Effects of Active Hyperthermia on Cognitive Performance

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Objective: Active hyperthermia elicited by a heat stress trial (HST) was hypothesized to negatively impact higher-order cognitive ability. **Design and Setting:** A test-retest design with one within-subjects variable was utilized for this investigation. The independent variable was thermal condition (normothermic and hyperthermic) and the dependent variables were four factors of cognitive performance (working memory, attention, response speed, and processing speed) with associated subtests. Participants completed practice tests and returned at least 24 hr later to perform the tests before and after the HST. **Subjects:** Eight healthy adult males (age= 24.9$\pm$3.2 yr; height= 123.0$\pm$46.8 cm; body mass= 89.9$\pm$10.5 kg) volunteered. **Measurements:** We assessed cognitive performance via the Headminder™ Cognitive Stability Index administered using a laptop computer online via a wireless secure internet browser in the normothermic and hyperthermic conditions. Core body temperature was measured via ingestion of a CorTemp™ Ingestible Core Body Temperature Sensor (HT150002, HQ Inc., Palmetto, FL). **Results:** The memory factor revealed a significant (t_7= 4.675, *p*=.002) 12.22% decrease in number correct for the hyperthermic (mean correct= 7.155$\pm$1.478) compared to the normothermic (mean correct= 8.151$\pm$.1.60) condition. Memory subtest 1 revealed significant ($F_{2,14}$= 9.196, *p*=.003) decreases in performance over time. The memory subtest 2 also revealed significant ($F_{2,14}$= 4.920, *p*=.024) decreases over time. No other significant differences were found. **Conclusion:** Our findings suggest that hyperthermia decreases working memory. Response speed, processing speed and attention are less vulnerable to the effects of elevated T_b. Therefore, athletic trainers should be aware of the detrimental effects of hyperthermia on working memory as they relate to injury prevention and evaluation. **Key Words:** heat stress, memory, processing speed

Hyperthermia refers to an elevated body core temperature (T_b) and is commonly categorized as mild (T_b = 37.7 - 39.4 °C) to severe (T_b usually greater than 40 °C).[1] Some degree of hyperthermia accompanies exertional heat illnesses such as heat cramps, heat exhaustion, and heat stroke. A recent review of the literature revealed that signs of exertional heat illness included confusion, altered state of consciousness, decreased mental acuity, and an overall decrease in central nervous system function.[2]

Between 1960 and 2003, heat stroke, resulting in severe hyperthermia, has been the cause of 101 deaths in young American football players with 21 occurring in the last eight years. Since 1974 a dramatic reduction in heat stroke deaths has been observed with the exception of 1978, 1995, 1998, when there were four each year, and 2000 when there were five.[3] In the southeastern United States, athletic events occur in hot, humid environments throughout the spring and summer months into the early fall. The average South Florida temperature between May and August is 82.8 °F with a mean morning relative humidity of 85%.[4] In addition to environmental factors, football uniforms contribute significantly to the heat load on a player. T_b in football players during an actual football practice fluctuates with activity and with level of equipment worn. T_b increases during the periods of intense exertion with full equipment, and

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decreases during rest periods.[5] These conditions are considered unsafe for football activities by the Inter-Association Task Force on Exertional Heat Illness Consensus Statement. The recommendations include a work/rest ratio of 15-20 min of work to 5-10 min for water/rest break and practices should be in shorts only.[6]

Excessive heat retention causes changes in brain function and metabolism.[7-9] The underlying link between the thermal information processing system (located in the hypothalamus) of the central nervous system, hyperthermia, and brain dysfunction is not clearly understood; however; it appears that the extent of nervous tissue injury depends on the duration and intensity of heat exposure. Increased permeability of the blood-brain barrier allows brain edema formation. This breakdown of the blood-brain barrier is similar in nature to what occurs to the central nervous system following trauma indicating that signs and symptoms of hyperthermia can mimic a concussion.[1]

Furthermore, the literature is lacking research in regards to how active hyperthermia influences cognition in physically active males. Since American football practices occur in hot, humid environments it is important that athletic trainers understand and recognize subtle changes in mental performance that accompany hyperthermia in order to make more educated decisions regarding player safety and sport performance. To our knowledge our study was the first to use this tool to identify the effects of active hyperthermia on cognition in a hot, humid environment. Therefore, the purpose of this study was to examine the effects of active hyperthermia on cognitive performance, using the Headminder™ Cognitive Stability Index (CSI), in physically active males.

Methods

Experimental Design

A test-retest design with one within-subjects variable was utilized for this investigation. The independent variable was thermal condition (normothermic and hyperthermic) and the dependent variables were four factors of cognitive performance with associated subtests. Participants completed practice tests and returned at least 24 hr later to perform the tests before and after the heat stress trial (HST). We expected to find reduced cognitive performance, specifically higher-order cognitive ability, based upon previous research in heat stroke patients,[1] workplace employees,[10] and in experimentally induced dehydration.[11,12]

Subjects

Participants were eight healthy, physically active volunteers (age = 24.9 ±3.2 yr; height = 123.0±46.8 cm; body mass = 89.9 ±10.5 kg) recruited from Florida International University and the surrounding community. Participants signed the approved informed consent form, were informed of potential risks, and informed that their participation was voluntary. The study was approved by the Institutional Review Board.

Instruments

Cognitive performance. The Headminder™ Cognitive Stability Index (CSI) test is an internet-based test designed to monitor cognitive status in healthy, at-risk, and afflicted populations. The Headminder™ CSI subtests measured reaction time, processing speed, memory, and attention/executive functioning, and reported strong concurrent validation with standard paper-and-pencil neuropsychological tests. Test-retest reliability was adequate for the four factors between the first and second administrations (response speed; r=.80, processing speed, r =.78; memory, r =.68; attention, r =.73).[13] Spatial and working memory were measured via subtests: Memory Cabinet 1 and 2.[13]

Thermoregulatory measures. Core body temperature was measured via ingestion of a

CorTemp™ Ingestible Core Body Temperature Sensor (HT150002, HQ Inc., Palmetto, FL) which was tracked prior to, during, and following the HST with the CorTemp™ Miniaturized Ambulatory Data Recorder (HT150016, HQ Inc., Palmetto, FL).

Cardiovascular measures. Heart rate was measured using a Polar® heart rate monitor (Polar Electro Inc., Woodbury, NY). Blood pressure was assessed using a stethoscope and sphygmomanometer (American Diagnostics, West Babylon, NY) and mean arterial pressure was calculated. Resting heart rate and blood pressure was recorded after resting prone on a table for 5 min, and exercise measures was recorded at 0 min, and at 15 min intervals throughout the practice. Rating of perceived exertion (RPE) was also measured throughout the practice. The use of the Borg scale[14] was implemented to measure RPE which is reproducible (no bias between trials)[15] in a three trial series and a reliable (r=0.78)[15,16] measure of exertion.

Hydration measures. Body mass was measured using a digital medical platform scale (model BWB-800S, Tanita Inc., Brooklyn, NY). A urine color chart (Human Kinetics, Champaign, IL) was used to determine urine concentration with closest color on the chart or half point color recorded. Urine specific gravity was measured using a clinical refractometer (Model 300CL Atago Inc., Japan).

Procedures

Familiarization session. During a familiarization session (6-8 days prior to data collection), potential participants read and signed the health/injury history and physical fitness readiness questionnaires and the informed consent form. During the familiarization session data were collected as baseline measures and CSI was performed three times to reduce a learning effect.

Research trial period. On the day of data collection, each participant was asked to completely void urine and body mass data were recorded. A euhydration body mass was confirmed as less than $\pm$1% of baseline body mass. Participants then performed the pre-test/normothermic CSI. Each HST commenced with a 15-min jog warm up at 60% of the participant's heart rate range on a level, mowed grass surface. For the lower extremity HST, each participant exercised at 75-80% of their heart rate range across a minimum of 10 sets of 10 repetitions of 30 yard sprints (approximately 15-sec in duration) with a 10-sec rest period between sprints and a 2-min rest between sets. The exercise task was performed on a level grass field with two cones placed 9.1 m (10 yards) apart.

The HST was performed in a subtropical hot, humid environment (mean ambient temperature= 34.3$\pm$2.2 °C; mean relative humidity = 50.8 $\pm$9.9 %; mean wind speed = 1.9 $\pm$1.2 mph) with each participant wearing a full American football uniform. Core body temperature (T_b) was assessed prior to, during, and following the HST. After reaching the target T_b = 39.0 °C each participant performed the post-test/hyperthermic CSI. Participants removed the helmet and shoulder pads and rested in an air conditioned environment until T_b returned to baseline levels at which time the post-test/normothermic CSI was performed.

Statistical Analysis

Statistical analyses were conducted on the participants' cognitive performance factor scores and subtest raw scores. Dependent t-tests were used to identify differences between the normothermic and hyperthermic conditions on factor scores of processing speed, response speed, memory, and attention and each associated subtest. A *post hoc* one-way ANOVA with repeated measures on the time factor (normothermic, hyperthermic, post-test normothermic) with a Bonferroni correction was performed for the factor scores found to be significant. Data were analyzed using the SPSS 13.0 for Windows Statistical Package (SPSS Inc., Chicago, IL). For all statistical analyses, an α-level of $p < 0.05$ was used.

Results

Participants were significantly ($t_7 = 9.032$, $p \leq .001$) hyperthermic (mean $T_b = 38.8 \pm .4$ °C) following the HST compared to the normothermic (mean $T_b = 37.2 \pm .1$ °C) condition. The memory factor revealed a significant ($t_7 = 4.675$, $p = .002$) 12.22% decrease in number correct for the hyperthermic (mean correct = 7.155±1.478) compared to the normothermic (mean correct = 8.151±.1.60) condition. The memory cabinet 1 subtest revealed significant ($F_{2,14} = 9.196$, $p=.003$) decreases in performance over time. Compared to the normothermic condition (mean correct= 8.1250 ±1.458), in the memory cabinet 1 subtest participants demonstrated a 27.69% decrease in the hyperthermic (mean correct = 5.875 ±2.232) condition and a 21.54% decrease in the post-test normothermic (mean = 6.375 ±1.847) condition. The memory cabinet 2 subtest also revealed significant ($F_{2,14} = 4.920$, $p = .024$) decreases over time. With the memory cabinet 2 subtest, participants demonstrated a 22.39% decrease in the post-test normothermic (mean correct = 6.500 ±.824) condition when compared to the normothermic (mean = 8.375 ±.625) condition.

Discussion

The HST and environmental conditions were successful in eliciting elevated T_b in the exercising participants. The hyperthermia achieved by anaerobic exercise in a hot, humid environment had negative effects on cognitive performance. Of the four factors comprising cognitive performance (response speed, attention, memory, processing speed), we found working memory to be most vulnerable to elevated T_b. Spatial memory was also impaired in the hyperthermic condition. Our results pertaining to memory deficits, specifically spatial memory supported our hypotheses. These findings coincide with a current trend in the literature[11,13,17] that the more simple functions such as response speed and reaction time are less affected while the more complex functions such as processing speed and memory are more vulnerable to the adverse effects of hyperthermia.

Substantial research[1,7-12,17,18] has been performed in the field of heat stress and its effects on cognitive performance. Unfortunately, the body of research has not been detailed in a systematic manner because of the thermal, experimental, and participant variables. The variables include task type, duration of heat exposure, skill, and acclimatization level. One study[11] that employed the Headminder™ CSI with actively dehydrated physically active males found inconclusive evidence in comparison to other studies[10,12,17,18] that found decrements in cognitive performance. Functional brain image recordings have demonstrated an increase in amplitude and a decrease in latency, suggesting an increase in the utilization of neural resources or effort by subjects to maintain the same level of performance as under thermally neutral conditions.[18] It may be this increased neuronal utilization that lead to decreased cognitive performance in our participants.

Our participants informally reported sensations of fatigue upon reaching the required 39.5 °C core body temperature. Theoretically, the level of hyperthermia elicited in our participants may have been accompanied by some perception of central fatigue; however, we were unaware of a good method to clinically measure this CNS phenomenon. We did not monitor blood content changes in the present study. Plasma concentrations of the hormones cortisol and adrenaline are better indicators of cognitive activity than the plasma concentrations of the neurotransmitters noradrenaline and serotonin, although changes in plasma concentrations of noradrenaline did predict changes in perceptions of fatigue post-recovery.[19] Changes in cortisol concentration have bee demonstrated to be a significant indicator of cognition in the posttreatment condition and is indicative of high levels of anxiety so would appear that, in these conditions, cognition is predicted by central perceptions of the stress rather than the activity of adrenaline and noradrenaline in their roles as regulators of heat stress peripherally.[19]

Clinical Implications

Based on how our findings relate to current literature and cognitive performance theory, we can draw several clinical conclusions. First, athletic trainers and coaches should understand that a hyperthermic athlete may not be able to function mentally as efficiently as a normothermic athlete. Impairments in memory may result in sacrificed safety and performance in the later stages of a competition. For example, a hyperthermic quarterback may not be able to remember plays as they are sent on to the field or may not be able to read and adjust to the opposition. This type of mental breakdown could lead to a sacrificed personal safety. Secondly, hyperthermia may affect administration of concussion testing in that it could confound the effects of a concussion, primarily amnesia. It is necessary for the athletic trainer or other allied health professional to measure and address the athlete's thermal condition at the time of testing. Athletic trainers may need to record T_b as part of concussion testing protocol in order to accurately determine the cause of symptoms. Therefore, we should be aware of the detrimental effects of elevated T_b on cognitive performance as they relate to sport performance, athlete safety, and concussion testing.

References

1. Sharma HS, Hoopes PJ. Hyperthermia induced pathophysiology of the central nervous system. *Int J Hyperthermia.* 2003;19:325-354.
2. Binkley HM, Beckett J, Casa DJ, Kleiner DM, Plummer PE. National Athletic Trainers' Association Position Statement: Exertional Heat Illnesses. *J Athl Train.* 2002;37:329-343.
3. Cantu RC, Meuller FO. Annual survey of catastrophic football injuries 1977 – 2003. *National Center for Catastrophic Sport Injury Research.* Accessed on July 7, 2004 from http://www.unc.edu/depts/nccsi/SurveyofFootballInjuries.htm.
4. Average temperature and humidity of South Florida in August. Available at http://www.cityrating.com/cityweather.asp?city=Miami. Accessed on April 28, 2005.
5. Godek SF, Godek JJ, Bartolozzi AR. Thermal responses in football and cross-country athletes during their respective practices in a hot environment. *J Athl Train.* 2004;39(3):235.
6. Casa DJ, Almiquist J, Anderson S, Cleary, M. A. et al. (2003). Inter-Association Task Force on Exertional Heat Illness consensus statement. *NATA News. 6*:24-29.
7. Sharma HS, Westman J. Brain functions in a hot environment. *Prog Brain Res.* 1998;115:1-527.
8. Sharma HS. Pathophysiology of blood-brain barrier, brain edema and cell injury following hyperthermia: New role of heat shock protein, nitric oxide and carbon monoxide. An experimental study in the rat using light and electron microscopy. *Acta Universitatis Upsaliensis.* 1999;830:1-94.
9. Sharma HS, Westman J. Pathophysiology of hyperthermic brain injury. Current concepts, molecular mechanisms and pharmacological strategies. *Res Leg Med Hyperthermia, Burning and Carbon Monoxide.* 2000;21:79-120.
10. Hancock PA, Vasmatzidis I. Effects of heat stress on cognitive performance: The current state of knowledge. *Int J Hyperthermia.* 2003;19:355-372.
11. Zuri RE, Cleary MA, Lopez RM, Jones LC. Effects of active dehydration on cognitive performance. *J Athl Train.* 2004;39:S-57.

12. Gopinathan PM, Pichan G, Sharma VM. Role of Dehydration in Heat Stress-Induced Variations in Mental Performance. *Arch Environ Health.* 1988;43:15-17.
13. Headminder Inc. (2002). Headminder™ CSI professional manual. Available at www.Headminder.com. Accessed November 7, 2003.
14. Borg G. *Borg's perceived exertion and pain scales.* Stockholm: Human Kinetics. 1998.
15. Doherty M. Rating perceived exertion during high-intensity treadmill running. *Med Sci Sports Exerc.* 2001;33(11):1953-1958.
16. Pfieffer KA. Reliability and validity of the Borg and OMNI rating of perceived exertion scales in adolescent girls. *Med Sci Sports Exerc.* 2002;34(12):2057-2061.
17. Sharma VM, Sridharan K, Pichan G, Panwar MR. Influence of heat-stress induced dehydration on mental functions. *Ergonomics.* 1986;29:791-799.
18. Hocking C, Silberstein RB, Lau WM, Stough C, Roberts W. Evaluation of cognitive performance in the heat by functional brain imaging and psychometric testing. *Comp Biochem Physiol.* 2001;128:719-734.
19. McMorris T, Swain J, Smith M, Corbett J, Delves S, Sale C, Harris RC, Potter J. Heat stress, plasma concentrations of adrenaline, noradrenaline, 5-hydroxytryptamine and cortisol, mood state and cognitive performance. *Int J Psychophysiol.* 2005 Nov 22; [Epub ahead of print].