ORIGINAL PAPER

International Journal of Occupational Medicine and Environmental Health 2023;36(2):192–200
https://doi.org/10.13075/ijomeh.1896.02065

SENSITIVITY AND SPECIFICITY OF USING EXERCISE HEART RATE IN A THERMONEUTRAL ENVIRONMENT TO PREDICT HEAT TOLERANCE STATUS

SARAH NORTHWAY, DOUGLAS M. JONES and MICHAEL J. BUONO

San Diego State University, San Diego, CA, USA
School of Exercise and Nutritional Sciences

Abstract
Objectives: Following heat illness, a return to activity may require passing a heat tolerance test (HTT). However, there are several logistical limitations to the widespread use of the HTT. Thus, it would be advantageous to develop a test that could be conducted in a thermoneutral (~22°C) environment to predict heat tolerance status. The purpose of the current study was to determine the sensitivity and specificity of using the criteria of a heart rate (HR) ≥130 bpm following 30 min of thermoneutral exercise in detecting heat-intolerant and heat-tolerant individuals. **Material and Methods:** Sixty-five subjects visited the lab on 3 separate days. The first visit consisted of completing a maximal oxygen uptake ($VO_{2\,max}$) test to assess cardiovascular fitness. For lab visits 2 and 3, subjects randomly completed a 2-hour walking treadmill test in either a hot (40°C, 40% relative humidity [RH]) or thermoneutral (22°C, 40% RH) environment. **Results:** Forty-eight subjects were classified as heat-intolerant and 17 subjects as heat-tolerant. Using the criterion of a HR ≥130 bpm at 30 min of exercise in the thermoneutral environment, specificity (54%) and sensitivity (100%) of passing the HTT was calculated. Secondary analysis using multiple regression revealed 3 significant variables for predicting ending HR during the HTT. They were: 1) absolute $VO_{2\,max}$ (l/min), 2) age, and 3) HR at 30 min of exercise during thermoneutral exercise. **Conclusions:** Exercise in a thermoneutral environment had a positive predictive value of 100%, thus, if a subject has a HR ≥130 bpm at 30 min of exercise in a thermoneutral environment, they are very likely to fail a subsequent 2-hour HTT in the heat and be classified as heat-intolerant. Therefore, prior screening has the potential to save time and money, along with providing safety to a heat-intolerant subject. Int J Occup Med Environ Health. 2023;36(2):192–200

Key words:
exercise, heat, heart rate, heat intolerance, heat tolerance testing, return to activity

INTRODUCTION

Physical work or exercise in hot environments poses a significant physiological challenge to humans [1,2]. To balance the complex metabolic demands of physical activity in the heat requires a well-coordinated response from both the thermoregulatory and cardiovascular systems, to dissipate heat and thus control body temperature [1]. The ability to manage heat stress in hot environments has been found to be influenced by many physiological factors, such as cardiovascular fitness, body composition, prior heat illness, dehydration, acclimatization, and recent illness [1,3].

Exertional heat illness (EHI) varies in terms of symptoms and severity and could be related to an acute illness or representative of a persistent condition, such as heat intolerance [1]. Heat intolerance is the inability to adapt

Funding: this work was supported by Leidos, Inc (project No. SDSUF # 59333C entitled "Sensitivity and specificity of using exercise heart rate in a thermoneutral environment to predict heat tolerance status," project manager: Michael J. Buono).
Received: September 7, 2022. Accepted: December 23, 2022.
Corresponding author: Douglas M. Jones, San Diego State University, School of Exercise and Nutritional Sciences, 5500 Campanile Drive, San Diego, CA 92120, USA (e-mail: jones.douglas4@gmail.com).

to the demands of exercise in a hot environment, as evidenced by excessive tachycardia and hyperthermia, which may put these individuals at a higher risk for developing heat exhaustion and/or heat stroke [4].

Professional and recreational athletes, various occupational workers (e.g., firefighters, bakery, construction, agricultural, etc.) and military personnel routinely perform tasks that require physical work in hot environments which exposes these individuals to heat stress [5]. For example, the annual incidence rate of heat illnesses in the U.S. military has been reported to be approx. 1667 cases of heat exhaustion and 475 cases of heat stroke per year. In the 10 years between 2008–2018, it was estimated that heat illness cost the U.S. military USD 1 billion in lost productivity, personnel retraining, and medical expenses [5,6].

Following EHI, the current return-to-activity (RTA) guidelines for physicians and occupational medicine clinicians are variable and subjective. For >30 years, military groups around the world (e.g., Israel, USA, the United Kingdom, and Singapore) have used a heat tolerance test (HTT) to objectively determine the suitability of military personnel to return to active duty following a heat illness [3,4,7,8,9]. Traditionally the HTT is a 2-hour walking treadmill test conducted in an environmental chamber set to 40°C and 40% relative humidity (RH). To successfully pass an HTT, the subject must walk at 5.31 km/h at 4% grade (Naval Health Research Center HTT protocol) for 120 min and maintain a heart rate (HR) >160 bpm and/or a core body temperature >38.6°C, respectively [3,4,7]. If the individual does not pass the HTT, they are usually not able to RTA due to their inability to tolerate a hot environment and are defined as heat-intolerant [3,7,8].

One major limitation of the widespread use of the HTT to predict RTA is the need to have an environmental chamber to control the ambient air temperature and relative humidity. In addition, the current HTT protocols are long as they require 2 h of exercise in the heat and need sophisticated and expensive laboratory equipment (e.g., esophageal or rectal thermistors, ingestible core temperature pills, etc.) to accurately measure core body temperature. Thus, it would be advantageous to develop a predictive test that could be conducted in a thermoneutral (~22°C) environment, which is short in duration that could be used to screen for heat-intolerant individuals prior to their attempting a full 2-hour HTT in the heat, thus saving time and resources.

Previous research by Mandel et al. [10] found a strong correlation (r = 0.83) between ending heart rate during a HTT (40°C, 40% RH) with heart rate after 30 min of similar intensity exercise performed in a thermoneutral environment (22°C, 40% RH). Considering the strong relationship between intrasubject HR during hot and thermoneutral exercise, it seems reasonable to hypothesize that HR after 30 min of thermoneutral exercise could be used as the basis of predicting whether someone would pass or fail the HTT.

Jones et al. [11] examined the HR response and maximal oxygen uptake ($VO_{2\ max}$) in individuals who attempted a HTT. They found that subjects who passed the HTT had a significantly higher $VO_{2\ max}$ (51.4 vs. 44.5 ml/kg/min, $p = 0.03$) compared to those who failed the HTT [11]. Additionally, a significantly higher HR during thermoneutral exercise was found in those who failed the HTT (131 vs. 104 bpm, $p = 0.02$).

Considering the strong relationship between successfully passing the HTT and having a lower HR during thermoneutral exercise and overall cardiovascular fitness, the purpose of the current study was twofold. The first objective was to determine sensitivity and specificity using the criteria of a HR ≥130 bpm following 30 min of thermoneutral exercise in detecting heat-intolerant and heat-tolerant individuals. Traditionally, test sensitivity is the ability of a test to correctly identify those with the disease (true positive rate), whereas test specificity is the ability of the test to correctly identify those without the disease (true negative rate). The second objective was to develop a multiple regression equation using anthropometric and physiological measurements collected during thermoneutral exercise to predict the ending HR of an individual during a HTT.

MATERIAL AND METHODS

The subjects for this study were 65 healthy, moderately active volunteers (32 females and 33 males). They had a mean (M) ± standard deviation (SD) age 23.4±3.6 years, height 1.70±0.10 m, weight 69.4±13.5 kg, and maximal oxygen uptake of 46.6±10.1 ml/kg/min. Subjects were recruited through flyers and word of mouth on the San Diego State University campus and were required to be physically active (i.e., min. 3 exercise sessions/week), to not have previously experienced any heat illness symptoms, and to not be pregnant. All participants were required to fill out the *Physical Activity Readiness Questionnaire* (PAR-Q) and sign an informed consent prior to participating in the study. This study was approved by the Institutional Review Board at San Diego State University (#208-0260) in accordance with the Helsinki Declaration.

All measurements took place at the San Diego State University Exercise Physiology Laboratory, USA. Study participants were required to report to the laboratory on 3 separate occasions. On the first visit, participants completed study paperwork and, after sitting for 15 min, resting heart rate (Pulse Oximeter CMS60DL, Crucial Medical Systems, Atlanta, GA, USA) and blood pressure (Prestige Medical Sphygmomanometer, Northridge, CA, USA) were recorded. Female participants were then asked to collect a small urine sample in a private bathroom for the purpose of conducting a urine pregnancy test (Sure-Vue Urine hCG Fisher HealthCare, Houston, TX, USA). All female subjects were required to have a negative pregnancy test to continue participating in the study.

Next, skinfolds (chest, midaxillary, triceps, subscapular, abdominal, hip and thigh) were measured with a skinfold calliper (Lange, Beta Technology Incorporated, Cambridge, MD, USA) and gender-specific percent body fat was estimated. Height and weight were measured using a Detecto 439 Physician Beam scale (Detecto, Webb City, MO, USA) and used to calculate BMI. Each participant then completed an incremental $VO_{2\ max}$ test to volitional exhaustion on a Cosmed treadmill (Chicago, IL, USA). Expired gases were collected each minute using a 1-way valve (Hans Rudolph, Shawnee, KS, USA) and a True One 2400 (Parvo Medics, Salt Lake City, UT, USA) metabolic measurement system. Heart rate was measured each minute using a Polar H7 (Polar, Kempele, Finland) heart rate sensor.

The second and third visits required the participant to walk on a treadmill (Fitnex Fitness Equipment Inc, Dallas, TX, USA) for 120 min at a speed of 5.31 km/h and a 4% grade in either a hot 40°C or thermoneutral 22°C environment (40% RH for both trials) in a Norlake climate chamber (Hudson, WI, USA). The speed and grade were in accordance with the NHRC HTT protocol [3,4,7]. The order of the hot and thermoneutral trials was randomly assigned and separated by a minimum of 48 h.

Prior to each of the last 2 trials the subjects were asked to ingest a temperature pill (CorTemp Temp Sensor Palmetto, Florida , USA) at least 6 h prior to testing and to drink 1l of water the night and morning before testing to ensure hydration. Once the subject arrived, the core temperature was checked using a CorTemp Data Recorder (model 262K, HT150001 HQ Inc, Palmetto, Florida, USA), and resting heart rate was measured using a Garmin Premium heart rate monitor synchronized to a Garmin Forerunner 35 (Garmin, Olathe, KS, USA) recorder. Urine specific gravity was measured by a handheld refractometer (Cole-Palmer RSA-BR90A Refractometer, Vernon Hills, IL, USA) and required to be <1.018.

The subject then entered the environmental chamber and commenced walking on the treadmill at 5.31 km/h and a 4% grade while core temperature and HR were recorded every minute and RPE (6–20-point scale) every 15 min. Subjects were able to drink water *ad libitum*.

Table 1. Anthropometric and aerobic fitness measures of the heat intolerant vs. heat tolerant subjects, San Diego, USA, 2020

Variable	Participants (N = 65)	
	heat intolerant (N = 48)	heat tolerant (N = 17)
Age [years] (M±SD)	22.9±3.2	24.7±4.3
Height [m] (M±SD)	1.68±0.1	1.77±0.1*
Weight [kg] (M±SD)	67.1±13.2	75.8±12.5*
BMI [kg/m^2] (M±SD)	23.67±3.1	24.1±2.8
Resting heart rate [bpm] (M±SD)	73±11	62±8**
VO_2 max (M±SD)		
ml/kg/min	43.2±8.4	56.3±7.9**
l/min	2.92±0.92	4.18±1.02**
Body fat [%] (M±SD)	19.1±7.3	14.4±6.6*

* Significant difference between groups p < 0.05.
** Significant difference between groups p < 0.01.

The treadmill test was discontinued if the subject met any of the following criteria: 1) core temperature ≥39°C, 2) heart rate ≥180 bpm, 3) the subject wished to discontinue the test, or 4) the 120 min time limit was reached. The subject was classified as heat intolerant if their core temperature reached ≥38.6°C, or HR ≥160 bpm during the HTT performed in the heat.

Paired t-tests were used to compared mean data collected on heat-intolerant vs. heat-tolerant subjects as shown in Table 1. Significance was set to $p < 0.05$. Automatic forward stepwise multiple regression analysis was performed using SPSS.

RESULTS

Specificity and sensitivity of using the criterion of a HR ≥130 bpm at 30 min of exercise in a thermoneutral environment were calculated for the 65 participants, as previously suggested by Jones et al. [11]. Each subject was classified as heat-tolerant, or heat-intolerant based on their core temperature and heart rate during the HTT in the heat. As shown in Table 1, there were 48 subjects classified as heat-intolerant while 17 were heat-tolerant. In the heat-intolerant group, 8 reached the core temperature criteria (≥38.6°C) while 40 reached the heart rate criteria (HR ≥ 160 bpm). Mean height, body weight and $VO_{2\ max}$ were all significantly lower in the heat-intolerant vs. heat-tolerant groups. Additionally, the M±SD HR for the heat-tolerant and heat-intolerant groups were 130±18 bpm and 158±9 bpm, respectively. In addition, M±SD core temperature for the heat-tolerant and heat-intolerant groups were 38.0±0.4 and 38.2±0.3°C, respectively. As shown in Table 2, the predictive test had a sensitivity of 54% and a specificity 100%.

Automatic forward stepwise multiple regression analysis was used to examine the predictive relationships between physiological (e.g., absolute and relative $VO_{2\ max}$, resting HR and core temperature, HR and core temperature at 30 min of exercise in a thermoneutral environment, age) and anthropometric (e.g., BMI, % fat, height, weight) measures to predict ending HR during the HTT. The results indicated that the model provided a significant prediction of ending HR during the HTT. The model

Table 2. Sensitivity and specificity of using heart rate (HR) during thermoneutral exercise to predict heat tolerance test (HTT) in 65 healthy volunteers, San Diego, USA, 2020

HTT	Participants (N = 65) [n]				
	heat intolerant (N = 48)	sensitivity	heat tolerant (N = 17)	specificity	total
Overall test score		54%		100%	
positive (HR ≥130 bpm)	26 (true positives)		0 (false positives)		26 (positive prediction value 100%)
negative (HR <130 bpm)	22 (false negatives)		17 (true negatives)		39 (negative prediction value 46%)

Using the test criteria of a HR ≥130 bpm at 30 min of exercise in a thermoneutral environment were calculated for the 65 participants as previously suggested by Jones et al. [11]. Heat intolerant individuals were determined as having a core temperature >38.6°C or a HR >160 bpm during the HTT.

explained 55% ($r = 0.74$) of the variance of the ending HR during the HTT ($F_{(3, 61)} = 24.32$, $p < 0.001$). The forward variable selection based on results of simple regression with single explanatory variable indicated that HR (bpm) at 30 min of exercise in the thermoneutral environment ($\beta = 0.69$, $p < 0.001$), absolute $VO_{2\ max}$ (l/min) ($\beta = -0.26$, $p < 0.05$), and age ($\beta = -0.19$, $p < 0.05$) each contributed significantly and uniquely to the outcome variable. Normalized regression coefficients (β values) indicate the strength of the effect of each independent variable to the dependent variable, each considered individually in simple regression model. Thus, HR at 30 min of exercise had the strongest effect on predicting ending HR during the HTT, followed by absolute $VO_{2\ max}$ (l/min) and then age, respectively. The final predictive model was:

$$\text{Ending HR during the HTT} = 141 + (0.48 \times \text{HR [bpm]}) + (-1 \times \text{age [years]}) + (-4.40 \times VO_{2\ max}\ \text{[l/min]}) \quad (1)$$

DISCUSSION

The HTT is a screening tool that has been used for >30 years in both military and occupational medicine settings that aims to identify individuals who may be susceptible to heat illness, to identify cases of potential exertional heat illness, and determine RTA status in those recovering from a heat illness [3,12,13]. During exercise, body temperature is determined by the balance between heat accumulation and heat dissipation [1,2]. Heat storage is the result of excessive heat accumulation and the inability to dissipate body heat [1,2,14]. Individuals who accumulate heat at a faster rate than what would be expected display signs of greater physiological strain [1,2,13,14]. These individuals are usually defined as heat-intolerant, due to their inability to adapt to work or exercise in hot environments and have increased susceptibility to heat illness [1,2,13,14].

Heat intolerance has been shown to be multi-factorial [1,13,15] including both inherent and permanent factors, and/or a temporary functional condition [1,2,13,14]. Due to the serious nature of heat illness and that heat intolerance has a 11.4% rate of repeated heat illness [13], various HTT protocols were developed and utilized to identify individuals' susceptibility to heat stress. Heat intolerance can be ascertained through environmentally controlled heat exposure and is functionally defined as a core temperature ≥38.6°C or a HR ≥160 bpm during 120 min of walking in the heat [7,10,11]. Interestingly, in the current study, of the 48 subjects who were classified as heat-intolerant, 40 reached the heart rate criteria (HR ≥ 160 bpm) while only 8 reached the core temperature criteria (≥38.6°C). Such data suggests that cardiovascular strain is more limiting that hyperthermia when using the HTT in its current configuration. Future work should examine if the heart rate criteria should be increased to reflect heat tolerance status more accurately. It should be pointed out, however, that the threshold criteria of HR ≥160 bpm used in the current HTT is consistent with standard recommended by the American Conference on Governmental Industrial Hygienists (180 bpm–age). Alternately, cardiovascular strain as measured by HR, may be reached sooner than hyperthermia during a HTT as it has recently been shown that there is a discordance between increases in HR and core temperature during exercise in the heat [16].

In previous research it has been shown that HR after 30 min of exercise in a thermoneutral environment is strongly correlated with the ending HR during an HTT in the heat [10]. It has been suggested that using data obtained during a simulated HTT performed in a thermoneutral environment could provide a simple, practical test to predict heat tolerance status, which could be used to screen for heat-intolerant individuals prior to attempting a full 2-hour HTT in the heat [10,17]. Such a hypothesis is supported by the data of Mandel et al. [8] who found a strong correlation ($r = 0.83$) between the ending HR during a hot HTT with the 30-minute HR obtained during exercise in thermoneutral conditions. In addition, both Shvartz et al. [17] and Maunder et al. [18] found moderate to strong correlations between mean HR during thermoneutral exercise and HR during exercise in the heat. Lastly, when comparing heat-tolerant vs. heat-intolerant subjects Jones et al. [11] found that the heat-intolerant subjects had a significantly higher HR during thermoneutral exercise (M±SD 131±11 vs. 104±13 bpm, $p = 0.02$). Thus, past research suggests that there is a strong relationship between the within subject HR during exercise in hot and thermoneutral environments.

The results of the current study found some support for using heart rate data collected during exercise in a thermoneutral environment to predict heat tolerance during a HTT (Table 2). Specifically, the negative predictive value was found to be 46% – in other words if a subject had a HR <130 bpm during thermoneutral exercise they would have about a 50% chance of passing the HTT in the heat. However, individuals who are pre-screened via thermoneutral exercise for whom HR ≥130 bpm, would not likely pass the HTT, using established HR and core temperature criteria, as these individuals were found to be heat-intolerant 100% of the time. In other words, the positive predictive value of the test was 100%.

Often in medical diagnosis the validity of a newly developed method of testing for a disease is compared to a gold standard or an existing preferred method [19]. Currently no gold standard exists for diagnosing or pre-screening personnel for heat intolerance without these individuals attempting an HTT. The use of a HTT to confirm heat intolerance at times has been questioned as a diagnostic tool. Schermann et al. [15] argue that the HTT is a functional test that reflects only the current physiological state of an individual. There are a multitude of intrinsic and extrinsic factors that can temporarily influence heat intolerance [1,3,14]. Although there is inherent or acquired pathological heat intolerance, more often the underlying cause is related to physiological factors that are modifiable such as aerobic fitness, body weight, and lack of heat acclimatization [1,15].

As there are many factors that influence heat tolerance, it was hypothesized that multiple regression analysis might be useful to predict an individual's ending HR during an HTT. The association between age, gender, anthropometric and aerobic fitness measures have been previously examined as to how they affect performance during exercise in the heat [1,3,11]. In the current study, multiple regression analysis revealed the 3 significant independent variables for predicting ending HR during an HTT, were absolute $VO_{2\ max}$ (l/min), age, and HR after 30 min of exercise during thermoneutral exercise.

Cardiovascular fitness (i.e., $VO_{2\ max}$) has been shown to have a moderately strong relationship with heat tolerance regardless of gender or physical characteristics of the subject [1,3,11]. Aerobic fitness, expressed as $VO_{2\ max}$, is known to improve exercise efficiency, increase blood volume and augment sweating – all of which mediate performance in the heat. This is supported by the regression model based in the current study, as absolute $VO_{2\ max}$ (l/min) was found to be a significant independent variable in predicting ending HR during the HTT.

When comparing the $VO_{2\ max}$ of the individuals classed as heat-intolerant (failed the HTT) vs. those who were heat-tolerant (passed the HTT), the former had a significantly lower $VO_{2\ max}$ (M±SD 2.92±0.92 vs. 4.18±1.02 l/min, $p < 0.01$). These findings are supported by Lisman et. al. [3] who reported that $VO_{2\ max}$ had the most significant effect on physiological strain (e.g., HR, core temperature) during treadmill walking in the heat. Cardiovascular fitness is accompanied by physiological adaptions that allow efficient heat dissipation and increases the individual's ability to compensate during heat stress. When performing the HTT, lower cardiovascular fitness reduces the ability to thermoregulate and tolerate the metabolic demands of the activity.

Interestingly, absolute $VO_{2\ max}$ (l/min) was found to be the significant predictor of an individual's ability to pass the HTT, not relative $VO_{2\ max}$ (ml/kg/min) which considers bodyweight. Although there were significant differences in weight between the heat-intolerant and heat-tolerant groups (M±SD 67.1±13.2 vs. 75.8±12.5 kg, $p < 0.05$) and estimated body fat percentage (19.1±7.3 vs. 14.4±6.6%; $p < 0.05$), there were no significant differences in BMI (23.7±3.1 vs. 24.1±2.8 kg/m^2, $p > 0.05$).

Lisman et al. [3] has indicated that body fat percentage and BMI were significant factors in predicting an unsuccessful HTT. Superior cardiovascular function, however, may contribute to a reduced work intensity (relative to $VO_{2\ max}$) independent of body mass [1]. Although there was significantly higher body weight in the heat-tolerant group, the significantly lower estimated body fat percentage suggests that the weight differential could be attributed to a larger percentage of lean tissue and reduced adipose tissue. Lean tissue such as skeletal muscle, is more efficient at dissipating heat compared to adipose tissue and a higher body fat percentage has been shown to exaggerate the HR response to exercise in the heat [3]. Therefore, individuals who have significantly higher cardiovascular fitness and a higher percent of lean tissue, independent of body weight/mass, may perform more efficiently in the heat.

Over the lifespan, cardiovascular fitness and thermoregulatory function, and the resulting ability to tolerate heat, has been shown to be related to age [1,4,15]. Young children and older adults (>50 years old) are 2 population groups that are at increased risk for heat illness when exposed to hot environments [1,20]. Age-related functional physiological and cardiovascular factors that may be compromised in older adults or immature in children can negatively affect thermoregulation. These include decreased sweat gland activity, cardiac output, and maximal oxygen uptake [1,17].

A study by the U.S. military in 2018 found that the highest incidence of heat stroke and heat exhaustion were among male service members who were <20 years old [6]. Additionally, in the case study evaluations by Moran et al. [2] the 4 individuals who were determined to have heat illness were all <21 years old. In the current study, the correlation between age and ending HR during the HTT was found to be weak ($r = -0.38$), however it was found to be a significant independent variable that strengthened the multiple regression model. The average age of the heat tolerant individuals in the current study was M±SD 24.7±4.3 years while the heat intolerant subjects were slightly younger at 22.9±3.2 years, which was not significant ($p > 0.05$).

Pandolf [21] indicates that tolerance for heat stress in middle-aged (45–64 years) people is less than younger individuals. However, the physiological responses to exercise in the heat of habitually active or aerobically trained middle-aged persons has been shown to be the same or better than younger people [22]. Stapleton et al. [23] indicate that endurance-trained adults exhibit a better thermoregulatory response to heat due to partially acquiring acclimatization through regular activity compared to non-endurance trained counterparts [24].

A key strength of the current study must be noted. The sample population had almost equal representation of male (N = 33) and female (N = 32) subjects. Many studies [3,14,17] that examined heat tolerance testing had extremely low or no female participants. Previous work by Druyan et al. [25] has indicated that women more often are defined as heat intolerant based on a failed HTT which may have led to the exclusion or limitation of female subjects. The current study examined males and females as one population, without making gender comparisons or controlling for potential gender differences.

It must also be noted that 1 limitation of the current study relates to the generalizability of the of the regression equation to other populations. This was controlled for up to a point by a large sample size and limiting predictor variables to 3, however, further testing on another sample population would be warranted to evaluate cross-validation of the regression analysis.

CONCLUSIONS

Heat illnesses pose a significant threat to individuals who are exposed to hot environments during recreational and occupational pursuits. Identifying individuals at risk for developing heat illness or that might meet heat intolerant criteria during an HTT, could potentially be assessed via thermoneutral exercise. The results of the current study show that heat-intolerant subjects were correctly identified only 54% of the time using HR data collected during exercise in a thermoneutral environment. Thus, the specificity is quite low and not much better than the flip of a coin. However, heat-tolerant subjects were correctly identified 100% of the time. Therefore, if a subject has a HR >130 bpm at 30 min of exercise in a thermoneutral environment, they are very likely to fail a subsequent 2-hour HTT in the heat and be classified as heat intolerant. Therefore, prior screening has the potential to save time and money, along with providing safety to a heat-intolerant subject by not having to do a 2-hour HTT that they likely will fail. Furthermore, an individual's absolute $VO_{2\,max}$ and age strengthen the predictability of using HR collected during thermoneutral exercise to determine heat tolerance status via a HTT.

REFERENCES

1. Epstein Y. Heat intolerance: predisposing factor or residual injury? Med Sci Sports Exerc 1990; 22(4): 29-35.
2. Moran DS, Erlich T, Epstein Y. The heat tolerance test: an efficient screening tool for evaluating susceptibility to heat. J Sport Rehabil 2007; 16: 215–221. https://doi.org/10.1123/jsr.16.3.215.
3. Lisman P, Kazman JB, O'Connor F, Heled Y, Deuster PA. Heat tolerance test: association between heat intolerance and anthropometric and fitness measurements. Mil Med 2014; 179(11): 1339-1345. https://doi.org/10.7205/MILMED-D-14-00169.
4. Amit D, Itay K, Ran Y, Yoram E, Yuval H. Refining the distinction between heat tolerant and intolerant individuals during a heat tolerance test. J Therm Biol 2013; 38: 539–542. https://doi.org/10.1016/j.jtherbio.2013.09.005.
5. Kodack M. Heat-related illness increasing among U.S. military personnel. The Center for Climate and Security. [cited April 21, 2022]. Available at https://climateandsecurity.org/2019/08/heat-related-illness-increasing-among-u-s-milita ry-personnel/.
6. Armed Forces Health Surveillance Branch: Update: Heat illness, active component, U.S. Armed Forces, 2020. [cited April 21, 2022.] Available at https://health.mil/News/Arti cles/2021/04/01/Update-Heat-Illness.
7. Heaney JH. Components of an effective heat tolerance test for military populations. J Sci Med Sport 2017; 20: 57-58.

8. Mitchell K, Cheuvront SN, King MA, Meyer TA, Leon L, Kenefick R. Use of the heat tolerance test to access recovery from exertional heat stroke. Temperature 2019; 6: 106-119. https://doi.org/10.1080/23328940.2019.1574199.
9. House C, de Sa D. Comparison of performance on a heat tolerance test of military personnel that have suffered heat illness and subsequently been diagnosed with malignant hyperthermia and controls. Extrem Physiol Med. 2015; 4 (Suppl 1): A22. https://doi.org/10.1186/2046-7648-4-S1-A22.
10. Mandel M, Jones D, Pautz C, et al. Thermoneutral exercise correlates with end of trial heart rate during exercise in the heat. Med Sci Spts Exerc 2017; 49(5S): 453.
11. Jones D, Mandel M, Pautz C, Rostomily K, Cooper C, Bergquist-Turori D, et al. Reduced cardiorespiratory fitness causes heat tolerance test failures. Med Sci Spts Exerc 2017;49(5S):453.
12. Moran DS, Erlich T, Epstein Y. The heat tolerance test: an efficient screening tool for evaluating susceptibility to heat. J Sport Rehabil 2007; 16: 215-221. https://doi.org/10.1123/jsr.16.3.215.
13. Schermann H, Craig E, Yanovich E, Ketko I. Exertional heat illness probability of heat intolerance: standardized interpretation of heat-tolerance testing results versus specialist judgement. J Athl Train. 2018;53(4):423–430. https://doi.org/10.4085/1062-6050-519-16.
14. Moran DS, Heled Y, Still L, Laor A, Shapiro Y. Assessment of heat tolerance for post exertional heat stroke individuals. Med Sci Monit 2004; 10(6): CR252-CR257.
15. Schermann H, Yuval H, Chen F, et al. The validity of the heat tolerance test in prediction of recurrent heat illness events. J Sci Med Sport 2018; 21(6): 549-552. https://doi.org/10.1016/j.jsams.2017.10.001.
16. Ruas AC, Maia PA, Roscani RC, Bitencourt D, Amorim F. Heat stress monitoring based on heart rate measurements. Rev Bras Med Trab.; 18(2):232-240. https://doi.org/10.47626/1679-4435-2020-449.
17. Shvartz E, Shibolet S, Meroz A, Magazanik A, Shapiro Y. Prediction of heat tolerance from heart rate and rectal temperature in a temperate environment. J Appl Phys Respir Environ Exerc Physiol 1977; 43(4): 684-648. https://doi.org/10.1152/jappl.1977.43.4.684.
18. Maunder E, Plews DJ, Merien F, Kilding AE. Stability of heart rate at physiological thresholds between temperate and heat stress environments in endurance trained males. Int Jour Sports Physiol Perf 2021; 16: 1204-1207. https://doi.org/10.1123/ijspp.2020-0351.
19. LaMorte WM. Screening for disease: positive and negative predictive values. Available at http://sphweb.bumc.bu.edu/otlt/MPH.Modules/EP/EP713_Screening/EP713_Screening5.html; accessed April 21, 2022.
20. Binkley HM, Beckett J, Casa DJ, Kleiner DM, Plummer PE. National athletic trainers' association position statement: exertional heat illness. J Athl Train 2002; 37(3): 329-343.
21. Pandolf KB. Aging and human heat tolerance. Aging Clin Exp Res 1997; 23(1): 69-105. https://doi.org/10.1080/03610739708254027.
22. Meade RD, Notley SR, Kenny GP. Aging and human heat dissipation during exercise: an update and future directions, Curr Opin Physiol 2019; 10: 219–225. https://doi.org/10.1016/j.cophys.2019.07.003.
23. Stapleton JM, Poirier MP, Flouris AD, Boulay P, Sigal RJ, Malcolm J, et al. Aging impairs heat loss, but when does it matter? J Appl Physiol 2014; 118(3): 299–309. https://doi.org/10.1152/japplphysiol.00722.2014.
24. Rahimi GRM, Albanaqi AL, Van der Touw T, Smart NA. Physiological responses to heat acclimation: a systematic review and meta-analysis of randomized controlled trials. J Sports Sci Med 2019;18(2):316-326.
25. Druyan A, Makranz C, Moran D, Yanovich R, Epstein Y, Heled Y. Heat tolerance in women – reconsidering the criteria. Aviat Space Environ Med 2012; 83(1): 58-60 https://doi.org/10.3357/asem.3130.2012.