metabolic strain in women because of their generally lower average aerobic fitness [35]. Indeed, maximal oxygen uptake ($VO2_{max}$) has been

identified as the strongest predictor of HTT success in women, with heat-tolerant women demonstrating higher aerobic capacity [36]. Physiologically, women tend to exhibit higher baseline heart rates and core temperatures, often failing the HTT because of cardiovascular strain (heart rate >150 bpm) rather than thermal strain [35]. While women generally possess a larger body surface area-to-mass ratio that aids heat dissipation in compensable conditions, this provides no advantage in the uncompensable environment of the HTT [37]. Furthermore, female thermoregulation fluctuates with hormonal changes; for instance, the luteal phase of the menstrual cycle elevates baseline core body temperature and is associated with a lower probability of being classified as heat tolerant [36]. Consequently, applying male-derived absolute criteria to women may lead to a high rate of false-positive HI classifications, highlighting the need for considering sex-specific, individualized criteria that account for aerobic fitness, anthropometrics, and hormonal fluctuations to optimize safe return-to-duty decisions.

Summary

Since the pioneering work in the gold mines of South Africa, numerous modalities and protocols for screening heat susceptibility have been proposed. These tests are best regarded as functional tests, since their primary objective is to assess an individual's thermoregulatory capacity under heat stress rather than to serve as diagnostic tests (although the IDF HTT can help identify hypohidrosis or hyperhidrosis). Whether other testing modalities, such as an indoor running test [38], can be applied effectively remains an open question. At present, the IDF HTT is the most widely used test. In a review of current HTT concepts, Butler and colleagues (2023) used the Strength of Recommendation Taxonomy to grade the strength of evidence for eaWch test [39]. According to their evaluation, the IDF HTT is the only test graded as A, signifying strong evidence for its effectiveness. Finally, returning an individual to duty after recovery from exertional heat illness, particularly exertional heat stroke, poses substantial medical challenges. The HTT should be considered a supportive tool for decision-making [40]. This review has limitations. It is a narrative rather than a systematic review: no formal search protocol was applied, no predefined inclusion criteria were used, and the individual studies were not appraised against a structured quality instrument, so its coverage of the literature cannot be assumed to be exhaustive. Much of the validation evidence for the protocol that is most prominent here was generated by a small number of research groups, and several comparator protocols rest on single reports or conference abstracts. Evidence on sex-specific criteria and cognitive assessment during the test comes from a small number of studies, some preliminary, and the conclusions should be regarded as provisional.

Conflict of interest

The authors declare no conflicts of interest.

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Disclaimer

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