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Current Clinical Concepts: Heat Tolerance Testing

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Heat tolerance testing (HTT) has been developed to assess readiness for work or exercise in the heat based on thermoregulation during exertion. Although the Israeli Defense Forces protocol has been the most widely used and referenced, other protocols and variables considered in the interpretation of the testing are emerging. Our purpose was to summarize the role of HTT after exertional heat stroke; assess the validity of HTT; and provide a review of best-practice recommendations to guide clinicians, coaches, and researchers in the performance, interpretation, and future direction of HTT. We also offer the strength of evidence for these recommendations using the Strength of Recommendation Taxonomy system.

Key Words: exertional heat stroke, return to activity, return to play, return to duty, heat intolerance, protocol considerations

Key Points

- Heat tolerance testing (HTT) is a functional evaluation used to assess thermoregulation after exertional heat stroke.
- When used appropriately, HTT can be an objective tool for guiding return-to-activity decisions after exertional heat stroke.
- Several HTT protocols exist; the Israeli Defense Forces protocol has been the most well established and widely used.
- In the future, investigators conducting HTT assessments should take a multifactorial approach, considering both intrinsic and extrinsic factors.
- Given several gaps in the literature, HTT remains controversial, with the need for future research to provide psychometric properties and clarify clinical utility.

Exercise and physical exertion in hot and humid environments can impair performance and put athletes, laborers, and military personnel at increased risk of developing exertional heat stroke (EHS).[1] Exertional heat stroke is a life-threatening condition and can result in long-term complications. Current recommendations for return to activity (RTA) after EHS[2] (Table 1) are based solely on experiences and anecdotes,[13] thus demonstrating the need for evidence-based guidelines. Furthermore, the lack of clear indications marking recovery from and potential recurrence of EHS presents a gap in the current clinical decision-making process, creating a possible role for heat tolerance testing (HTT). Emerging HTT protocols and variables considered in the interpretation of the testing require further consensus[2,14] to validate the critical role HTT can play in guiding RTA, tracking fitness, and monitoring heat acclimation progress.[13]

Traditionally, HTT has been performed after an EHS to determine an individual's ability to respond to heat in a thermally stressful environment, also known as *heat tolerance*, and has been considered a functional measure for RTA.[1] Several factors can affect a person's heat tolerance capacity. These include individual characteristics and variability, genetic factors, treatment for the initial EHS episode, and management post-EHS. Although additional methods are available for assessing thermoregulation, including direct calorimetry and estimated thermometry models,[15] their utility in RTA guidelines is currently unclear. Therefore, we focused on HTT, which historically has been more commonly used to characterize an individual's thermoregulation after an EHS. The purpose of this current clinical concepts article was to summarize the role of HTT and provide a review of best-practice recommendations to guide clinicians, coaches, and researchers in the performance, interpretation, and future direction of HTT. We used the Strength of Recommendation (SOR) Taxonomy to grade the strength of evidence.[16,17]

HISTORY OF HTT

With appropriate and timely recognition and treatment of EHS, most athletes, warfighters, and laborers fully recovered without complications[2]; however, when this was not the case, HTT could have been used as a functional tool to objectively facilitate the RTA process.[1] The concept of HTT was initially developed in the first half of the 20th century to identify laborers who could tolerate the hot working conditions in the South African gold mining industry.[18] Heat tolerance testing as we know it was created by the Israeli Defense Forces in the 1980s as a means to test a soldier's ability to return to duty after experiencing

Table 1. **Current Recommendations for Return to Activity After Exertional Heat Stroke**

Examples from the National Athletic Trainers' Association[2]	Other Examples
Rest period of 7 to 21 d after exertional heat stroke event	National Athletic Trainers' Association sample[2]
Must obtain normal results for blood work and physician clearance	American College of Sports Medicine[3]
Initiate physical activity progression under supervision of a medical professional with knowledge of exertional heat stroke event treatment and care (eg, low to high intensity, increase duration in a temperate environment, sports equipment added gradually if applicable)	Football case 1[4]
	Football case 2[5]
	Triathlete case[6]
	Running case[7]
	Military protocols
	US Army[8]
	US Army and Air Force[9]
	US Marine Corps[10]
	Israeli Defense Forces[11,12]

EHS.[1,19–21] Currently, the Israeli Defense Forces uses HTT as part of its clinical decision-making tool to determine if soldiers can safely RTA after EHS,[20,22] and the US military uses various protocols for treatment and testing post-EHS that are service and clinician dependent. The components of the traditional Israeli Defense Forces model are described in Table 2.

INDIVIDUAL CONSIDERATIONS

Although the Israeli Defense Forces model is the most widely used and accepted method for HTT, it does have some limitations. These include but are not restricted to EHS case specificity, individual factors, characteristics of heat intolerance, and timing of the HTT. We discuss how each of these factors relates to heat tolerance and why it may be important to use and adapt HTT protocols based on individual circumstances. When deciding on the need to use HTT, clinicians are strongly advised to first consider the most common HTT protocols described in this article. However, based on individual circumstances, providers may decide to use a less common protocol or, rarely, to adapt their own. Consulting experts who routinely perform and interpret HTT (see "Resources" section) is highly recommended when in doubt about which protocol to use.

Case Specificity of EHS

Exertional heat illness is an umbrella term that may include exercise-associated muscle cramps; heat syncope; heat exhaustion; exertional hyponatremia; and the most severe and sometimes fatal condition, EHS.[2] During HTT, core body temperature is monitored to determine susceptibility to the heat.[20] Yet other heat-related conditions, such as heat exhaustion and heat cramps, have little association with body temperature, indicating that HTT may not be relevant for an RTA protocol in those situations.[2] Therefore, with EHS, it is important to rule out other conditions and to distinguish between EHS and other exertional heat illnesses that would result in different treatment approaches, recoveries, and RTA plans.[2] Best practice for the diagnosis of EHS is observed cognitive impairment in addition to a core body temperature >40.5°C (105°F) measured rectally,[2,24] although the diagnostic criterion of 40.5°C versus 40.0°C remains controversial.[13]

After an appropriate diagnosis of EHS, the modality and timing of treatment are important for the survival, recovery, and RTA of the individual. Numerous cooling methods have been cited as treatments for EHS,[25] although cold-water immersion was considered the criterion standard treatment by the American College of Sports Medicine[26] and National Athletic Trainers' Association[2] due to

Table 2. **Components of Israeli Defense Forces Heat Tolerance Testing Protocol[a]**

Stage	Components
Before testing	All patients with exertional heat-related injuries undergo a standard exercise heat-tolerance testing about 6 wk after the injury.
	Participants achieve complete clinical recovery (asymptomatic and normal hematologic and blood chemistry results).
	General medical examination is required.
	Participants must have a baseline rectal temperature <37.5°C.
Testing preparation	Participants avoid exercise and alcohol for ≥24 h before testing.
	Participants obtain ≥7 h of sleep the night before testing.
	Participants avoid tobacco and caffeine before testing.
	Participants drink 0.5 L of water during the hour before testing.
	Participants are encouraged to wear light clothing (shorts, no shirt for male participants[1,23]).
	Testing is performed during early morning hours.
	Testing is performed in a controlled environmental chamber (40°C and 40% relative humidity).
	Wind speed: none
Testing protocol	Participants walk on a treadmill for 120 min at 5 km/h (3.1 mph) with 2% incline.
	Rectal temperature and heart rate are monitored throughout testing.
	Sweat rate is calculated (difference between body weight before and after testing).
Results interpretation	Individual passes the heat tolerance testing if protocol is completed.
	Individual is deemed to have heat intolerance if rectal temperature >38.5°C (>101.3°F), heart rate >150 bpm, or no plateau is achieved (>0.45°C/h or rectal temperature-to-heart rate ratio >0.279°C/bpm).

Abbreviation: bpm, beats per minute.

[a] See Mitchell et al[12] for a more detailed history of the Israeli Defense Forces model.

unsurpassable cooling rates. Delayed cooling or suboptimal cooling rates increased the risk for adverse outcomes, such as organ damage or failure, resulting in an increased duration of hospital stay,[27] and consequently may have affected heat tolerance. As such, whether an individual received rapid cooling could ultimately influence recovery in addition to the time frame of initiating HTT.[1,27] *SOR for adapting HTT protocol: C*.

Patient Characteristics

Fitness Level. An important and frequently overlooked factor to consider with HTT is the fitness level of the person. Most researchers[6,14,23] assessed HTT only in well-trained athletes (including tactical athletes), although individuals with lower levels of physical fitness were at the greatest risk for EHS. In addition, general health and comorbidities may have affected the recovery from EHS[11,28] and also inhibited performance on HTT. In contrast, the literature[6,12] supported the premise that some HTT may be insufficient to challenge individuals participating in athletic activities of high intensity. Just as when determining the appropriateness of return to sport for athletes after a musculoskeletal injury, the specificity of training, intensity, and the environment should be considered to help determine when to initiate HTT and an appropriate HTT protocol. *SOR for adapting HTT protocol: A*.

Heat Acclimation. Heat acclimation occurs after repeated heat exposures and results in physiological, perceptual, and performance adaptations.[29] These adaptations allow an individual to better tolerate exercise in the heat, which could be reflected by improved performance on HTT.[30] Furthermore, given that an HTT protocol requires exercising in the heat, it could also be beneficial as a heat-acclimation strategy. Although the benefits of these strategies occur as early as 1 to 2 weeks after initiation, heart rate and core temperature adaptations are lost at approximately 2.5% per day when sufficient exposures are no longer achieved.[31] Therefore, increased time between HTT trials or time spent in recovery from an EHS may result in the loss of any potential heat acclimation or training adaptations already achieved. Additionally, most research on HTT involved men,[6,14,23] yet emerging evidence suggested sex-dependent factors influence thermoregulation in general and heat acclimation adaptations specifically. As such, future HTT interpretations should take into account possible sex and menstrual cycle phase differences.[32,33] The most commonly used protocol, the Israeli Defense Forces model, does not control for heat acclimation status,[23] thereby limiting its interpretation and translation. As such, it is important to consider fluctuating the heat acclimation status for each patient with EHS and HTT. *SOR for adapting HTT protocol: B*.

Characteristics of Heat Intolerance

Heat intolerance occurs during exercise when the body is unable to maintain thermal balance, resulting in an extreme increase in body temperature. The mechanisms of heat intolerance are not fully understood but have been suggested to originate from 2 characteristics, state and trait, that can operate simultaneously. Heat intolerance may be a state of the human body when it occurs after an EHS episode.[34] Unlike trait, heat intolerance due to state would allow individuals to improve tolerance through training and recovery. This is supported by cases in which athletes who had experienced EHS were able to eventually pass the HTT.[7] Additionally, heat intolerance may be a trait of the human body when genetic predispositions limit one's ability to tolerate heat during exercise. Genetic mutations cause altered sensitivity to heat and exercise stress. Even though these specific mutations are not fully understood, this mechanism was supported by the literature, showing that people who experienced a previous EHS were at greater risk for experiencing another EHS.[7] Given that growing evidence supports the attribution of both state and trait to heat intolerance,[33] we can conclude that heat intolerance is multifactorial and is highly dependent on the individual. *SOR for adapting HTT protocol: C*.

Timing of HTT

In the Israeli Defense Forces model, HTT was traditionally performed after 4 to 6 weeks of rest post-EHS treatment. It is most common to allow only 1 attempt; still, a second test was allowed in some cases after 1 month.[22] Schermann et al[14] found no difference in HTT outcomes between those who were tested <6 weeks after an EHS event and those who were tested at >6 weeks. However, they did not account for the variables of each EHS case and individual factors. As discussed, HTT results depend on a myriad of situational and individual characteristics that indicate the timeline should not be standardized across cases. Appropriate diagnosis and fast, aggressive treatment of EHS benefit recovery, whereas delayed treatment or treatment with unfavorable cooling rates[35] may result in complications or prolonged recovery. Also, the fitness level and heat acclimation status may change during recovery or between HTT trials. Additionally, individuals who are intolerant to heat because of state would benefit from appropriate training before HTT more than a person who is intolerant because of trait. *SOR for adapting HTT protocol: B*.

The clinical algorithm to guide RTA decisions after an EHS, originally constructed by Kazman et al,[23] was adapted to incorporate these considerations (Table 3).

OTHER HTT MODELS

Although the Israeli Defense Forces model is the only validated HTT and the most used in laboratories and clinics, it is important to explore modified versions that have been created throughout the world in military, occupational medicine, athletics, and research laboratories to test the thermoregulatory response to exercise in the heat under different conditions (Table 4). For example, the US Naval Health Research Center (NHRC), located in San Diego, California, conducts a modified version of the Israeli Defense Forces HTT primarily on US Navy and Marine Corps special warfare members who have experienced EHS and have not been allowed to resume normal duties.[37] Because of the high metabolic workloads of these warfighters, this protocol requires the participant to walk slightly faster (5.3 versus 5.0 km/h) on a greater incline (4% versus 2%).[44] However, to date, no validity studies have ascertained the effectiveness or utility of the NHRC protocol.

To our knowledge, no other HTT protocols have been replicated or used outside the context of their published

Table 3. Return to Activity After EHS With Considerations for Individual Event and Personal Factors

Event	Question	Response	Hypothetical Ideal Route for Return to Activity	Considerations
Recurrent EHS[a]	NA	*Yes*	Consider following up with experts[a]	Special[c]
EHS	Hyperthermia for <30 min?[a,b]	*No*	Consider following up with experts[a]	Special[c]
		Yes	Medical assessment and rest[a,d]	NA
	Normal examination after medical assessment and rest?[d]	*No*	Rest and modified physical activity[a,d] Reevaluation[a,d]	NA
		Yes	Gradually increase exposure[a,d]	NA
	Normal examination[d] after reevaluation?	*No*	Rest and modified physical activity[a,d] Reevaluation[a,d] Consider HTT[a]	NA
		Yes	Gradually increase exposure[a,d]	NA
	After gradually increasing exposure, has exercise progressed normally?	*No*	Consider HTT	NA
		Yes	Cleared for full return to activity	Alternate[e]
	Is HTT considered normal?	*No*	Rest and modified physical activity[a,d] Repeat HTT[a,d]	NA
		Yes	Gradually increase exposure[a,d]	Alternate[e]
	Is follow-up HTT normal?	*No*	Consider following up with experts[a]	Special[c]
		Yes	Gradually increase exposure[a,d]	Alternate[e]

Abbreviations: EHS, exertional heat stroke; HTT, heat tolerance testing; NA, not applicable.

[a] Modified from or added to the original algorithm of Kazman et al.[23]

[b] *Hyperthermia* was defined as core body temperature >40°C.

[c] Special considerations include (1) characteristics related to the EHS event (eg, time to treatment, treatment modality, time in the hyperthermic state, laboratory values after EHS, and time to normalized laboratory values) and (2) consideration of trait (eg, previous EHS or exertional heat illness episode; neurologic, skin or sweating, metabolic or thermoregulatory, or cardiovascular disorders; and age).

[d] Refer to Table 1 for recommendations.

[e] Alternate considerations include consideration of state, with the EHS most likely due to factors at the time of the event, such as body composition, poor fitness, environment (wet-bulb globe temperature on the day of the EHS event and on days before the event), equipment, dehydration, nutrition, recent illness, sleep deprivation, improper acclimation, clothing, high-intensity exercise, drugs or medications, and work-to-rest ratio.

studies (Table 4). The examples outlined in Table 4 may provide opportunities for the future direction of the HTT and to adapt the test to the individual's needs. Although outside the scope of this review, characterizing an individual's metabolic heat production may be an alternative or additional approach to determining and investigating impairment to heat tolerance post-EHS.[45]

ASSESSING THE RESPONSE TO HTT

Despite the lack of a current standard HTT, most look to the Israeli Defense Forces protocol, as all warriors who sustain an EHS in the Israeli Defense Forces are required to be cleared via the Forces' version of the HTT. Consequently, over the last several decades, a large pool of data has become available as a result of using this method. Under this protocol, if a participant demonstrates an abnormal thermoregulatory response (rectal temperature >38.5°C, heart rate >150 beats per minute [bpm]) or if neither rectal temperature nor heart rate reaches a plateau,[20] the soldier will be scheduled for a second test 1 to 3 months later. The appropriate time between a failed attempt and a second attempt is based on test results and previous EHS severity. After a second failed attempt, the individual is deemed heat intolerant and will not continue service in a combat military unit.

Table 4. Published Heat Tolerance Testing Protocols Extended on Next Page

	Military			Occupational[a]
Factors	Israeli Defense Forces[36]	US Naval Health Research Center[37]	Sagui et al[38] (2017)	Watkins et al[39] (2018)
Exercise type	Walk	Walk	Run	Walk
Duration/distance	120 min	120 min	8 km	40 min
Intensity	5 km/h, 2% incline	8.5 km/h (5.3 mph), 4% incline	As fast as possible on 2-km track	6 W/kg metabolic heat production
Clothing	Shorts (no shirt for male participants)	Shorts (no shirt for male participants)	Full combat gear	Protective clothing
Environmental condition	40°C + 40% relative humidity	40°C + 40% relative humidity	NA	50°C + 10% relative humidity
Objective test failure requirements	T_{rec} >38.5°C, heart rate >150 bpm, or no plateau[b]	T_{rec} > 38.5°C, heart rate >150 bpm	Unknown	Not tested
Strength of recommendation	A	B	C	C

Abbreviations: bpm, beats per minute; mph, miles per hour; NA, not applicable; T_{rec}, rectal temperature; VO_2max, maximum oxygen consumption; vVO_2max, velocity at which VO_2max was obtained; W, watts.

[a] Other occupation-specific protocols have been synthesized by Mitchell et al.[12]

[b] Indicates >0.45°C/h or T_{rec}-to-heart rate ratio >0.279°C/bpm.

Similarly, with the NHRC protocol, if participants have failed HTT (ending core temperature >38.5°C and heart rate >150 bpm), their chain of command or clinician may recommend additional attempts. As of 2020, the NHRC had explored using a slightly higher temperature (38.8°C) as a final core temperature cutoff.[46]

APPLICATION OF CLINICAL GUIDELINES

Interpreting HTT Results

As discussed in earlier sections, heart rate, core temperature, and the plateauing of either are the traditional methods of interpreting HTT. Additional metrics, such as dynamic physiological variables, may be considered when performing and interpreting HTT. The *thermal-circulatory ratio index*, which is the ratio between rectal temperature and heart rate, directly affects thermoregulatory processes.[47] Suggested cutoffs for heat intolerance are a maximum value of ≤0.279°C/bpm at the end of the 120-minute test or ≤0.320°C/bpm at the 60-minute mark. However, the data are currently limited regarding the latter, as it may shorten HTT.[48] In general, the thermal-circulatory ratio index is intended to prevent misinterpretation of heat intolerance.

Another dynamic variable is the *magnitude of increase of rectal temperature during HTT*, which has been defined as >0.45°C during the second hour of the test and may help identify those who are heat intolerant. Finally, a more recent variable that has been explored on a continuous scale is the probability of heat tolerance, which was designed to be used with borderline HTT results.[36] The *probability of heat tolerance* is defined using an algorithm calculator available via open access (probability of heat tolerance; https://phtheller.shinyapps.io/HTTest/). The calculator requires the time, rectal temperature, and heart rate and then provides a probability of heat tolerance value and cut-off scores. Although still relatively new, this variable may provide a more standardized interpretation, especially in the event of borderline results. Nonetheless, as addressed in previous sections, the decision to perform HTT and the interpretation thereof is multifactorial and should be individualized. *SOR: C*.

Using HTT to Help Guide RTA Decisions

To date, the US military services have different consensus recommendations regarding RTA post-EHS, and they do not routinely use HTT but instead rely on clinical judgment and heat acclimation variables.[22] They primarily use HTT for individuals with abnormal recoveries or multiple EHSs; in contrast, the Israeli Defense Forces uses HTTs for all warfighters who have sustained an EHS. Similarly, the RTA decision for athletes or laborers post-EHS is typically at the discretion of the physician or medical team to whom they are assigned. However, HTT can supply more objective, functional measures of the person's thermoregulatory state. Guidance for the RTA of warfighters, athletes, and laborers is offered in Table 3. *SOR: C*.

CONCLUSIONS

Guidelines for Clinicians and Future Direction

Unfortunately, no evidence-based, consensus guidelines or tools currently exist to direct clinicians, coaches, or athletes regarding HTT.[48] As of this writing, general recommendations for overseeing the care, recovery, and reintroduction into the heat of a person post-EHS included the synthesis of the individual's medical history; clinical biomarkers; subjective reports; and, if available or required, HTT.

Controversy exists regarding current HTT models, as many research gaps need to be clarified. For example, Schermann et al[36] used a mathematical model to obtain a quantitative estimate of the probability of heat tolerance, demonstrating sensitivity, specificity, and accuracy of 100%, 90%, and 92.06%, respectively. However, these psychometric properties have not been validated in other studies. In addition, current HTT models do not account or adjust for sex differences, age, varying workloads by aerobic capacity, high altitude, simulated real-world conditions (wearing heavy gear or uniforms, being sleep deprived, using dietary supplements with stimulants, etc), heat acclimation or training status, or body fat.[12,13] To more accurately measure an individual's ability to thermoregulate after an EHS, further investigation is warranted to

Table 4. Extended From Previous Page

Athletic			Research	
Johnson et al[6] (2013)	Mee et al[40] (2015)	Roberts et al[41] (2016)	Hosokawa[42] (2016)	Katch[43] (2020)
Cycle 90 min 70% VO_2max	Run 30 min 9 km/h, 2% incline	Run 70 min 10.5–12.9 km/h, 0% incline	Run 30 min 60% vVO_2max, 2% incline	Run 11.4 km (7.1 mi) 60% VO_2max, 2% incline
Unknown	Unknown	Running shorts and racing singlet	Shorts + T-shirt	Shorts + T-shirt
36°C + 50% relative humidity	40°C + 40% relative humidity	25.7°C + 60% relative humidity	40°C + 40% relative humidity	26.6°C + 50% relative humidity
T_{rec} >39.5°C	T_{rec} >39.7°C	T_{rec} >39.5°C	T_{rec} >39.9°C	T_{rec} > 39.9°C
C	C	C	C	C

better understand how these variables may influence the assessment of heat tolerance.[35] Therefore, the future of HTT may include activities more specific to the individual's needs, whether in an athletic event, at work, or in a military setting. For health care professionals, clinical judgment and individualized considerations are key for using, adapting, and interpreting HTT.

Resources

We provide information on the steps for performing HTT, yet caution is needed when attempting to conduct such testing without proper training, equipment, manpower, and expertise. As such, we recommend that individuals who request to perform HTT post-EHS should consult with a laboratory that specializes in heat physiology. Although not all-inclusive, the following are examples of locations within the United States that perform HTT.

- Naval Health Research Center Warfighter Performance Laboratory (San Diego, CA)
  Population: primarily US Navy and Marine warfighters
- Korey Stringer Institute, University of Connecticut (Storrs, CT)
  https://ksi.uconn.edu/services/athlete-testing/
  Population: athletes, warfighters, laborers
- Uniformed Services University (Bethesda, MD)
  https://champ.usuhs.edu/for-the-provider
  Population: military warfighters

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