Current Clinical Concepts: Heat Tolerance Testing

Cody R. Butler, DPT CSCS
Korey Stringer Institute, University of Connecticut, CT, USA
Air Force Institute of Technology, Wright-Patterson AFB, OH, USA

cody.butler@uconn.edu

Erin Dierickx, MS CSCS
Korey Stringer Institute, University of Connecticut, CT, USA
erin.dierickx@uconn.edu

Michelle Bruneau, DPT OCS FAAOMPT
Sports Optimization and Rehabilitation Laboratory, University of Connecticut, CT, USA
michelle.bruneau@uconn.edu

Rebecca Stearns, PhD ATC
Korey Stringer Institute, University of Connecticut, CT, USA
rebecca.stearns@uconn.edu

Douglas J. Casa, PhD ATC FNAK, FACSM, FNATA
Korey Stringer Institute, University of Connecticut, CT, USA
douglas.casa@uconn.edu
Corresponding Author.

Cody R. Butler, DPT CSCS
Korey Stringer Institute, University of Connecticut, CT, USA
Air Force Institute of Technology, Wright-Patterson AFB, OH, USA
cody.butler@uconn.edu

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ABSTRACT

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 Force protocol has been the most widely utilized and referenced, other protocols and variables considered in the interpretation of the test are emerging. Therefore, the purpose of this “Current Clinical Concepts” manuscript is to summarize the role of HTT following an exertional heat stroke (EHS), assess the validity of HTT, and to provide a review of best practice recommendations to guide clinicians, coaches and researchers in the performance, interpretation, and future direction of HTT. Furthermore, we will provide 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:

- Key point 1: HTT is a functional test in the assessment of thermoregulation following EHS.

- Key point 2: When used appropriately, HTT can be an objective tool for guiding return to activity decisions following EHS.

- Key point 3: Several HTT protocols exist, but the Israeli Defense Force protocol has been the most established and widely utilized.

- Key point 4: Future HTT assessments should take a multifactoral approach, considering both intrinsic and extrinsic factors.

- Key point 5: Due to several gaps in the literature, HTT remains controversial with the
need for future research to provide psychometric properties and clarify clinical utility.

Introduction

Exercise and physical exertion in hot and humid environments can impair performance and put athletes, laborers, and military personnel at an increased risk of developing exertional heat stroke (EHS).\(^1\) EHS is a life-threatening condition and can result in long-term complications. Current recommendations for return to activity (RTA) following an EHS (Table 1)\(^2\) are based solely on experience and anecdote,\(^3\) thus demonstrating the need for evidence-based guidelines. Furthermore, the lack of clear indication marking recovery from, and potential reoccurrence of, an EHS presents a gap in the current clinical decision making process, creating a potential role for heat tolerance testing (HTT). Emerging HTT protocols and variables considered in the interpretation of the test require further consensus\(^2,4\) to validate the critical role HTT can play in guiding RTA, tracking fitness, and monitoring heat acclimation progress.\(^3\)

Traditionally, HTT has been performed following an EHS to determine an individual’s ability to respond to heat in a thermally stressful environment, or heat tolerance, and is considered a functional measure for return to activity.\(^1\) There are several factors that can affect an individual’s heat tolerance capacity. These include individual characteristics and variability, genetic factors, treatment for initial EHS episode and management following EHS. Although there are additional methods to assess thermoregulation, including direct calorimetry or estimated thermometry models,\(^14\) their utility in RTA guidelines is currently unclear. Therefore, this article will focus on HTT, which historically has been more commonly utilized in the assessment of an individual’s thermoregulation following an EHS. The purpose of this “Current
Clinical Concepts” manuscript is to summarize the role of HTT and to provide a review of best practice recommendations to guide clinicians, coaches, and researchers in the performance, interpretation, and future direction of HTT. The Strength of Recommendation Taxonomy will be used to grade the strength of evidence (see Table 2).^15^

**History of HTT**

With appropriate and timely recognition and treatment of EHS, the majority of athletes, warfighters and laborers fully recover without complications;^2^ however, when this is not the case, HTT may be 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 20^th^ century for identifying laborers who could tolerate the hot working conditions in the South African gold mining industry.^16^ HTT, as we know it, was created by the Israeli Defense Force in the 1980s as a means to test all soldiers’ ability to return to duty after they experienced an EHS.^1,17–19^ Currently, the Israeli Defense Force uses HTT as part of its clinical decision-making tool to determine if soldiers can safely RTA following an EHS,^18,20^ whereas the United States (US) military has varying protocols in the treatment and testing following EHS and are service and clinician dependent. The components of the traditional Israeli Defense Force model are described in Table 3.

**Individualized Consideration**

Although the Israeli Defense Force model is the most widely utilized and accepted method for HTTs, it does have some limitations. These include but are not limited to EHS case specificity, individual factors, characteristics of heat intolerance, and timing of HTT. Below, we discuss how each of these factors relates to heat tolerance and therefore may be
important to use and adapt HTT protocols to individualized circumstances. When deciding on the need to use HTT, clinicians are strongly recommended to first consider the most common HTT protocols described in this paper. However, based on individualized circumstances, the decision may be made to use a less common protocol, or in the rare event, to adapt their own. Consulting experts who routinely perform and interpret HTT (see “Resources” section below) is highly recommended when in doubt.

**EHS Case specificity**

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. During HTT, core body temperature is monitored to determine susceptibility to the heat. However, other heat related conditions, such as heat exhaustion or heat cramps, have very little association with body temperature, indicating HTT may not be relevant for a RTA protocol. Therefore, in EHS cases, it is important to rule out other conditions as well as distinguish between other exertional heat illnesses that would result in different treatment approaches, recovery, and RTA plans. Best practice for the diagnosis of EHS is observed cognitive impairment in addition to a core body temperature exceeding 40.5°C (105°F) measured via rectal temperature, although the diagnostic criteria of 40.5°C versus 40.0°C remains controversial.

Upon 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 a treatment for EHS, yet cold-water immersion is considered the gold standard treatment by the American College of Sports Medicine and National Athletic Trainers’ Association due to unsurpassable cooling rates. Delayed cooling or sub-optimal cooling rates
increase risk for adverse outcomes, such as organ damage or failure resulting in increased duration of hospital stay and may therefore impact heat tolerance. As such, whether or not an individual received rapid cooling can ultimately influence the recovery and furthermore, the timeframe of initiating HTT.\textsuperscript{1,26} Strength of recommendation for adapting HTT protocol: C.

**Individual Characteristics**

Fitness level

An important and frequently overlooked factor to consider with HTT is the fitness level of the individual. Most studies have only assessed HTT in well-trained athletes (including tactical),\textsuperscript{4,8,21} even though individuals with lower physical fitness are at the greatest risk for EHS. In addition, general health and comorbidities may affect recovery from EHS\textsuperscript{13,27} and therefore also may inhibit performance on a HTT. In contrast, literature supports the premise that some HTTs may not be sufficient to challenge individuals participating in athletic activities of high intensity.\textsuperscript{8,22} Just as with return to sport for athletes following a musculoskeletal injury, specificity of training, intensity, and environment should be considered to help determine when to initiate a HTT and an appropriate HTT protocol. Strength of recommendation for adapting HTT protocol: A.

Heat acclimation

Heat acclimation occurs after repeated heat exposures and results in physiological, perceptual, and performance adaptations.\textsuperscript{28} These adaptations allow an individual to better tolerate exercise in the heat which can be reflected by improved performance on a HTT.\textsuperscript{29} Furthermore, since a HTT protocol requires exercising in the heat, it may also be beneficial as a heat acclimation strategy. While these benefits occur as early as one to two weeks, heart rate and core temperature adaptations are lost when sufficient exposures are no longer met at
approximately 2.5% per day. Therefore, increased time between HTT trials or time spent in recovery from an EHS may result in loss of any potential heat acclimation or training adaptations already achieved. Additionally, while most research on HTT involves males, emerging evidence suggests sex-dependent factors influence thermoregulation in general and heat acclimation adaptations specifically. As such, future HTT interpretations should consider potential sex and menstrual cycle phase differences. The most commonly used protocol, the Israeli Defense Force model, does not control for heat acclimation status thereby limiting its interpretation and translation. As such, it is important to consider fluctuating heat acclimation status for each individual EHS case and HTT. Strength of recommendation 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 two characteristics: state and trait, and can operate simultaneously. Heat intolerance may be a state of the human body when it occurs following an EHS episode. Unlike trait, heat intolerance due to state would allow individuals to improve tolerance through training and recovery. This is supported by cases where athletes who had experienced an EHS were able to eventually pass the HTT. 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 the altered sensitivity to heat and exercise stress. While these specific mutations are not yet fully understood, this mechanism is supported by literature showing individuals who have experienced previous EHS are at a greater risk for experiencing another EHS. Since growing evidence
supports the attribution of both state and trait on heat intolerance, it can be concluded that heat intolerance is multifactorial and therefore highly dependent on the individual. *Strength of recommendation for adapting HTT protocol: C.*

**Timing of HTT**

In the Israeli Defense Force model, HTT is traditionally performed following 4-6 weeks of rest after the treatment of an EHS. While it is most common to only allow one attempt, some cases allow a second test after 1 month. Shermann et al., found no difference in HTT outcomes between those who were tested less than 6 weeks after an EHS event and those who were tested after 6 weeks. However, this study did not account for the variables of each EHS case and individual factors. As discussed above, it is important to recognize that results of HTT are dependent on a myriad of situational and individual characteristics that indicate the timeline should not be standardized across cases. First, appropriate diagnosis and fast, aggressive treatment of EHS benefit the recovery of an individual, whereas delayed or treatment with unfavorable cooling rates may result in complications or prolonged recovery. Secondly, fitness level and heat acclimation status may change during the time of recovery or between HTTs. Furthermore, individuals who are intolerant to heat due to state would benefit from appropriate training prior to HTT more than an individual who is intolerant due to trait. *Strength of recommendation for adapting HTT protocol: B.*

The clinical algorithm to guide RTA decisions following an EHS, originally constructed by Kazman et al., was adapted to incorporate the aforementioned considerations (see Figure 1 below).

**Other HTT Models**
Although the Israeli Defense Force model is the only validated HTT and therefore the most utilized in laboratories and clinics, it is important to consider 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 (see Table 4). For example, the United States Naval Health Research Center (NHRC), located in San Diego, CA, conducts a modified version of the Israeli HTT on primarily US Navy and Marine Corps Special warfare members who have experienced an EHS and have not been allowed to resume normal duties.\textsuperscript{35} Due to the high metabolic workloads of these warfighters, this protocol requires the participant to walk slightly faster (5.3 versus 5.0 k/hr) with a greater incline (4\% versus 2\%).\textsuperscript{36} To date, though, there have been no validity studies to ascertain the effectiveness or utility of the NCRC protocol.

To the authors’ knowledge, no other HTT protocols have been replicated or utilized outside the context of their respective published study. However, the examples outlined in Table 4 may provide opportunities for future direction of the HTT and to adapt the test to the individual’s needs. While outside of the scope of this paper, it is important to note that determining an individual’s metabolic heat production may be an alternative or additional approach to determine and investigate impairment to heat tolerance following an EHS.\textsuperscript{37}

Assessing response to HTT

Although there is no current standard HTT, most look to the Israeli Defense Force protocol, as all warriors who sustain an EHS in the Israeli Defense Force are required to be cleared with their version of the HTT. Therefore, there has been a large pool of data to evaluate over the last several decades from using this specific methodology. Under this protocol, if a participant demonstrates an abnormal thermoregulatory response (rectal temperature >38.5°C,
HR >150 bpm), or if neither rectal temperature or heart rate reach a plateau, the soldier will be scheduled for a second test between 1-3 months later. The time between failure and second attempt is based on test results and prior EHS severity. After a second failure, the individual is deemed heat intolerant and will not continue service in a combat military unit.

Similarly, with the NHRC protocol, if a participant fails the HTT (ending core temperature >38.5 °C and HR >150 bpm), they may be recommended by their chain of command or clinician to perform additional attempts. As of 2020, the NHRC has explored using a slightly higher cut-off (38.8 deg C) as a final core temperature cut-off.44

**Application Guidelines/Clinical Guidelines**

**Interpreting HTT results**

As has been discussed in earlier sections, HR, core temperature and plateauing of either are the traditional methods of interpreting HTT. However, there are additional metrics, dynamic physiological variables, which may be considered when performing and interpreting HTT. The thermal-circulatory ratio (TCR) index, which is the ratio between rectal temperature and heart rate, directly impacts the thermoregulatory processes.45 Suggested cutoff for heat intolerance includes a maximum value of ≤0.279 °C/bpm at the end of the 120-min test, or ≤0.320 °C/bpm at the 60 minute mark. However, the data is currently limited regarding the use of the latter, as it may shorten the HTT for those who have this value.46 In general, the TCR index is meant to help prevent misinterpretation of heat intolerance.

Another dynamic variable includes the magnitude of increase of rectal temperature during HTT, which has been defined as >0.45 °C during the second hour of the test, which may be helpful in identifying those who are heat intolerant. Finally, a more recent variable that has
been explored on a continuous measure is the probability of heat tolerance, which was designed to be used with borderline HTT results. The probability of heat tolerance is defined using an algorithm calculator that is available open access at https://phtheller.shinyapps.io/HTTest/, and the calculator requires the time, rectal temperature, and heart rate, which then provides a probability of heat tolerance value and cut-off scores. Although still relatively new, this variable may provide more standardized interpretation, especially in the event of borderline results.

However, as has been discussed in previous sections, the decision to perform HTT, and the interpretation thereof, is multi-factorial and should be individualized. *Strength of recommendation: C.*

**Using HTT to help guide RTA decisions**

To date, the US military services have differing consensus recommendations regarding RTA after EHS, and they do not routinely use HTT, instead, using clinical judgment and heat acclimation variables. HTTs are primarily used with abnormal recovery or multiple EHS, unlike the Israeli Defense Force, which uses HTTs on all warfighters who have suffered an EHS.

Similarly, the RTA decision for the athlete or laborer after an EHS event typically falls to the discretion of the physician or medical team to whom they are assigned to. However, HTT can provide more objective, functional measures to the thermoregulatory state of the individual.

*Figure 1* can be used to help guide RTA for the warfighter, athlete, and laborer. *Strength of recommendation: C.*

**Conclusion/Summary**

**Guidelines to clinicians and future direction**

Unfortunately, there are currently no evidence-based, consensus guidelines or tools in directing clinicians, coaches or players regarding HTT. As of this writing, general
recommendations for overseeing the care, recovery and reintroduction of a person into the heat
post-EHS include the synthesis of the individual’s medical history, clinical biomarkers,
subjective reports, and if available or required, HTT.

It is important to recognize that controversy exists with current HTT models, as there are
many research gaps that need to be clarified. For example, previous literature has utilized a
mathematical model to give 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 by other studies. In addition, current HTT models do not account or adjust for gender differences, age, varying workload by aerobic capacity, high altitude, simulating real-world conditions (wearing heavy gear/uniforms, sleep deprived, dietary supplements with stimulants, etc), heat acclimation/training status or body fat. To more accurately measure an individual’s ability to thermoregulate following an EHS, further research is warranted to better understand the impact the above variables may influence assessment of heat tolerance. Therefore, the future of HTT may include activities more specific to the individual’s needs, whether in an athletic event, at work, or within a military setting. As health care professionals, clinical judgment and individualized considerations are key in the use, adaption, and interpretation of HTT.

Resources

Although this “Current Clinical Concepts” paper provides information on the steps to perform HTT, caution is warranted when attempting to conduct one without proper training, equipment, manpower and expertise. As such, it is the recommendation of these authors that individuals who are requesting to perform HTT post-EHS should consult with a laboratory that
specializes in heat physiology. Although not all-inclusive, below are some examples of locations within the United States that perform HTT.

**Naval Health Research Center Warfighter Performance Laboratory (San Diego, CA)**

Website currently under construction

Population: primarily Navy and Marine warfighters

**Korey Stringer Institute, University of Connecticut (Storrs, CT)**

[https://ksi.uconn.edu/services/athlete-testing/](https://ksi.uconn.edu/services/athlete-testing/)

Population: athletes, warfighters, laborers

**Uniformed Services University (Bethesda, Maryland)**

[https://champ.usuhs.edu/for-the-provider](https://champ.usuhs.edu/for-the-provider)

Population: military warfighters
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| ACSM<sup>3</sup> | NATA<sup>2</sup> | Other Examples |
|-----------------|-----------------|-----------------|
| Refrain from exercise for 7 days after release from medical care for treatment of an EHS | 7 to 21-day rest period following EHS event | 1. NATA sample<sup>2</sup> |
| Follow-up in about 1 week for physical examination and repeat lab testing or diagnostic imaging of affected organs that may be indicated, based on physician evaluation | Must obtain normal blood-work results and physician clearance | 2. Football Case 1<sup>6</sup> |
| When cleared, begin exercise in cool environment; gradually increase duration, intensity, and heat exposure for 2 weeks to acclimatize and demonstrate heat tolerance | Initiate physical activity progression under supervision of medical professional with knowledge of EHS treatment and care (e.g., low to high intensity, increase duration in a temperate environment; sport equipment added gradually if applicable) | 3. Football Case 2<sup>7</sup> |
| If return to activity is difficult, consider laboratory exercise (i.e., HTT) about 1-month post EHS | | 4. Triathlete Case<sup>8</sup> |
| Clear the athlete for full competition if heat tolerance exists after 2 to 4 weeks of training | | 5. Running Case<sup>9</sup> |
| | | 6. Military Protocols: |
| | | • US Army<sup>10</sup> |
| | | • US Army and Air Force<sup>11</sup> |
| | | • US Marine Corps<sup>12</sup> |
| | | • Israeli Defense Force<sup>13</sup> |

Abbreviations: EHS exertional heat stroke, ACSM American College of Sports Medicine, NATA National Athletic Training Association, HTT heat tolerance testing, US United States
Table 2. The Strength of Recommendation Taxonomy

| Strength of Recommendation | Definition                                                                 |
|----------------------------|---------------------------------------------------------------------------|
| A                          | Recommendation based on consistent and good-quality patient-oriented evidence |
| B                          | Recommendation based on inconsistent or limited-quality patient-oriented evidence |
| C                          | Recommendation based on consensus, usual practice, opinion, disease-oriented evidence, or case series for studies of diagnosis, treatment, prevention, or screening |
Table 3: Components of Israeli Defense Force HTT protocol*

| Components                                      |
|------------------------------------------------|
| Prior to testing                                |
| All patients of exertional heat related injuries undergo a standard exercise HTT about 6 weeks following the injury |
| Achieve complete clinical recovery (asymptomatic and normal hematologic parameters and blood chemistry levels) |
| General medical exam required                   |
| Must have baseline $T_{rec} < 37.5 ^\circ \text{C}$ |
| Testing preparation                             |
| Avoid exercise and alcohol for at least 24 h prior to the test |
| Obtain at least 7 h of sleep the night prior to testing |
| Avoid tobacco and caffeine prior to the test    |
| Drink 0.5 L of water during the hour prior to the test |
| Participants are encouraged to wear light clothing (shorts, no shirt for males\textsuperscript{1,21}) |
| Perform testing during early hours of the morning |
| Perform testing in a controlled environmental chamber (40°C and 40% relative humidity) |
| Wind speed: none                                |
| Testing protocol                                |
| Walk on treadmill for 120 min at 5 km/h (3.1 mph) with 2% incline |
| $T_{rec}$ and HR are monitored throughout test  |
| Sweat rate is calculated (difference between body weight before and after test) |
| Results interpretation                          |
| Individual passes the HTT if protocol is completed |
| Individual is deemed heat intolerant if $T_{rec} > 38.5^\circ \text{C}/101.3^\circ \text{F}$, $HR>150$ bpm, or no plateau is achieved ($>0.45^\circ \text{C}/\text{hr or } T_{rec}/HR$ ratio $>0.279^\circ \text{C}/\text{bpm}$) |

Abbreviations: HTT heat tolerance testing, $T_{rec}$ rectal temperature, $HR$ heart rate, bpm beats per minute

*The authors recommend Mitchell et al.\textsuperscript{22} for a more detailed history of the Israeli Defense Force model.
| Factors                  | Military                  | Occupation                  | Athlete                  | Research                  |
|-------------------------|---------------------------|-----------------------------|--------------------------|---------------------------|
| Exercise type           | Walk                      | Walk                        | Run                      | Run                       |
| Duration                | 120 min                   | 120 min                     | 40 min                   | 90 min                   |
| Intensity               | 5 km/h, 2% incline        | 5.3 mph, 4% incline         | As fast as possible on 2km track | 6 W/kg metabolic heat production |
| Clothing                | Shorts (no shirt for males) | Shorts (no shirt)           | Full combat gear         | Protective clothing       |
| Environment condition   | 40 °C + 40% RH            | 40 °C + 40% RH              | N/A                      | 50 °C + 10% RH           |
| Objective test failure requirements | T_{rec} > 38.5°C, HR > 150 bpm, or no plateau* | T_{rec} > 38.5°C and HR > 150 bpm | Unknown | T_{rec} > 39.5°C |
| Strength of recommendation | A                        | B                           | C                        | C                         |

Abbreviations: HTT heat tolerance testing, vVO2 velocity at which VO2max was obtained, RH relative humidity, T_{rec} rectal temperature, HR heart rate
* T_{rec} > 38.5°C and HR > 150 bpm or T_{rec}/HR > 0.279°C/bpm. Other occupation-specific protocols have been synthesized by Mitchell et al.\cite{22}.
Figure 1. Algorithm for Return to Activity following an EHS with considerations for individuality of event and personal factors

Abbreviations: EHS exertional heat stroke, EHI exertional heat illness, RTA return to activity, PA physical activity, HTT heat tolerance testing, WBGT wet bulb globe temperature

Hyperthermic is defined as a core body temperature greater than 40°C

Boxes highlighted in thick borders are modified from or added to the original algorithm from Kazman et al., 2013.21

White boxes refer to a hypothetical ideal route for RTA with no EHS history, early and effective treatment (<30 minutes), and normal progression back to activity.

a Refer to Table 1 for existing literature for recommendations

b Refer to box “Special Considerations”

c Refer to box “Alternate Considerations”
