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The Effects of Rectal Temperature and Hydration Status on Perceptual Ratings in Dehydrating Males

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REVIEW OF THE LITERATURE

Exertional Heat Stroke

Exertional Heat Stroke (EHS) is defined as hyperthermia (core body temperature >40^{o}C) associated with central nervous system disturbances and potential multiple organ system failure. According to the position stand by the American College of Sports Medicine et al. (1), it occurs most frequently in hot and humid conditions, and can affect athletes during high-intensity or long-duration exercise, resulting in withdrawal from physical activity or collapse. The symptoms of EHS include disorientation, confusion, dizziness, unusual behavior, inappropriate comments, irritability, headache, inability to walk, collapse, profound fatigue, hyperventilation, vomiting, diarrhea, delirium, seizures, or coma. Clearly, EHS is a life-threatening medical emergency. The American College of Sports Medicine (1) asserts that the clinical changes associated with EHS can be easy to miss. Therefore, coaches, medical personnel, and athletes must be extremely vigilant, especially in hot-humid conditions. They urge that any changes in personality or performance should immediately trigger an assessment for EHS. It is critical to be watchful for the symptoms of EHS to catch a dangerous physiological situation before it causes permanent damage to the athlete or death.

Critical Internal Temperature

Internal body temperature is often studied in athletes exercising in the heat to observe physiological responses at extreme temperatures. Internal temperature is either measured with an esophageal or intestinal probe, while rectal temperature is measure with an athlete-inserted thermistor. The notion of a critical internal temperature has been suggested as a cause of volitional exhaustion during exercise in the heat, so that athletes halt exercise before reaching core temperatures associated with EHS. González-Alonso et al. (9) tested this theory by having male cyclists perform bouts of cycle ergometry in the heat (40^{o}C) until volitional exhaustion.

They found that fatigue during prolonged exercise in uncompensable hot environments occurred at the same critical level of hyperthermia when the initial value and the rate of increase in body temperature were altered. The critical internal temperature at which subjects fatigued was 40.1 - 40.2^{o}C. Armstrong et al. (2) found that subjects reached volitional exhaustion at a similar internal temperature (39^{o}C). Subjects performed repetitive box lifting followed by treadmill walking in the heat (33^{o}C) until subjects finished the trial or reached volitional exhaustion. The trials in which subjects reached exhaustion support the existence of a critical internal temperature at which volitional exhaustion occurs, but only in nearly uncompensable or uncompensable conditions (e.g. a partial or full football uniform). Uncompensable heat stress occurs when internal body temperature continually rises without a plateau because heat dissipation is prevented, usually by clothing insulation.

Interestingly, despite very different modes of exercise and subject attire, the results of both González-Alonso et al. (9) and Armstrong et al. (2) support the idea that uncompensable heat stress leads to exhaustion when a critical internal temperature is reached while exercising in the heat. This volitional exhaustion occurs to prevent the athlete from reaching an extreme internal temperature which could result in EHS. Armstrong et al. (2) also found that participants had similar thermal, thirst, and rating of perceived exertion perceptual measurements at the point of exhaustion, showing that perceptual measurements may be predictive of the internal temperature of an athlete exercising in the heat.

Thermal Perception

Development of the Thermal Perception Scale

Laboratories studying the effects of exercising in the heat on the human body need a standardized scale to measure thermal perception. Young et al. (18) performed a study that analyzed the effect of cooling different body surfaces during upper and lower body exercise. In addition to analyzing physiological responses to cooling the skin, they measured the perceptual response to cooling the skin. To do so, they developed a Thermal Sensation Scale ranging from 0.0 (*Unbearably Cold*) to 8.0 (*Unbearably Hot*), which this study utilized (see Figure 1).

Relation of Thermal Perception to Core Temperature

In using the thermal perception scale they developed, Young et al. (18) observed that the thermal ratings (THM) of subjects progressively increased (i.e. the subjects felt increasingly hotter) with each of three 50 minute bouts of exercise in 35^{o}C heat. They found that these increases in THM ratings coincided with increasing rectal temperatures (T_{re}) during each of the three trials. However, in disagreement with this, Johnson et al. (10) (using data from the same study as Armstrong et al. (2)) observed that there was no correlation between THM and T_{re} at the end of exercise. THM and T_{re} were not correlated because a participant's THM was nearly maximally rated on the scale before the participant reached the T_{re} threshold leading to fatigue. Thus, as the partially- or fully-uniformed participant continued to exercise in the heat, his THM was already maximally-rated and remained near the maximum until exercise cessation, despite a continual rise in T_{re}. However, Johnson et al. (10) acknowledged that because of the increased humidity inside the football uniform, the higher levels of moisture at the skin might have increased THM, resulting in elevated perceptual ratings before increased heat storage and elevated T_{re}. The data of Young et al. (18) may not show this lack of correlation between THM and T_{re} because the participants in their study only experienced a small change in T_{re} (0.4 - 0.8^{o}C) so the subjects did not approach the T_{re} threshold for fatigue and their THM were not maximally-rated.

Tyler et al. (17) also found data to support an uncoupling of thermal sensation and T_{re}. Participants completed two running trials at 70% VO_{2max} in the heat (32°C): one with and one without a cooling collar. They found that cooling the neck region with a cooling collar increased the time to reach volitional exhaustion by 13.5%. Interestingly, while subjects ran for longer and tolerated increases in final T_{re} (39.61°C vs. 39.18°C without a cooling collar), they fatigued at identical RPE and THM values. Cooling the skin increased the time to volitional exhaustion by dampening the perceived level of thermal strain, showing that cooling the skin can fool perceptual values (see next section). Cheung (5) cited that distraction was effective in altering participant's THM, and claimed this "reinforces the plasticity of the psychological perception of thermal stimuli." This statement explains why many contradictory findings have been made relating internal body temperature to thermal perception. Athletes exercising in the heat must be wary because dampening the perception of thermal strain allows one to tolerate increased physiological values (e.g. T_{re}) which can endanger the individual.

Influence of Skin and Core Temperature

Many recent studies have analyzed the influence and the relative contribution of changes in skin and core temperature to thermal perception. Cheung (5) found that mean body temperature, a combination of both skin and core temperature, was the primary determinant for self-regulation of thermal comfort during rest and periodic exercise in a cold environment. There has been much debate in the literature (13, 6, 18, 15, 8) as to which temperature (skin, core, or mean body) most strongly affects THM.

One group of researchers believes that skin temperature (T_{sk}) has the greater effect on THM. Maw et al. (13) had subjects perform 30 minutes of cycle ergometry at a rating of perceived exertion (see later) equivalent to "somewhat hard" in hot (40°C), neutral (24°C), and cool (8°C) conditions. They found that mean T_{sk} was influenced more by the environment than by the change in T_{re}, and that THM scores generally followed the changes seen in mean T_{sk}, with subjects rating significantly lower sensations in the cool environment and significantly higher in the hot environment. Therefore, Maw et al. suggested that THM is more heavily influenced by the environment than the thermal state of the core, and that THM is derived primarily from cutaneous thermoreceptors and the rate of change of mean T_{sk}. In addition, their results demonstrated a minimal influence of T_{re} on THM.

Similar to these results, Cotter et al. (6) found that a small change in local skin temperature (4°C) had a significant impact on whole body thermal perception. They altered the temperature of 10 patches of skin and recorded the changes in their subjects' thermal perception. Young et al. (18), the developers of the THM scale, found that even though increasing the skin surface area being cooled decreased T_{re}, there was no effect on THM. They suggested that T_{sk} probably provided a more important cue for THM than T_{re}. Finally, Schlader et al. (15) found that by using a water-perfused suit to selectively increase or decrease T_{sk}, THM generally reflected the changes observed in T_{sk}.

Other researchers believe that T_{re} has the greater influence on THM. These researchers do not aim to disprove that T_{sk} plays a role in thermal perception; instead, with the knowledge that thermosensors exist in both the skin and the viscera, these investigators wish to quantify the relative contribution of T_{sk} *and* T_{re} to thermal perception. Frank et al. (8) analyzed how each of these inputs contributes to THM by driving each in opposite directions. To do so, he used a combination of a thermally regulated mattress to alter and maintain mean T_{sk} at cold, neutral, or warm temperatures (14°C, 34°C, or 42°C, respectively) while simultaneously accomplishing rapid core cooling by the infusion of cold (4°C) intravenous fluid at 70mL/min. They analyzed the THM ratings in relation to core temperature (T_c) measured at the tympanic membrane and T_{sk} using a linear regression, and found an about equal contribution of T_c and T_{sk} to subjective thermal comfort with regression coefficients of .96 for T_c and .91 for T_{sk}.

Thus, Frank et al. (8) found that the T_c/T_{sk} contribution ratio was approximately 1:1 for THM; interestingly, the T_c/T_{sk} ratio ranged from 2:1 to 4:1 for autonomic thermoregulatory responses including vasoconstriction, metabolic heat production, and plasma catecholamine concentrations. Thus, while T_c and T_{sk} affected thermal comfort approximately equally, the driving force for autonomic thermoregulation was changes in T_c. These investigators hypothesized that the relatively greater contribution of T_{sk} to subjective thermal comfort than to autonomic thermoregulatory responses may serve to "more efficiently utilize behavior as the first-line defense to maintain body temperature in humans, thus avoiding the need for more physiologically demanding adrenergic responses." They explained that because T_{sk} changes more rapidly and to a greater extent than does T_c, the large contribution of T_{sk} to thermal comfort serves to preempt the oncoming thermal challenges and stimulate behavioral thermoregulation before activation of more metabolically consumptive responses.

Overall, there is a larger quantity of research showing that THM is more heavily influenced by T_{sk}. Yet the research by Frank et al. (8) is very compelling in that it considers both T_{sk} and T_{re} and quantifies the relative contribution of each. One can see that both T_{sk} and T_{re} have an effect on THM, and that THM can give the researcher some idea of the T_{sk} and T_{re} a subject is experiencing.

Relation of Thermal Perception to Hydration Status

It is important to realize that no experiment is performed in a vacuum: there will be other variables that affect the output perceptual values. Besides T_{re}, the other main physiological influence on perceptual values will probably be hypohydration. As subjects exercise and continue to lose water by sweating, their perceptions may be skewed by the change in composition of their body fluids. Maresh et al. (11) performed a study where they dehydrated cyclists to 4% body mass loss and then had them cycle vigorously in the heat (37^{o}C) until volitional exhaustion. Each participant performed three trials: (1) they orally rehydrated right before exercise, (2) they were intravenously rehydrated right before exercise, and (3) they were not rehydrated before exercise. Interestingly, these investigators found that the THM ratings for the subjects at minute five of the trials was significantly ($p < .05$) higher in the non-rehydrated trial than in either of the rehydrated trials. Thus, even in the intravenously rehydrated trial where the oral stimuli of drinking fluid were lacking, the THM ratings were still lower than in the non-rehydrated trial. Hydration status affected the participants' thermal perception.

Thirst Perception

Development of the Thirst Perception Scale

It is of interest to any research laboratory studying the effects of fluid loss to have a subjective way for subjects to quantify their thirst. The Thirst Perception Scale was developed by Engell et al. (7) to measure the subjective thirst sensations (TST) experienced by exercising subjects. The scale contains 37 different sensations or symptoms that are reported to be associated with thirst in the scientific or anecdotal literature and control symptoms unrelated to thirst. Examples of sensations or symptoms associated with thirst include: my mouth feels dry, I feel thirsty, and my mouth feels irritated. We use an adapted version of the Thirst Perception Scale and only ask subjects to rate their thirst on a scale from 1 (*Not Thirsty At All*) to 9 (*Very, Very Thirsty*) (see Figure 2). The scale developed by Engell et al. takes too much time to complete, so it would inhibit proper protocol during an exercise study.

Relation of Thirst Perception to Core Temperature

There is a dearth of information relating TST to T_{re}, compared to the wealth of studies assessing the relationship between THM or RPE and T_{re}. Johnson et al. (10) is the only well-known group who addressed the topic, and they found there is a significant positive correlation between the final TST rating of subjects during their exercise protocol and the rate of change in T_{re} throughout the experiment. Possibly, subjects experiencing a high rate of change in T_{re} anticipated a thermal onslaught coupled with hypohydration and felt thirstier at exercise cessation. Alternatively, it is possible that the subjects with the highest rates of change in T_{re} lost more water due to a higher sweat rate, and thus were more hypohydrated at exercise cessation. Either way, subjects with high rates of change in T_{re} during exercise felt thirstier after exercise.

Cross Effect of Dehydration

The cross effect of dehydration may be especially impactful for thirst perception. Engell et al. (7), the developers of the TST scale, theorized that sensations of thirst result from stimuli such as plasma osmolality, plasma volume, and angiotensin II. As subjects sweat and lose fluid, the composition of their body fluids changes and the body reacts by altering thirst sensations. This is supported by data from Maresh et al. (11) who claimed that there is a linear relationship between the level of hypohydration and thirst sensations. They supported this claim by showing that a significant correlation existed between TST and plasma osmolality in hypohydrated subjects during exercise. Similarly, Engell et al. (7) found that the median intensity of thirst sensations increased as hypohydration level increased, from a rating of 1 at 0% hypohydration to a rating of 7 at 7% hypohydration. They hypothesized that changes in sensations and symptoms make an important contribution to the experience of thirst in hypohydrated humans, in addition to physiological changes like an increase in plasma osmolality.

Clearly, one's level of hypohydration has an important effect on one's sensation of thirst. Furthermore, level of hypohydration can influence changes in T_{re}. Armstrong et al. (3) performed a study in which participants who were initially either hypohydrated or euhydrated performed a 90-minute heat stress test consisting of treadmill walking in a 33^{o}C environment. They found that hypohydrated subjects who were not allowed to drink water during the stress test had a significantly higher T_{re} at every time measured during exercise when compared to euhydrated subjects who also weren't allowed water during exercise. The hypohydrated subjects had a final T_{re} one degree Celsius higher than the euhydrated subjects. These studies show that there will be an effect of hypohydration on the subjects in our study, and that the level of hypohydration may affect thirst sensation and T_{re}.

Perceived Exertion

Development of the Rating of Perceived Exertion Scale

When performing a study involving exercise, it is difficult to measure subjective effort in a physiologically heterogeneous group. Thus, Borg (4) developed the Rating of Perceived Exertion (RPE) scale to do just that. He gives the example of performing an experiment on a group of people with a large age range. In order to have subjects exercise at a constant effort, heart rate cannot be used because 150 beats per minute would be very easy for some and very difficult for others, and a different percentage of their maximum heart rate. Therefore, RPE can be used because it is based on the premise that "man reacts to the world as he perceives it and not as it 'really is'." Borg believes that a subjective rating of exertion is derived from both central and local physiological cues and as such, RPE should be used as a complement to physiological stress indicators. The RPE scale consists of 15 ratings ranging from 6 (*no exertion at all*) to 20 (*maximal exertion*) (see Figure 3). Subjects are instructed how to rate their RPE, and to do so as accurately and naïvely as possible.

Relation of Rating of Perceived Exertion to Core Temperature

There is debate in the literature as to whether or not and how T_{re} affects RPE. Johnson et al. (10) found there was no correlation between RPE and final T_{re}; however, they did find a positive correlation between the rate of change in T_{re} and final RPE. The subjects undergoing uncompensable heat stress during exercise had a faster increase in T_{re}, and perceived their effort as greater. Armstrong et al. (2) found a main effect of RPE at the time of exhaustion. Increased RPE and elevated T_{re} coincided with earlier exhaustion in the partial- and full-uniform conditions as compared to the control condition. Interestingly, the RPE at exhaustion for the partial- and full-uniform conditions were 17 and 18, respectively, and the increase in T_{re} at exhaustion was 2.36^{o}C and 2.37^{o}C, respectively. RPE and T_{re} were very similar at the point of exhaustion, suggesting there may be a link between these two variables and volitional exhaustion. This provides further support for the critical internal temperature theory, and suggests that RPE may play a role in volitional exhaustion. This idea is supported by González-Alonso et al. (9), who found that subjects not only fatigued at identical internal temperatures, but their RPE at exhaustion were nearly identical regardless of whether subjects were precooled (RPE of 18.5) or preheated (RPE of 18.6).

Other researchers believe there are other stimuli that more strongly affect RPE. Maresh et al. (11) cited that blood lactate levels, sensations from exercising muscles and joints, T_{sk}, and thermal sensations also affect RPE. However, they acknowledged core temperature as a nonspecific mediator in the perception of exertion. This research group elaborated on the effect of T_{sk} on RPE citing that T_{sk} accounts for a significant amount of the variance in overall RPE during hot environmental conditions. They found that Tsk was significantly correlated with overall RPE for orally-rehydrating males exercising in the heat. Maw et al. (13) assessed the effects of environment on RPE and found that T_{sk} is the main contributor to effort perception, saying that RPE is most sensitive to peripheral input such as T_{sk} and heart rate, which depend on thermal and metabolic loads.

Some researchers suggest that a possible uncoupling between RPE and T_{re} may exist. Tikuisis et al. (16) compared the relationship between RPE and thermal discomfort as subjective analogs for the physiological counterparts of heart rate and T_{re}. They found that while aerobically untrained subjects generally matched perceptual strain with physiological strain, aerobically trained subjects consistently underestimated their actual physiological strain during exercise in the heat. While subjects terminated exercise at similar RPEs, Cheung (5) hypothesized that this "difference between perceived and physiological strain during exercise in the heat" may explain the higher final T_{re} achieved by aerobically fit humans exercising in the heat. Schlader et al. (15) found that for subjects exercising in moderate environmental conditions (18.3^{o}C) core temperature leveled off at about 39^{o}C while RPE and heart rate continued to rise throughout exercise, further supporting an uncoupling between T_{re} and RPE. Clearly, there is no consensus in the literature regarding the effects of T_{re} on RPE in humans exercising in the heat.

Effects of Dehydration and Other Variables on Rating of Perceived Exertion

There are other contributing variables to RPE besides T_{re} and T_{sk}. Maresh et al. (11) found that time can affect perceptual responses, as RPE responses increased over time in hypohydrated individuals exercising in the heat. Interestingly, they suggested that thirst may be an underlying cue for RPE during exercise in a hot environment. They found that hypohydrated, exercising subjects reported lower overall RPE scores when they were orally rehydrated as compared to intravenously rehydrated and not rehydrated. Oral rehydration may have stimulated both oropharyngeal and gastric responses, which resulted in lower thirst responses, and led to lower RPE scores. Beyond dehydration, Maw et al. (13) showed that RPE increased over time along with T_{re} and heart rate as participants exercised at a constant workload. Specifically, they found a linear relationship between changes in RPE and heart rate during 30 minutes of constant intensity exercise in hot (40^{o}C) conditions. This increased heart rate reflected an increased need for peripheral blood flow to dissipate heat. These researchers suggested that RPE can be affected by changes in cutaneous vasomotor tone in hot conditions.

Once again, one cannot deny that other variables such as time, T_{sk}, and environmental conditions influence perceptual values. Instead, these must be acknowledged and ignored to see if T_{re} and hydration status can be predicted by perceptual measurements.

Interrelations Between the Perceptual Measurements

Another complicating aspect of perceptual measurements is that there may be correlations between the scales. Johnson et al. (10) and Maresh et al. (11) found that RPE was positively correlated with both thirst and thermal perception. Johnson et al. (10) stated that, "These correlations indicated that all measured perceptions may be integrated and may influence RPE ratings." Correlations among the perceptual scales may complicate data analysis, but this knowledge can only enhance the understanding of new findings on the correlations between $T_{re,}$ percent dehydration, and perceptual measurements.

Conclusion

In conclusion, much research has been done regarding perceptual measurements of athletes exercising in the heat. Thermal perception, thirst perception, and rating of perceived exertion have been studied by many research groups using a variety of experimental protocols. However, the information linking these perceptual measurements to rectal temperature and percent dehydration is inconclusive. It is of interest to research labs, and to athletes and coaches everywhere, to decipher if perceptual measurements can reliably predict physiological states.

INTRODUCTION

Athletes push the limits of what the human body can handle every day. When they exercise in the heat, they can attain dangerous levels of internal temperature and dehydration. Since athletes are sometimes not aware when they are experiencing severe hyperthermia or hypohydration (17), it is of interest to anyone who exercises in the heat to study whether athletes are consciously aware that they are approaching dangerous physiological limits.

This study compares the perceptual values of athletes exercising in the heat to the changes in their internal temperature and hydration status, to see if athletes can reliably predict their heat and fluid stress. The findings of this research may affect the implementation of perceptual ratings in future research. More importantly, a greater understanding of perceptual ratings will help coaches and athletic trainers to better assess their athletes' levels of hyperthermia and hypohydration. This knowledge is important for athlete safety, and it may help coaches identify athletes before they reach a dangerous level of hyperthermia and hypohydration, related to Exertional Heat Stroke and Hypovolemia.

We hypothesize that (1) the perceptual measurements of thermal sensation, thirst sensation, and rating of perceived exertion will be correlated with changes in body mass for athletes exercising in the heat. We also hypothesize that (2) athletes exercising for an extended amount of time in the heat will continue to lose body mass throughout exercise, whereas rectal temperature will plateau after an initial rise. Based on this, we hypothesize that (3) the perceptual measurements will correlate better with percent body mass loss than they do with changes in rectal temperature. This may occur because they both change in a linear fashion during the first half of an extended exercise bout, but during the second half rectal temperature reaches a plateau while perceptual values and percent body mass loss may continue to change.

METHODS

Participants

Twenty-three healthy men (age = 22 ± 3 yr, height = 179.9 ± 8.8 cm, mass = 77.3 ± 12.8 kg, body fat = 10.6 ± 4.5 %) volunteered to participate in this study. Participants were required to be between the ages of 19 to 34, and a prerequisite for their participation was being accustomed to exercise to ensure their thermoregulatory capability. Participants submitted a medical history, which was reviewed by a physician, and they were excluded from participation if participation would have been a risk to their health. Other exclusionary criteria included: a present musculoskeletal injury, disease of the salivary glands, current tobacco usage, metabolic disorder, a history of exercise heat intolerance, syncope in the presence of needles or blood, the use of medication that altered fluid or electrolyte balance, or being outside the ages of 19 to 34 years. Before participating, all volunteers provided written informed consent. This protocol was approved by the University of Connecticut Institutional Review Board.

Perceptual Scales

Participants were familiarized with three scales to rate their perceptions. To rate participants' perceived thermal sensations, the Thermal Sensation Scale (THM) was used. Participants were asked the question, "How hot or cold do you feel right now?" and they responded by pointing to a number on the scale. The scale ranges from 0.0 (Unbearably Cold) to 8.0 (Unbearably Hot) in 0.5 increments, with 4.0 (Comfortable) being the center point (**Figure 1**). To rate participants' perceived thirst, the Thirst Perception Scale (TST) was used. Participants were asked the question, "How thirsty do you feel right now?"and they responded by pointing to a number on the scale. The scale ranges from 1 (Not Thirsty At All) to 9 (Very, Very Thirsty) in increments of 1 (**Figure 2**). To assess participants' subjective effort during exercise, the Rating of Perceived Exertion (RPE) scale was used. Participants were asked the question, "How hard are you working right now?" and they responded by pointing to a number on the scale. The scale ranges from 6 (no exertion at all) to 20 (maximal exertion) in increments of 1 (**Figure 3**). Participants were instructed that the perceptual scales are distinct from each other, and that they should rate their perceptions as subjectively as possible.

Familiarization Visits

The participants visited the laboratory five times before the experimental trials, to familiarize themselves with procedures and the laboratory atmosphere, and to have their baseline measurements collected. Investigators measured mass (Health o meter, Model: 349KLX, Pelstar, Bridgeview, IL), height, and age. Investigators also measured resting heart rate via telemetry (Polar Electro Inc., FT1, Kempele, Finland) which was used to calculate Heart Rate Reserve. Based on an intensity scaled to each participant's resting heart rate, participants cycled for brief bouts (three minutes) with increasing intensity on the cycle ergometer (Cycle Ops, Club Pro 300 PT, Madison, WI) until their heart rate was between 40% to 50% of their Heart Rate Reserve. The intensity, measured in Watts, which achieved this level of physiological strain for each participant was used as his intensity for the experimental trial. The specific measurements for each familiarization visit were as follows:

Visit 1 Day 1 ....body mass, height, age, heart rate, and a brief determination of maximal power output on a stationary bike

Visit 2 Day 2 ....body mass

Visit 3 Day 2 ....body mass

Visit 4 Day 3 ....body mass

Visit 5 Day 3 ....body mass and participants were instructed regarding insertion of the rectal temperature probe

After these visits, participants were well familiarized with the laboratory and knew what was expected during the experimental trials. These familiarization visits provided adequate baseline body mass measurements to make sure participants did not have large changes in weight between visits to the laboratory. Additionally, the day before each familiarization visit, subjects recorded a detailed diet record including all food and fluids they consumed for that day. These records allowed investigators to prescribe the proper fluid volume for consumption on the day prior to the experimental trials, to help participants maintain baseline body mass and hydration state.

Experimental Trials

This protocol involved two experimental trials: an active trial involving exercise and a passive trial without exercise. The only procedural difference was that the participants rode a stationary cycle ergometer during the exercise trial and relaxed while seated during the non-exercise trial. The order of the active and passive trial was randomized and counterbalanced. The only trial expected to provide adequate levels of hyperthermia and hypohydration for statistical analyses was the exercise trial, so the passive trial data was not used for this study.

Upon arrival at the Human Performance Laboratory for an active trial, participants were given a standardized breakfast consisting of one banana, one plain bagel with one tablespoon of cream cheese or peanut butter, and five ounces of water. Participants then had approximately an hour to digest the food before the trial began. During this time, participants inserted a rectal thermistor (YSI 401 rectal probe, Yellow Spring, OH) 10-15cm beyond the external anal sphincter for rectal temperature measurement during the trial. After the hour of digestion was finished, participants sat quietly for five minutes. Immediately before entering the chamber, baseline measurement of body mass plus thermal and thirst perception were recorded.

During the trials, participants wore socks, sneakers, and standardized biking shorts. On entering the heat chamber (Minus-Eleven Inc., model 2000, Malden, MA), which was maintained at 36^{o}C and 50% relative humidity, the trial began and time 0:00 measurements were taken of body mass as well as thermal and thirst perceptions. Active Trial participants began mild exercise on a stationary cycle ergometer, which was maintained at approximately 40% of peak power output, as determined during Familiarization Visit 1. The participants went through 30-minute cycles (alternating 25 min exercise, 5 min rest) for the entirety of the 5-hour trial. Immediately prior to each five minute rest, investigators measured rectal temperature plus thermal and thirst sensation. During each five minute rest, investigators measured a participant's mass without shoes. If a time point corresponded to a 1% body mass loss, it was noted. Exercise proceeded until a 5% body mass loss or the 5-hour time point was achieved, whichever occurred first. Passive Trial participants sat quietly in a chair in the environmental chamber, and the same measurements were taken at the same time points as in the Active Trial. Subjects consumed no water during either trial, but they were offered Sport Beans (Jelly Belly Candy Company, Fairfield, CA) at the 2-hour and 4-hour time points to reduce the possibility of hypoglycemia and discomfort. Upon completion of the 5-hour trial, participants exited the heat chamber and were provided electrolyte-rich fluids and fruit to rehydrate and refuel.

Statistical Analyses

SPSS (version 20.0, IBM Corporation, Armonk, NY) was used to calculate correlations and linear regressions. Microsoft Office Excel (version 2007, Microsoft, Redmond, WA) was used to generate graphs to compare trendline shape qualitatively. Only the data from the active trial was analyzed for this paper. An alpha level of $p < 0.05$ defined significance.

RESULTS

There are three ways the relationships between physiological and perceptual measurements were explored. First, graphs of each of the variables over time were compared qualitatively to assess intuitive trends. Second, Spearman moment correlations between the variables were analyzed to reveal significant correlations. Third, a linear regression of the variables evaluated how well perceptual measurements predicted physiological responses.

Qualitative Comparison

Figure 4 is a qualitative comparison of physiological to perceptual variables. The graphs are stacked, allowing for easy comparison. The horizontal axis for each graph is the same time scale (0-6 hours), and the vertical axes provide a range specific to each variable. The graphs show the best-fit trend line. Each trend line is either second or third order; the line with the highest r^2 value was chosen because it most accurately represents the relationship between the two variables.

The trend line for changes in rectal temperature appears asymptotic, as it rises quickly at first and then levels off as the individual reaches equilibrium. The graphs for both thermal perception and RPE follow a similar same trend. Thermal perception rises less drastically at the start of the trial, and but levels off at about the same time (t = 2.5 hours). RPE rises rapidly early in the trial, and plateaus at the same time as rectal temperature. On the other hand, the trend line for percent body mass loss appears almost linear, with a nearly constant increase in mass loss throughout the entire trial. Similarly, the trend line for thirst perception rises nearly constantly through the trial and the trend line is more linear than either of the other perceptual variables. Importantly, neither percent mass loss nor thirst perception show a plateau toward the end of the 5-hour trial.

From a qualitative assessment alone, rectal temperature seems to follow a similar trend as thermal perception and RPE. Also, percent mass loss appears to change in proportion to thirst perception.

Quantitative Statistical Analyses

Spearman Correlations

Table 1 presents the Spearman moment correlations between physiological and perceptual responses. The correlation coefficients displayed in Table 1 are r-values. Spearman correlations were calculated because the variables that were compared were not continuous: they were measured at 30-minute time points. For variables that are not measured continually, a Pearson correlation does not apply. Importantly, every correlation was significant at the $p < .01$ level. Furthermore, every correlation between variables was calculated with $n > 200$.

Rectal temperature was significantly correlated with each of the perceptual measurements. The correlation was positive, which makes sense as both rectal temperature and the perceptual values rose continually during the trial. Rectal temperature was significantly correlated with RPE ($r = .345$), thermal perception ($r = .440$), and thirst perception ($r = .549$). Interestingly, the strongest correlation is with thirst perception, while the qualitative comparison shows the trend lines of rectal temperature and thirst perception are the least similar. Even so, the significant correlation between rectal temperature and RPE and thermal perception confirms the similarity in shape of the trend lines of these variables. Unfortunately, the correlation coefficients are the r-values, which need to be squared to find the r^2 values. r^2 values describe the percentage of variance in the dependent variable that is explained by the independent variable. Although all of the relationships between perceptual values and rectal temperature are significant at the $p < .01$ level, the r^2 values are small. RPE ($r^2 = .119$) and thermal perception ($r^2 = .194$)

have r^2 values well below 0.3, showing that the correlation, while significant, is weak. Similarly, the r^2 value for the correlation relating thirst perception to rectal temperature is .301. This value shows that, while the correlation is significant, it is just over the threshold to being a moderate correlation, and may not be a reliable predictor of rectal temperature.

Percent mass loss was also significantly correlated with each of the perceptual measurements. The correlations were negative, which makes sense because as body mass dropped and percent mass loss became more negative, the three perceptual measurements increased in the positive direction. Percent mass loss was significantly and inversely correlated with RPE ($r = -.489$), thermal perception ($r = -.505$), and thirst perception ($r = -.699$). The strongest correlation was with thirst perception, as was also seen in the qualitative comparison. The r^2 values for these correlations are slightly higher than those for rectal temperature. Unfortunately, RPE ($r^2 = .239$) and thermal ($r^2 = .255$) are still below the threshold of 0.3, meaning that they are weak correlations even if they are significant. However, the correlation between percent mass loss and thirst perception has an r^2 value of .489. This is in the middle of the range for a moderate correlation (0.3 – 0.6) and shows that nearly 50% of the variance in percent mass loss can be accounted for by thirst perception.

While this study is only concerned with the relationships between physiological and perceptual measurements, Table 1 shows that a significant correlation exists between the two physiological measurements (percent mass loss and rectal temperature). Furthermore, all of the perceptual measurements are significantly correlated with each other. The factors influencing the perception or value of these variables may be related as they are all experienced and processed by one organism. This influence may complicate simple analyses of their predictive values, but a more in-depth analysis is beyond the scope of this study.

Linear Regression

Linear regressions were calculated to determine specifically how well perceptual measurements predicted physiological conditions. The significance of the regressions between rectal temperature and the three perceptual measurements are: RPE, $p = .062$; thermal perception, $p = .562$; and thirst perception, $p = .109$. While none of these were significant at the $p < .05$ level, RPE approached significance most closely. The prediction equation that relates changes in rectal temperature to RPE is

$$y = 0.193x - 0.306$$

where y is change in rectal temperature, and x is RPE. Interestingly, thermal sensation was the least significant predictor of rectal temperature. While it lacks statistical significance, RPE is the best predictor of rectal temperature based on this regression.

The significance of the relationships between percent mass loss and the three perceptual measurements are: RPE, $p = .687$; thermal perception, $p = .821$, and thirst perception, $p = .000$. This regression does not show a statistically significant relationship between RPE and percent mass loss, or thermal perception and percent mass loss. However, the regression between percent mass loss and thirst perception is significant, at less than the .05 level. The prediction equation that relates percent mass loss to thirst perception is

$$y = 0.675x - 0.435$$

where y is percent mass loss, and x is thirst perception. With this equation, one can use thirst perception as x (the independent variable) to predict percent mass loss as y (the dependent variable).

DISCUSSION

The purpose of this study was to determine if perceptual responses can reliably predict physiological variables during prolonged exercise in the heat. Previous investigators (9) have shown that athletes can reach dangerous levels of hyperthermia and hypohydration during prolonged exercise in the heat, so it is of interest to athletes and coaches everywhere to find a quick and easy method to assess levels of physiological strain.

Rectal Temperature and Thermal Sensation

A qualitative comparison of the graphs of rectal temperature and thermal sensation in Figure 4 shows that both graphs have the same general shape: they increase in the beginning of the trial and level off soon after. The asymptotic shape of the rectal temperature graphs is intuitively reasonable: the athletes in this study were experiencing compensable heat stress, so after an initial period where their body temperatures rose, heat loss would be equivalent to heat gain, and their rectal temperatures would stop rising. However, thermal sensation may involve an interplay between core and skin temperature (8), so the relationship must be analyzed further. The qualitative comparison of the two graphs shows that they follow the same general trend, so thermal sensation may be a reliable predictor of rectal temperature, at least in a general sense (i.e. has core temperature increased or decreased).

The Spearman correlation showed a significant relationship between these two variables, but with $r = .440$, the correlation is weak. The low r^2 value shows that thermal sensation, at least statistically, is not a reliable predictor of rectal temperature. The linear regression provides a similar conclusion, as the relationship between the variables is far from significant ($p = .562$). Therefore, while rectal temperature and thermal sensation appear to track well when compared qualitatively, the statistics show that the relationship between them does not provide the answers sought by this study. Thermal sensation is not a reliable predictor of rectal temperature. This conclusion is reasonable, as most thermosensors are in the skin and there are very few visceral thermosensors (14), so a change in thermal sensation may reflect more of a change in skin temperature than a change in core temperature.

Rectal Temperature and Thirst Sensation

The qualitative comparison of the graphs of rectal temperature and thirst sensation in Figure 4 shows that the variables have very different trends. Rectal temperature increases initially and then plateaus as body temperature stabilizes, while thirst perception continually increases nearly linearly as body mass continually decreases. The only physiological relationship between rectal temperature and thirst sensation is purely speculative. Johnson et al. (10) hypothesized that changes in rectal temperature could "feed-forward" to alert the body of possible future fluid loss, increased thirst sensation before the individual becomes hypohydrated. This hypothesis is purely speculative, and is not supported by the results of the present study because these two variables do not track well together.

The statistical analyses yield similar results. Interestingly, of the three perceptual measurements, thirst sensation is most strongly correlated with rectal temperature. Its r^2 value of .301 puts it just over the threshold of being a moderate correlation. This significant correlation may be explained by the "feed-forward" hypothesis (above). However, the results from the linear regression show little predictive power of thirst sensation for rectal temperature. The regression was not significant on the .05 level, with $p = .109$, showing that a significant equation could not be calculated to predict changes in rectal temperature using thirst perception. Therefore, despite the moderate correlation between the two variables, the qualitative comparison and the linear regression show that thirst perception cannot be reliably used to predict changes in rectal temperature.

Rectal Temperature and Rating of Perceived Exertion

The graphs of rectal temperature and rating of perceived exertion have the same general asymptotic shape. They increase rapidly during the first half of the trial, then level off around t = 2.5 hours. Importantly, this leveling-off does not occur because the variables reach their maximum rating. Rectal temperature rises to an average of about 38.5^{o}C, well below the theoretical maximum or even the temperature of volitional exhaustion (9). Rating of perceived exertion levels off at about 16, while the maximum rating is 20. Therefore, this leveling off is not because of a limitation in the rating scales. Both of these variables level off at the same time point, so the mechanisms surrounding changes in them may be related. Based on the qualitative comparison, rating of perceived exertion may be a good predictor of changes in rectal temperature.

The statistical comparison of these two variables yields concordant results. Rectal temperature was significantly correlated with RPE and, while the correlation was weak, it was significant ($p < .01$). Interestingly, the linear regression between the two variables yields an equation with a significance of $p = .062$. While this is not significant at the $p < .05$ level, RPE was the best predictor of rectal temperature of the three perceptual variables. This suggests that an athlete exercising in the heat can sense changes in his rectal temperature by how hard his effort feels. The higher one's rectal temperature, the harder one perceives exertion.

Percent Mass Loss and Thermal Sensation

The trendline of the percent mass loss graph is linear, showing that participants continually lost constant amounts of mass throughout the entire trial. The shape of this graph is very different from the asymptotic shape of thermal sensation, where the values increased sharply in the beginning of the trial, but reached a plateau by 2.5 hours. Based on the qualitative comparison, thermal sensation was not expected to be a predictor of percent mass loss. The statistical analyses agree with this assumption. The Spearman correlation coefficient shows that, while the relationship between the two variables is significant, the correlation is weak ($r^2 = .255$). Furthermore, the linear regression using thermal sensation to predict percent mass loss was not significant ($p = .821$). Based on these calculations and the qualitative comparison of the two variables' graphs, thermal perception was not a good predictor of level of hypohydration.

Percent Mass Loss and Thirst Sensation

Upon qualitative comparison of their trendlines, thirst sensation and percent mass loss look very similar. They both have nearly linear trendlines, that continually increase by a constant amount. This constant mass loss is fitting, as the experimental design had participants exercise at a constant intensity for a long period of time. A constant exercise intensity in a constant environment should lead to consistent fluid loss, at least up until physiological extremes are reached. If humans can perceive thirst by somehow judging percent body mass loss in term of fluid loss, then it follows that thirst perception can predict percent mass loss. Thus, based on the qualitative comparison of the graphs alone, thirst sensation could be a predictor of percent mass loss.

The Spearman correlation also shows that thirst perception may reliably predict percent mass loss. The coefficient was the highest of any of the perceptual-physiological correlations ($r = -.699$). Furthermore, the r^2 value of .489 demonstrates that this inverse correlation is a moderate correlation, and that thirst perception can account for nearly 50% of the change in percent mass loss. Furthermore, the linear regression calculated an equation significant at p <

.001 level. Based on these results, thirst sensation was a reliable predictor of percent body mass loss.

Percent Mass Loss and Rating of Perceived Exertion

The qualitative comparison of the graphs of percent mass loss and RPE shows that they have different shapes. RPE has an asymptotic shape, while percent mass loss is linear. Thus, based on this comparison alone, RPE may not be a good predictor of percent mass loss. Similarly, while the correlation between the two variables is significant, $r^2 = .239$, showing that the correlation is weak. Thus, changes in RPE can only account for a small amount of the changes in percent mass loss, and RPE may not be a good predictor for percent mass loss. Finally, the linear regression does not even approach significance ($p = .687$). Based on these results, RPE was not a reliable predictor of percent body mass loss.

Initial Hypotheses Revisited

In the introduction, three hypotheses were put forth that can now be evaluated based on the present data. First, it was hypothesized that the three perceptual measurements would be correlated with changes in body mass for athletes exercising in the heat. Based on the statistical analyses, all three perceptual measurements *are* significantly correlated with percent body mass loss. However, based on the regression analysis and the qualitative comparison of the changes in the variables over time, the best, most statistically significant predictor of percent body mass loss is thirst perception. Second, it was hypothesized that, as the participants exercise in the heat for the extended trial time, they would continue to lose body mass, while rectal temperature would plateau after an initial rise. Based on the trendlines of the graphs in Figure 4, this hypothesis is confirmed. Subjects continued to lose body mass in the form of sweat throughout the entire trial almost linearly, and rectal temperature rose initially before reaching a plateau. Third, it was hypothesized that the perceptual measurements would correlate better with percent body mass loss than with changes in rectal temperature because of the plateau of rectal temperature. Interestingly, this hypothesis is also confirmed. While we found statistically significant results correlating rating of perceived exertion with changes in rectal temperature, and thirst perception with percent body mass loss, the correlation coefficients and regression equations were better for relating the perceptual measurements with percent body mass loss.

CONCLUSIONS

The purpose of this study was to find a noninvasive way for athletes and coaches to assess levels of physiological stress during prolonged bouts of exercise in the heat. The results show there are significant interactions between perceptual measurements and levels of physiological stress. This study yielded two main results. (1) We found that rating of perceived exertion is a reliable predictor of changes in rectal temperature during prolonged exercise in the heat. Perhaps counterintuitively, individuals exercising in the heat can sense their changes in rectal temperature not by how hot they feel, but by how hard they think they are working. In order to assess one's level of hyperthermia, one can ask, "How hard are you working right now?" and use the regression equation from this study to dependably predict one's increase in rectal temperature. (2) We found that thirst sensation is a reliable predictor of percent body mass loss during prolonged exercise in the heat. This result is intuitive, as one normally associates sweating with thirst. One can ask, "How thirsty do you feel right now?" to assess one's level of hypohydration. One can take this value and use the regression equation calculated by this study to predict one's percent body mass loss. With this information in hand, athletes and coaches can better attend to changes in body temperature and hydration status before they reach dangerous levels.

The main limitation of these results is their specificity: the predictive value of these perceptual ratings has only been confirmed under experimental conditions. These results are specific for men who fit the criteria of this study (exercise accustomed, age 19 to 34 years, etc.) and who are exercising at a constant, moderate intensity for an extended period of time under constant environmental conditions (approximately 36^{o}C and 50% relative humidity). Outside of this very specific population, the predictive value of our results is unknown. Future research may involve repeating these experiments under broader experimental conditions. It would be interesting to experiment with subjects of varying genders, ages, body fat contents, and levels of physical conditioning while they perform different intensities of physical activity under numerous environmental conditions.

THERMAL SENSATION SCALE

0.0	**Unbearably Cold**
0.5	
1.0	**Very Cold**
1.5	
2.0	**Cold**
2.5	
3.0	**Cool**
3.5	
4.0	**Comfortable**
4.5	
5.0	**Warm**
5.5	
6.0	**Hot**
6.5	
7.0	**Very hot**
7.5	
8.0	**Unbearably Hot**

Figure 1. **The Thermal Sensation Scale** was used by subjects to subjectively rate their thermal sensation. Subjects indicated their response to the question, “How hot or cold do you feel right now?” by pointing to a number on the scale.

THIRST SCALE

1 NOT THIRSTY AT ALL

2

3 A LITTLE THIRSTY

4

5 MODERATELY THIRSTY

6

7 VERY THIRSTY

8

9 VERY, VERY THIRSTY

Figure 2. **The Thirst Sensation Scale** was used by subjects to subjectively rate their thirst sensation. Subjects indicated their response to the question, “How thirsty do you feel right now?” by pointing to a number on the scale.

RATING OF PERCEIVED EXERTION SCALE

6	
7	VERY, VERY LIGHT
8	
9	VERY LIGHT
10	
11	FAIRLY LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD
16	
17	VERY HARD
18	
19	VERY, VERY HARD
20	

Figure 3. **The Rating of Perceived Exertion Scale** was used by subjects to subjectively rate their level of exertion. Subjects indicated their response to the question, "How hard are you working right now?" by pointing to a number on the scale.

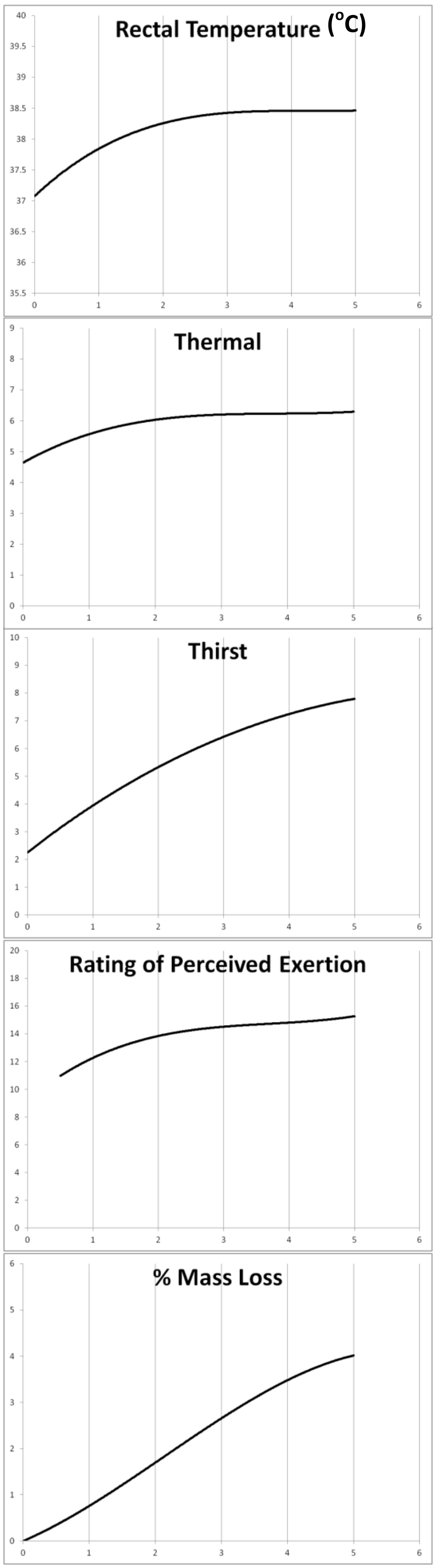

Figure 4. **Qualitative Comparison of Physiological and Perceptual Measurements.** Measurements were taken every 30 minutes during 5 hours of exercise in the heat. The graphs show the best-fit trend line for the outcome values plotted over time. These trend lines can be compared qualitatively to asses if two changing variables track each other well over time. The horizontal axes for all graphs is time, divided in one hour increments. The vertical axes for the three perceptual ratings are specific to their scales. The vertical axis for rectal temperature is marked in degrees Celsius, and that of percent mass loss is marked in percentage point losses of total body mass. Note: the trend line for RPE begins at 30 minutes because this perceptual measurement was not assessed at rest (time point 0).

	Mass %	Trec	RPE	THM	TST
Mass %	--				
Trec	-0.688	--			
RPE	-0.489	0.345	--		
THM	-0.505	0.440	0.656	--	
TST	-0.699	0.549	0.690	0.696	--

Table 1. **Spearman Moment Correlation Matrix of Physiological and Perceptual Responses During Exercise in the Heat**. This correlation matrix displays r-values generated by SPSS statistical analysis software. All correlations were significant at the $p < 0.01$ level (2-tailed). Every correlation was calculated with an $n > 200$. Abbreviations: Mass %, percent body mass loss; Trec, rectal temperature; RPE, rating of perceived exertion; THM, thermal sensation; TST, thirst sensation.

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