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Perceptual Variations in Thermoregulation During Exercise in a Hot Environment

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ABSTRACT

Professionals are seeking to find ways to prevent exertional heat illness (EHI) in populations working in hot environments as well as populations that are physically active. The purpose of the present study was to evaluate individuals' ability to accurately perceive core temperature ranges associated with homeothermic and EHI temperatures during exercise. Ten physically active males exercised on a treadmill at a self-selected rate until core temperature reached 39°C. Participants rated perceived core and skin temperature on 100 mm scales each time core temperature increased 0.25° C (37.5-39.0° C), along with thermal comfort and sweating sensation. During exercise core temperature was overestimated by 0.46 ±0.11° C. Following exercise, participants consistently underestimated core temperature by a mean perceived rating of 0.71 ±0.05° C. Skin temperature was overestimated by 1.45 ±1.21° C. Correlations were found between core temperature and perceived core temperature ($r = 0.54$), perceived skin temperature ($r = 0.55$), thermal comfort ($r = 0.41$), and sweating sensation ($r = 0.42$). No correlation was found between core and skin temperature ($r = 0.02$). These data suggest that although people are able to recognize increases in core temperature to the point of overestimation during exercise, they may return to exercise or work too quickly following breaks to cool themselves.

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CHAPTER 1

Introduction

Safety in respect to body temperature, especially high temperatures, is a prevalent area of concern among workers, athletes, and physically active individuals competing and working in hot environments. Homeostatic temperature ranges between 36.5 and 38.5° C. When temperatures vary outside this range for an extended period of time, physiological functions may be inhibited and even death may occur (Moran & Mendal, 2002). As endotherms, humans regulate temperature through internal heat generation via heat production, absorption, and loss (Lim et al., 2008). Professionals are continually seeking to better monitor body core temperature changes in hot environments to reduce incidents of exertional heat illness (EHI). EHI causes dysfunction in essentially all systems within the body and is characterized by high body temperature levels, induced by strenuous physical activity and/or high environmental temperature (O'Connor et al., 2010). During physical activity, more than 70% of heat production must be moved to the skin to be dissipated (i.e., loss). When metabolic heat production increases beyond the body's ability to dissipate it, an increase in body temperature occurs (Lim et al., 2008). If this increase in body temperature is not reduced, then EHI becomes a possibility.

To date, the most applicable techniques of core temperature (T_c) and EHI assessment recommended are rectal and gastrointestinal temperature readings (Ganio et al., 2009). Rectal temperature (T_{re}) measurements are typically performed in controlled laboratory settings as the equipment needed to perform such measurements generally limits application. Gastrointestinal temperature (T_g) measurements have been validated using T_{re}, as one of the only other applicable measures of T_c (Casa et al., 2007). The monetary cost of T_g technology poses limitations to the practical application of this technology. Previous research has shown that skin temperature (T_{sk}) is an inaccurate method of evaluating T_c, even in the commonly utilized axillary locations (Ganio et al., 2009; Jensen et al., 2000). Due to the limitations of these assessment techniques, it has become increasingly important to find another accurate and reliable method of EHI assessment, especially to be used in field settings.

The inherent dangers of EHI and limitations of T_c and T_{sk} temperature monitoring elucidate the importance of evaluation of the human body's own perception of T_c. As the human race has survived in a variety of environmentally challenging conditions, it appears that most humans do an adequate job in recognizing elevated T_c and making efforts to decrease it without the use of a monitoring device. Previous research has shown that perceived thermal intensity of an external stimulus is not influenced by changes in T_c; however, perceived thermal pleasantness is affected by changes in T_c (Mower, 1976), making it of interest to determine whether thermal perceptions could be a strong enough internal alert system to cause individuals to make efforts to cool themselves when in hyperthermic states. Previous research has also shown that humans' perception of body water loss during physical activity is consistently underestimated (O'Neal et al., 2012; Passe et al., 2007). Taking a similar approach to this idea of physical state perception, the evaluation of perceived core temperature (T_{pc}) could be beneficial as well. A recent study showed that rating of perceived exertion is higher during exercise in environmentally hot conditions compared to cool conditions (Crewe et al., 2008), and credited this to the model of a subconscious central governor system that regulates the body to prevent humans from reaching dangerous exertional levels (St. Clair Gibson & Noakes, 2004). It is possible that this same central governor could work similarly with rating T_{pc} levels.

Previous research shows that both T_c and T_{sk} have an impact on thermal comfort (Frank et al., 1999), making it of interest to evaluate core temperature perceptions during a thermal stimulus. It is well known that T_c increases in response to exercise (Shapiro & Seidman, 1990); therefore making it an externally valid stimulus for this evaluation. While T_{sk} is an inaccurate method of evaluating T_c (Ganio et al., 2009; Jensen et al., 2000), due to the presence of non-linear relationships between T_{sk} and the currently recommended T_c evaluation methods, perceptions of T_{sk} as it applies to perceived dangerous T_c

levels could still be of value within EHI prevention efforts. T_{sk} could be a vital aspect in temperature perception due to the afferent signals sent by thermoreceptors at the skin, which impact perception and behavioral responses (Green, 2004).

If it is determined that a majority of humans can accurately and reliably perceive T_c, especially during hyperthermia, this information could possibly improve self-regulatory behaviors of both perceptual responders and non-responders. This could be used to move the field of thermoregulation in a new direction in regards to EHI prevention efforts. Therefore, the purpose of the present study was to evaluate individuals' ability to accurately perceive T_c and T_{sk} temperature ranges associated with homeothermic and EHI temperatures during exercise.

CHAPTER 2

Methods

Subjects participating in the present study consisted of well-trained college-aged males. In order to minimize physiological strain to the current study's protocol, well trained was defined as engaging in some combination of cardiovascular and strength training activities a minimum of 3 days per week for 12 weeks prior to participation. Written consent was obtained from all participants prior to testing.

Subjects were familiarized and instructed about procedures of the present research prior to testing. Subjects were asked to document food and fluid consumption for the day prior to testing, and consume 500 ml of water at 2100 hours to help ensure euhydration the following day. Subjects were also asked to abstain from strenuous exercise on the day prior to as well as the day of testing. Urine color, specific gravity, and urine volume were measured prior to each trial to confirm hydration levels.

Each subject participated in one trial. Upon entering the lab, to determine pre-trial weight, subjects emptied their bladder, and were then weighed (Detecto Scale, Brooklyn NY). During the trial, increases in body core temperature were induced by moderate physical activity consisting of a walk/run protocol on a

(Trackmaster treadmill, Newton KS) at a self-selected pace and incline until T_c reached 39°C or the subject requested to stop. Trials were conducted in a climate-controlled chamber at a mean temperature of 35˚ C and a mean relative humidity of 29% (Isothermex, Columbus Inst., Columbus OH). T_c was monitored using T_{re}. T_{re} and T_{sk} were monitored throughout the trials using a rectal thermocouple, and skin thermocouples at the chest, forearm, and calf (Physitemp Inst., Cliftton NJ). T_c >39˚ C was set as criterion for removal of subjects from the climate controlled environment to ensure safety. Subjects were not provided fluids during trials.

Participants were also asked to rate their perceptual estimations using 100 mm scales, including thermal comfort, sweating sensation, perceived core (T_{pc}) perceived skin temperature (T_{ps}). Each scale was presented separately in an effort to avoid cross scale contamination. Visual analog scales have been found to be efficacious in perceptual rating (Bishop & Herron, 2015). These measures were taken each time core temperature increased by 0.25˚ C until T_c reached >39°C or the participant chose to stop. Once high T_c levels were reached participants stopped exercise, but remained in the climate chamber and passive cooling was used to reduce T_c. Perceptual measures continued to be recorded as temperatures returned to resting levels (<38°C).

CHAPTER 3

Results

Participant demographics can be found in Table 1. Present data revealed that during exercise participants consistently overestimated T_c levels with a mean perceived rating of 0.46 ±0.11° C higher than T_c (Table 2 and Fig. 1). To reach 39° C, participants exercised at mean 46.58 ±12.00 minutes, and following exercise took 23.03 ±7.31 minutes to return to 38° C at rest. Following exercise, participants consistently underestimated T_c levels with a mean perceived rating of 0.71 ±0.05° C lower than T_c (Fig. 1). Statistical significance was shown between T_{pc} and T_c in the majority of data points (Table 2) as readings were recorded at each 0.25° C change in T_c (11 data collection points) from 37.5° C to 39° C and during return to 38° C.

T_{ps} was also overestimated with a mean perceived rating of 1.45 ±1.21° C higher than T_{sk} (Table 3 and Fig. 2). Following exercise, T_{ps} did not track with core perceptions above, and participants continued to overestimate T_{sk} as T_c returned to 38° C. Statistical significance was shown between T_{ps} and T_{sk} in the majority of data points as well (Table 3), as readings were taken at each 0.25° C change in core temperature.

Correlations were calculated to determine relationships between T_c and T_{pc}, T_{sk} and T_{ps}, thermal comfort, and sweating sensation. A positive correlation was found between T_c and T_{pc} (r=0.54). No correlation was found between T_c and T_{sk} (r=0.02); however, a positive correlation was shown between T_c and T_{ps} (r=0.55). Both thermal comfort and sweating sensation exhibited a positive correlation with T_c of r=0.41 and r=0.42, respectively.

CHAPTER 4

Discussion

This study evaluated individuals' ability to accurately perceive T_c ranges associated with homeothermic and EHI temperatures during exercise. Healthy college age males completed one trial of exercise in a climate-controlled chamber at a mean temperature of 35˚ C on a treadmill at a self-selected pace and incline until T_c reached >39˚ C. Participants rated T_{pc} on 100 mm scales each time T_c increased 0.25˚ C, along with T_{ps}, thermal comfort, and sweating sensation

Results showed that during exercise participants consistently overestimated T_c levels with a mean perceived rating of 0.46 ±0.11˚ C higher than T_c. Following exercise participants consistently underestimated T_c levels with a mean perceived rating of 0.71 ±0.05˚ C lower than T_c. T_{ps} was overestimated with a mean perceived rating of 1.45 ±1.21˚ C higher than T_{sk}. Unlike the underestimation of T_{pc} following exercise, the overestimation of T_{ps} and correlation of T_{ps} to T_c (r=0.55), suggests that T_{ps} might be a possible EHI prevention tool as it was able to recognize elevated temperature levels after exercise. Correlations were also found between core and T_{pc} (r=0.54), , thermal comfort (r=0.41), and sweating sensation (r=0.42). No correlation was found between core temperature and T_{sk} (r=0.02). According to the correlations found, clinicians may want to consider utilizing actual temperature ratings for EHI prevention versus the more typically used thermal perception ratings. This could be achieved using temperature education as an intervention method for EHI prevention.

In reference to EHI, these data suggest that humans are able to recognize elevation in T_c levels from the beginning and throughout sustained exercise. The highest health risk appears to be immediately following exercise. It is possible that although people are able recognize increases in T_c, and even overestimate them, they may return to exercise/work too soon following a break when increasing T_C is recognized. This is supported by the findings that participants underestimated T_c immediately following exercise and continued to underestimate until 38° C was reached. Much like this T_c underestimation following exercise, previous research also found that humans' perception of body water loss during physical activity is consistently underestimated (O'Neal et al., 2012; Passe et al., 2007). Together, these findings suggest that humans may not adequately recover following physical activity, which could lead to increased health risk.

The fact that participants were able to recognize elevated levels during exercise, though overestimating them, compares well with previous research that found that thermal sensation increases with exercise workload in the same environment (Goto et al., 2000). Instead of quantifying temperature, thermal sensation is rated through temperature related words (i.e. very cold, cold, cool, slightly cool, neutral, slightly warm, warm, hot, very hot). However, this study found that after 15 minutes of exercise, thermal sensation exhibited a steady state response, unlike the increasing linear fashion of T_c shown in the present study. This seems to indicate that thermal and sweat sensation may not be a suitable method for evaluating risk of EHI. This is unlike previous research, which credits both thermal comfort (Frank et al., 1999) and sweating sensation (Nielsen & Endrusick 1990) in being serviceable perceptual ratings in relation to T_c.

The evidence of a central governing system first proposed by St. Clair Gibson & Noakes (2004) that subconsciously works to prevent health risk was also of interest. Though many participants verbally expressed their ignorance of their current T_c state, the fact that perceptions increased in such a linear fashion in a similar pattern to core temperature, though higher, suggests the possibility that this governor does indeed exist. In no way do these data prove its existence, but they do support the theory behind it. The overestimation of T_c during exercise could work quite well in efforts of preventing the body from reaching dangerously high temperature levels. However, during cool down periods participants' underestimation of T_c levels are less promising. T_{ps} did recognize elevated temperature levels as well as correlate with T_c. This is especially interesting due to the fact that previous research has shown perception of temperature to be independent of T_c and more dependent on peripheral temperatures (Mower, 1976). Also, skin temperature itself has been proven to be a poor predictor of core temperature (Ganio et al., 2009; Jensen et al., 2000), and this was supported by no correlation found between T_c and T_{sk} in the present study (r=0.02). It is possible that since participants were unsure of core temperature and their ability to sense it, they were able to associate T_{ps} with more of a sensory based 'feeling.' Due to the correlation between T_{pc} and T_c, this 'feeling' may have been more related to T_c than realized. Additionally, the overestimation of T_{ps} following exercise could possibly be credited to how the body responds to T_c and T_{sk}. Past literature reveals that the autonomic systems within body are more sensitive to changes in T_c than T_{sk} (Frank et al., 1999). The lack of sensitivity to T_{sk} may impact our perceptions, causing the delay in the drop of T_{ps} during recovery.

Future research is needed in the area of EHI prevention. Though the results in the present study provide some knowledge of how people may perceive T_c variations during exercise, the small sample size limits its use. Though participants were able to recognize changes in T_c and may lend support to aforementioned central governor theory, perceptual changes during recovery require further investigation as it relates to safe return to work/activity within hot environments. Due to the small variability of the surface area to mass ratio of the participants in this study, it is of interest to find if the same results would be found in populations with a higher level of variability. Future research is also needed to bridge the gap between T_{pc} and perceptions of health risk associated with that temperature. How individuals perceive T_c changes in relation to their own health and safety are required to fully understand the relationship between T_{pc} and EHI prevention.

CHAPTER 5

Tables and Figures

Table 1. *Participant Demographics* (N=10)

	Mean ± SD
Age (yrs)	21.30 ± 2.41
% Body Fat	17.37 ± 4.94
BMI (kg/m^2)	27.56 ± 5.85
Urine Specific Gravity	1.02 ± 0.003
Urine Color	3.60 ± 1.07

Table 2. *Perceptual Core Temperature Data* (N=10)

Core Temp.	Perceived Core Temp. ± SD	p- value
37.50	37.88 ±0.61	0.13
37.75	38.10 ±0.81	0.20
38.00	38.63 ±0.69	0.02
38.25	38.83 ±0.58	0.01
38.50	39.03 ±0.48	0.007
38.75	39.20 ±0.55	0.03
39.00	39.35 ±0.49	0.0498
38.75	38.11 ±0.63	0.02
38.50	37.78 ±0.53	0.002
38.25	37.50 ±0.47	0.0007
38.00	37.26 ±0.38	0.0002

Note. Perceptual ratings were taken using 100mm scales

Table 3. *Perceptual Skin Temperature Data* (N=10)

Skin Temp ± SD	Perceived Skin Temp. ± SD	p- value
35.22 ±0.55	34.72 ±2.05	0.61
35.75 ±0.53	35.20 ±2.41	0.52
35.82 ±0.23	36.53 ±2.22	0.30
36.08 ±0.16	37.85 ±1.67	0.007
35.80 ±0.23	37.83 ±1.56	0.003
36.14 ±0.17	38.80 ±1.59	0.001
36.27 ±0.47	39.35 ±1.14	0.0005
32.80 ±0.45	35.42 ±1.90	0.0004
32.36 ±0.28	34.25 ±1.82	0.001
31.93 ±0.15	33.13 ±1.35	0.04
31.83 ±0.38	32.83 ±1.21	0.08

Note. Perceptual ratings were taken using 100mm scales

Table 4. *Thermal Comfort and Sweating Sensation* (N=10)

Core Temp.	Thermal Comfort ± SD	Sweating Sensation ± SD
37.50	36.63 ±22.91	37.36 ±35.10
37.75	46.60 ±29.61	52.60 ±33.59
38.00	54.50 ±27.88	73.80 ±26.28
38.25	64.50 ±28.96	84.10 ±18.78
38.50	68.60 ±12.16	86.40 ±14.01
38.75	78.30 ±12.92	88.30 ±12.86
39.00	85.80 ±10.16	93.90 ±7.22
38.75	27.56 ±29.06	40.44 ±30.93
38.50	19.00 ±18.95	28.10 ±24.63
38.25	14.80 ±16.14	13.80 ±15.62
38.00	8.90 ±13.74	7.80 ±8.72

Note. Perceptual ratings were taken using 100mm scales

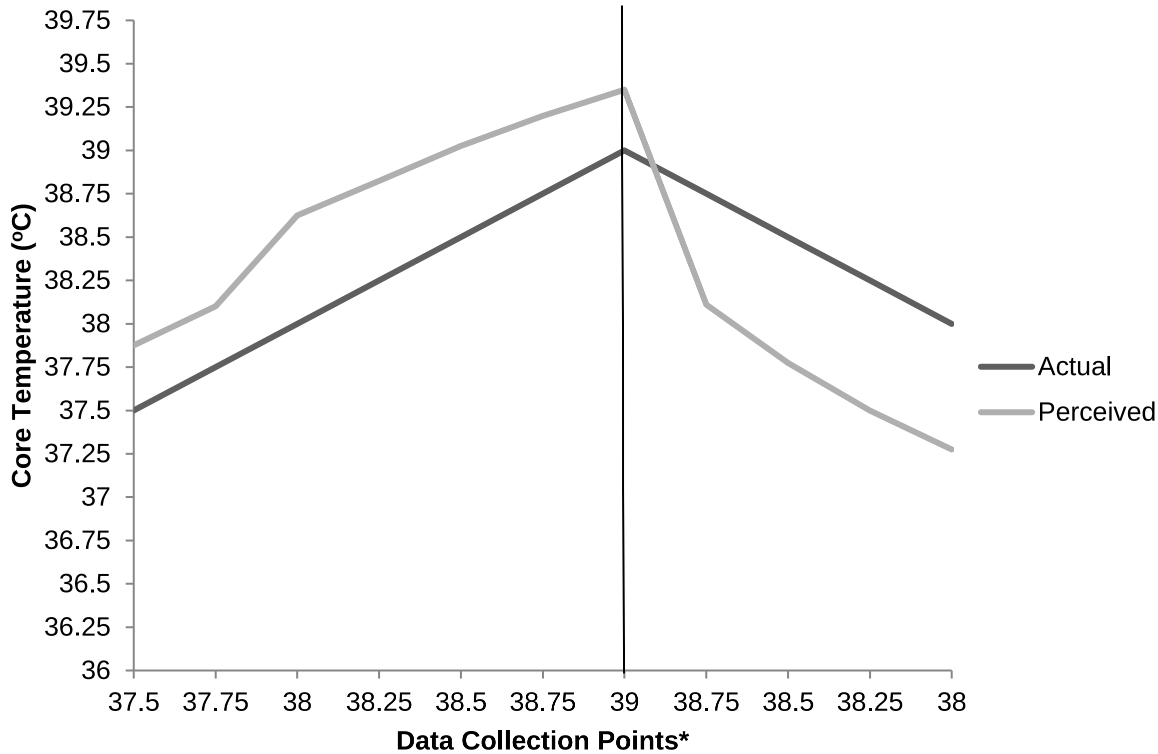

Figure 1. Core VS Perceived Core Temperatures

Note. Vertical line at Data Collection Point 39 indicates stopping exercise

*****Data collection points were recorded at core temperature changes of 0.25° Celsius

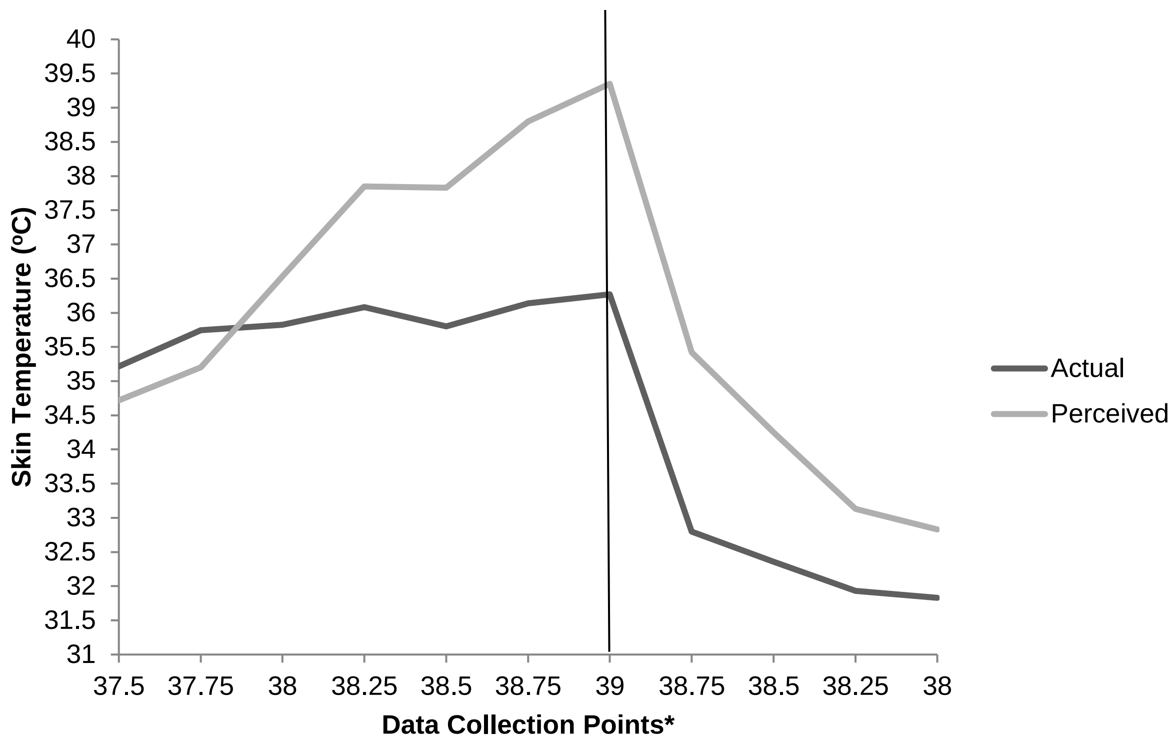

Figure 2. Skin VS Perceived Skin Temperatures

Note. Vertical line at Data Collection Point 39 indicates stopping exercise

*****Data collection points were recorded at core temperature changes of 0.25° Celsius

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VITA

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