The Effect of *Ad Libitum* Hydration on Cognitive Function Following Exercise in the Heat

Wittbrodt

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THE EFFECT OF AD LIBITUM HYDRATION ON COGNITIVE FUNCTION FOLLOWING EXERCISE IN THE HEAT

by

Matthew Wittbrodt

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Science
Department of Human Performance and Health Education
Advisor: Christopher C. Cheatham, Ph.D.

Western Michigan University
Kalamazoo, Michigan
August 2012
WE HEREBY APPROVE THE THESIS SUBMITTED BY

Matthew Wittbrodt

ENTITLED The effect of ad libitum hydration on cognitive function following exercise in the heat

AS PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF Master of Science

Human Performance and Health Education

(Department)

Exercise and Sports Medicine

(Program)

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Dean of The Graduate College

Date August 2012
THE EFFECT OF *AD LIBITUM* HYDRATION ON COGNITIVE FUNCTION FOLLOWING EXERCISE IN THE HEAT

Matt Wittbrodt, M.S.
Western Michigan University, 2012

The purpose of this study was to quantify the effect of different hydration strategies on physiological and cognitive variables after an exercise bout in the heat. On three occasions, twelve males performed three heat stress tests of 50min at 60%VO₂peak in a hot environment (32°C; 65%RH). The heat stress tests differed in hydration strategy to be implemented during exercise (NF: no fluid, AL: *ad libitum*, FR: full fluid replacement). A cognitive battery was administered pre- and post-exercise to examine alterations in cognition. Fluid loss during NF was greater than the AL and FR (NF: 1.54 %; AL: 0.29 %; FR: 0.13 %). The NF condition experienced greater increases in core temperature, mean skin temperature, heart rate, rating of perceived exertion, and thermal sensation ~35-50min into exercise compared to AL and FR. The AL condition experienced decreases in mean response time for the letter-digit recognition test and pattern comparison (PC) tasks. The NF condition experienced decreases in mean and median response time for the PC task while FR only experienced a decrease in median response time. In conclusion, the AL strategy is optimal in minimizing thermoregulatory stress and producing cognitive benefits following a bout of moderate intensity exercise.
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2012
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First and foremost, I need to thank my family. Without the undying support of my parents and brother, I would not be in this position. I love and wish the absolute best for them, and I will do my utmost best to repay their support in the future.

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To all the subjects who participated in this study, I thank you. Your time and effort made this thesis possible.

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Matthew Wittbrodt
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Cognitive decrements are a consequence of a moderately dehydrated state (~2% body mass) in response to increased thermoregulatory demands, either through heat exposure or exercise (Adam et al., 2008). Various cognitive functions exhibit impairment with dehydration: perception of fatigue, perceived discrimination, visual-motor tracking, short-term memory, long-term memory, attention, arithmetic efficiency, and choice reaction time (Grandjean & Grandjean, 2007). Gopinathan, Pichan, and Sharma (1988) are widely credited as the first to identify the relationship between dehydration and cognitive performance (mental performance). As Gopinathan et al. (1988) state, “The impairment recorded in mental performance is proportional to the degree of dehydration and is highly significant (p<0.001) at 2% dehydration for all the functions.”

Each measured cognitive function is a delineation of the working memory (Lieberman, 2007). Tests which experience plasticity with respect to hydration status therefore assist in elucidating the aspects of working memory which are altered with decrements in hydration status. The vast array of cognitive tests and batteries has led to minimal agreement amongst researchers, which is problematic when assessing human cognitive function (Lieberman, 2007). Table 1 lists commonly used cognitive assessments and the observed effect of dehydration.
<table>
<thead>
<tr>
<th>Cognitive Assessment</th>
<th>Citation</th>
<th>Aspect of Memory</th>
<th>Degree of Dehydration</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Match to Sample Task</td>
<td>Ganio et al., (2011)</td>
<td>Working Memory, Pattern Recognition</td>
<td>≥1% BM</td>
<td>↑ Resting response time</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psychomotor Vigilance Task</td>
<td>Ganio et al., (2011)</td>
<td>Sustained Attention</td>
<td>≥1% BM</td>
<td>↓ Premature Errors</td>
</tr>
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<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Letter-Digit Substitution</td>
<td>Sharma et al., (1986)</td>
<td>Perceptual Speed, Associative learning ability</td>
<td>3% BM</td>
<td>↓ Correct Attempts</td>
</tr>
</tbody>
</table>

Table 1: Previous research regarding specific cognitive assessments, delineation of the working memory, and consequences of dehydration
The human thermoregulatory systems are normally sufficient in a resting state and can dissipate heat effectively. In such contexts, thermoregulation is necessary to sustain the homeostatic environment which governs normal physiological functioning. However, with exercise, heat production resulting from metabolic inefficiencies creates a dynamic internal environment and subsequent thermoregulatory challenge. The body relies on sweating as the principle cooling mechanism. Being so, exercise-induced dehydration is a natural consequence of exercising in thermally challenging environments. The magnitude of sweating response, and therefore degree of dehydration, varies greatly with exercise type, exercise intensity, body mass, and ambient conditions (ACSM, 2007). The extent of exercise-induced dehydration is defined as the difference between body mass pre- and post-exercise.

Contained within the paradigm of hydration-influenced thermoregulatory stress is the *ad libitum* (AL) hydration strategy. An AL hydration strategy relies upon the thirst mechanism to trigger the consumption of fluids. The thirst mechanism will be intensified with increasing ambient temperatures and being in a hypohydrated state (Sunderland & Neville, 2004; Maresh et al., 2004). In a warm environment (33 °C; 50%), Douglas et al., (2009) found no significant differences in AL fluid intake when compared against an intake aimed at counteracting sweat losses. Multiple studies have identified that, in experienced athletes, ~30% of sweat loss is replaced voluntarily through an AL hydration strategy (Passe et al., 2007). Both Douglas et al., (2009) and Passe et al., (2007) measured AL intake in a time trial setting. This
setting, with outcome performance measures, promotes pacing strategies which may impact AL hydration. In a model with set intensity and duration, Rivera-Brown et al., (1999) found a much greater percentage of sweat volume replacement. Passe et al. (2007) observed that experienced runners underestimate and cannot accurately predict sweat rate, which severely impedes the ability to fully replace sweat loss. However, the idea that it is necessary to fully replace sweat loss is a highly debated topic.

Hydration and Cognitive Function

The relationship between different hydration strategies and cognition has not been heavily investigated. The present body of research identifies 2% body mass loss as a critical junction where cognitive decrements are initially experienced (Gopinathan et al., 1988). The measured 2% body mass loss is largely identified as total body water loss. It is unclear whether shifts in fluid compartments may be an underlying factor responsible for cognitive decrements. Using 2% body mass as a reference value can be problematic given the different mechanisms available to promote body mass loss. Liberman et al. (2007) identifies the most commonly used methods are an exercise and non-exercise induced dehydration protocol in either hot or neutral ambient temperatures.

This review will focus on exercise-induced dehydration methodology and the subsequent effects on cognition. Morely et al. (2012) found no alterations of cognitive function from pre vs. post assessments during a walking protocol in a
heated room. Ganio et al. (2011) found mild cognitive decrements at ≥1% body mass compared to a euhydrated group following a light exercise protocol (walking). Sharma et al. (1986) found cognitive decrements starting at 3% body mass with a light exercise protocol, albeit in a warm environment (hot-hum, hot-dry). Under a greater exercise stimulus of 60% maximal oxygen uptake (VO$_{2\text{peak}}$), Grego et al. (2005) found an initial decrease in cognition during exercise, but some cognitive enhancements from 80-120 min. However, as exercise progressed beyond 120 min, the gains in cognition were mitigated and subjects were more error-prone.

Interestingly, 2% of body mass loss is also commonly referenced as a ‘tipping point’ in environmental physiology; a fine line where performance and thermoregulation become compromised. Therefore, it can be logically postulated that, in a thermally challenging environment, 2% body mass loss may influence the decrements in cognition as a result of insufficient thermoregulation. Exercise induced dehydration of ~2% body mass is a common occurrence in sporting contexts, indicating possible implications for decreased post-exercise cognition (Byrne et al., 2006; Yeargin et al., 2006).

In their review, Maughan, Shirreffs, and Watson (2007) provide a plausible physiological context for intervening cognitive deficits with dehydration. Dehydration is representative of body water loss, a large percentage of which is drawn from blood plasma, resulting in more viscous blood. Increasing blood viscosity compromises thermoregulation, and therefore increases core temperature ($T_c$). Maughan, Shirreffs, and Watson (2007) reference the central governor model
of Noakes as a plausible rational to describe alterations in cognition. This model revolves around the desire for the central anatomy (brain, spinal cord) to maintain homeostasis via a feed-forward mechanism, which is challenged by increases in thermoregulatory stress (Noakes, 2005). The central response to thermal challenge is to reduce central nervous system activity, which leads to decreased cognition (Maughan, et al, 2007). The redistribution of resources outward enhances peripheral heat dissipation mechanisms, which are engineered to prevent a life-threatening heat-related illness.

Noakes’ theory revolves around a central governor which provides neural feedback to the body during exercise (Noakes, 2011). The central governor is modified by a plethora of treatments which simultaneously have been shown to alter cognitive function. Performance modifiers include both ingested substances such as naloxone (drug to counter opiate overdose; Sgherza et al., 2002; de Camp et al., 1992), caffeine (Astorino et al., 2012; Lieberman et al., 2002), amphetamines (Swart et al., 2009b; Wyndham et al., 1971; Silber et al., 2006) and physiological alterations such as sleep deprivation (Martin, 1981; Ståle et al, 2011) and mental fatigue (Marcora et al., 2009; Boksem et al., 2006; Cook et al., 2007). Providing a correlative effect between the effects of each performance modifier on exercise and cognition is not possible. However, for each of the listed performance modifiers, exercise and cognition are either enhanced or encumbered similarly.

The relationships of performance modifier, exercise, and cognition provide some evidence that interplay between the central nervous system and exercise
exists. Further, the positive relationship lends validity to the premise that any substance which affects exercise or cognition will similarly affect the alternative. Swart et al. (2009a) argues that exercise is maintained and governed by a central governor via a feed-forward mechanism. In a subsequent study, Swart et al. (2009b) found evidence that amphetamines had no impact on the initial feed-forward mechanism before an exercise stimulus. However, amphetamines allowed a more attenuated fall in cycling power outputs. Swart et al. (2009b) postulates that amphetamines modify the central governor’s interpretation of the afferent feedback signals.

Application and Purpose

Performance and occupational environments consistently involve cognitive stressors which can determine sporting outcomes or occupational safety. Ad libitum fluid intake governs a majority of hydration schedules across exercisers, and therefore presents the main strategy implemented to combat body water loss. Previously, ad libitum intake has shown to be deficient in adequately replacing fluids lost through sweating, potentially inducing cognitive decrements post-exercise (Cheuvront & Haymes, 2001; Tam, Nolte, & Noakes, 2010). Further, the magnitude of deficit is seemingly dependent on environmental heat stress and event duration (Tam et al., 2010). In concordance with declines in cognitive performance associated with dehydration, it is plausible to investigate the efficiency of an ad libitum hydration strategy in countering any cognitive decrements incurred from a
dehydrated state. In his review, Lieberman (2007) identifies that futures studies should utilize heat/exercise-induced dehydration along with cognitive tests which have previously shown sensitivity to hydration status. Therefore, the purpose of this study is to quantify the effect of *ad libitum* hydration on cognitive function after an exercise bout in the heat. To this extent, we have included the cognitive tests: visual vigilance, trial making, match-to-sample test, letter-digit substitution, and pattern comparison tests.

Given the relative minimal research within the field of dehydration and cognition, this study has potential to contribute further to our understanding of mechanisms involved in cognitive function post-exercise. Previous research has focused on dehydration protocols and resulting cognitive decrements. This study will provide insight into a commonly utilized hydration strategy and the efficacy in mitigating potential alterations in cognition.
Subjects

Twelve male subjects (Age: 22.17 ± 2.41 yr, Height: 175.08 ± 5.70 cm, Body Mass: 76.13 ± 6.93 kg, Body Mass Index: 24.82 ± 1.69 kg·m⁻², VO₂peak: 42.83 ± 4.82 mL·kg⁻¹·min⁻¹) volunteered for participation in the study. Inclusion criteria for the study were: i) non-smoking, ii) healthy, free of disease and free of medication use, iii) free of any orthopedic injuries or conditions that would make exercise difficult, iv) classified as “Low-Risk” classification (asymptomatic for cardiovascular, respiratory, or metabolic diseases and possessing ≤ one risk factor for atherosclerotic cardiovascular disease), v) recreationally active, and vi) non-obese (body mass index < 30 kg·m⁻²). This study was approved by the Human Subjects Institutional Review Board at Western Michigan University. All subjects read and signed the informed consent before initiating their participation in the study.

Experimental Design

This study was a quasi-experimental design, where each subject served as their own control. Each subject visited the Human Performance Laboratory at Western Michigan University six times for one orientation session, two cognitive familiarization sessions, and three heat stress tests. The three heat stress tests differed in the fluid intake protocol. Each subject exercised with a fluid protocol of: no fluid replacement (NF), ad-libitum fluid intake (AL), and a fluid replacement
protocol (FR) equal to body mass (BM) loss from NF condition defined as:

\[ \text{FR intake} = \text{BM}_{\text{pre-NF}} - \text{BM}_{\text{post-NF}}. \]

Each subject completed the NF trial first, allowing for the calculation of fluid intake for the FR trial. The order of FR and AL trials were random and counterbalanced amongst subjects. The order of cognitive tests was also randomized for all heat stress trials mitigating any potential order-effect.

**Research Procedures**

The initial session consisted of reading/signing the informed consent document, initiation to the cognitive test battery, and a graded exercise test on a cycle ergometer (*ERG 551, Bosch, Farmington Hills, MI*) to determine maximal aerobic capacity (*VO₂*peak). Before each test, the metabolic cart was calibrated using a 3 liter syringe and gases of known oxygen and carbon dioxide concentrations. The subject’s expired gases were collected throughout the duration of the test and analyzed using a metabolic cart (*TrueOne 2400, ParvoMedics, Sandy, UT*). The graded exercise test began with a two minute warm up at 60W and increased in intensity by 20 W·min⁻¹ until volitional fatigue was experienced.

Subjects then visited the laboratory on two further instances to minimize a learning effect for each of the cognitive tests. The three total practice exposures are, at minimum, in agreement with other psychological testing batteries (Perez, et al., 1987).
The last three visits to the laboratory were for the heat stress tests in which the fluid intake protocol was manipulated. Prior to participation in each heat stress test, each subject was given instruction to abstain from exercise for the previous 24hrs and alcohol and caffeine for the previous 12hrs. Each subject was further instructed to consume liquids, and a urine specific gravity (USG) test was completed to confirm adequate hydration before the heat stress test. A USG value of ≤1.020 g·mL\(^{-1}\) was required for criteria to continue with the heat stress tests. A USG of 1.020 g·mL\(^{-1}\) was referred to as the euhydration cut-off value by the recent American College of Sports Medicine position stand on hydration and fluid replacement (ACSM, 2007).

Upon arrival to the laboratory for each heat stress test, each subject completed the cognitive battery (details provided below). Subjects then voided and a nude body mass (BM\(_{\text{pre}}\) was measured using a physician’s beam scale (Health o meter, Boca Raton, FL). Subjects then inserted a rectal thermometer probe (Physitemp Instruments Inc., Clifton, NJ) 13cm past the anal sphincter to measure core temperature (T\(_c\)). Following insertion of the rectal thermometer, subjects had skin thermocouples (Physitemp Instruments Inc., Clifton, NJ) attached at four sites (chest, triceps, thigh, and calf) using waterproof tape (Hy-Tape, Patterson, NY) to determine skin temperature (T\(_{sk}\)) (Ramanathan, 1964). Core and skin temperature readings were taken at 15-sec intervals and stored within PC-computer software (DASY Lab V, Measurement Computing, Norton, MA). Subjects were then fitted with
a heart rate monitor (Polar USA, Lake Success, Long Island, NY). Subjects then sat upright, wearing only athletic shorts, for a 25min baseline period in a warm environment (32°C, 65% RH).

Following the seated rest, the subject then mounted an electronically braked cycle ergometer and was allowed to warm-up for 2-min at a low intensity (50-70W). Following the warm-up period, subjects cycled for 50 minutes in the warm environment at 60% VO_{2peak} for 50 minutes. Heart rate, Borg ratings of perceived exertion (0-20), and thermal sensation were measured every five minutes. The thermal sensation scale is a 16-item Likert scale scaled from 0-8, where 0 = Unbearably Cold, 4 = Neutral, and 8 = Unbearably Hot (Gagge et al., 1967). All subjects were instructed on proper usage of each scale prior to exercise.

At the onset of the NF heat stress test, expired gases were measured from minutes 0-8. If subjects were not within ±5% of 60% VO_{2peak}, workload corrections were made to ensure the subject was exercising at the desired intensity. To synchronize the exercise stress during each heat stress test, workload, including adjustments, was replicated for the AL and FR trials. During AL trial each subject was made aware of an infinite supply of water and was not given any fluid consumption feedback. During the FR trial, each subject was verbally instructed to consume the prescribed fluid amount steadily throughout the exercise bout.

Immediately following exercise, the subject was dismounted from the cycle ergometer and ushered to the cognitive testing station in a neutral environment.
Following completion of the cognitive battery, the subject again voided, and body mass was measured (BM\text{post}). A post-exercise USG sample was collected from post-exercise void.

**Cognitive Battery**

The cognitive battery included five tests (match-to-sample task, pattern comparison test, trial making test, letter-digit substitution, and perceptual visual vigilance task) on a widely-available Windows computer software program (*PEBL Build 0.11, pebl.sourceforge.net*). The cognitive battery was assessed with a common keyboard, mouse, and laptop and was completed in a room without any distractions. Recently, Piper et al. (2011) has published data demonstrating similar plasticity between *PEBL* and other cognitive batteries verifying the ability of *PEBL* to capture valid cognitive responses of a given population. Each cognitive battery took 20-23 minutes to complete.

**Match-to-Sample Task**

The match-to-sample task presented an initial stimulus of a 4x4 matrix with an alternating pattern of yellow and red squares. Once the initial stimulus was quickly memorized, after a brief delay, the subject was then shown two 4x4 matrices. The task was to identify which matrix matched the original stimulus. This was repeated for thirty trials. Percent of correct responses, mean response time, and median response time were the measured variables.
**Pattern Comparison Test**

The pattern comparison task presented two simultaneous four by four matrices. The task was to determine whether the pattern in the matrices were either identical or different. This was repeated for sixty trials. Variables measured were percent of correct responses, mean response time, and median response time.

**Trail Making Test**

The trail making test utilized the *PEBL* software to create a random display of dots on the laptop screen, each with an identifier inside. The overarching goal of this task was to connect each dot in a successive sequence using a common computer mouse. There were two differentiated sequences; each presented four times (eight total trials). The first sequence required the subjects to connect the dots in a simple numerical order (i.e. 1-2-3-4-5….28). The second sequence required the subjects to alternate letter and number identifiers (i.e. 1-A-2-B-3-C….N). For ease of analysis, reciprocal mean completion time was calculated and multiplied by 100. Therefore, the greater number signifies greater performance on the test. Percent correct mouse clicks was analyzed to determine accuracy of response.

**Letter-Digit Substitution**

The letter-digit substitution task required the subjects to match a stimulus (letter) with a specific digit on the keyboard. During this test there was a sequence of letters presented at the top of the screen, each with a number below. Each
number corresponded to the identical number on the top row of the keyboard.

During the test, a letter was shown in the middle of the screen, and the subject was required to match the letter to the corresponding letter-digit combination at the top of the screen.

**Perceptual Visual Vigilance Task**

The perceptual visual vigilance task (PPVT) task required subjects to respond to numerous stimuli presented over a ≈10-11 minute period. The stimuli were presented randomly after intervals of 100-800msec delay. Upon recognizing the stimulus, the subject was required to hit the space bar with the minimum latency. Because correct number of responses was a measured variable, the PPVT was programmed to present 90 stimuli total. If the subject hit the spacebar before a stimulus was present, that was deemed a premature error. To measure the overall performance on the test, mean reciprocal reaction time was analyzed.

**Statistical Analysis**

The physiological and perceptual variables were analyzed using a two-way repeated measures analysis of variance (ANOVA). The factors used in the analysis were condition (NF, AL, FR) and time. Both factors were repeated measures factors. If necessary, post-hoc testing was performed using a simple effects analysis.

The cognitive variables were analyzed using paired sample t-tests. Pre-test values between the different heat stress tests were analyzed to determine if any
differences were evident prior to the manipulation of the fluid replacement protocols. Pre- versus post-test values were also analyzed for each heat stress test (i.e. fluid manipulation protocol).

All data is presented as means (M) ± standard error (SE). The level of significance was established a priori as P ≤ 0.05.
CHAPTER III

RESULTS

**Exercise Intensity**

The measured exercise intensity for subjects was 63.23 ± 1.61 %VO$_{2peak}$.

**Hydration Variables**

Table 2 displays the body mass loss and fluid intake measures during all three conditions. As expected, the subjects experienced significantly greater body mass loss during the NF condition compared to the AL and FR conditions (p < 0.001). There was no difference between AL and FR body mass loss (p = 0.54). As expected, AL and FR conditions elicited significantly greater fluid intake than NF (p < 0.001). There was no difference between fluid intake in AL and FR conditions (p=0.12).

<table>
<thead>
<tr>
<th>Variable</th>
<th>No Fluid</th>
<th>Ad Libitum</th>
<th>Fluid Replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Mass Loss (%)</td>
<td>1.54 ± 0.65 **</td>
<td>0.29 ± 0.75</td>
<td>0.13 ± 0.31</td>
</tr>
<tr>
<td>Fluid Intake (L)</td>
<td>0.00 ± 0.00 **</td>
<td>0.94 ± 0.32</td>
<td>1.18 ± 0.47</td>
</tr>
</tbody>
</table>

**Table 2: Body mass loss and fluid intake during three hydration conditions**

** denotes significant differences between NF and AL and FR conditions
Physiological Variables

Heart Rate

Figure 1 displays the HR response during exercise in the NF, AL, and FR conditions. Overall, the main effect for condition was significant (p < 0.001) with HR being greater for the NF condition (158 ± 5 b·min⁻¹) compared to both the AL (149 ± 5 b·min⁻¹) and FR conditions (146 ± 5 b·min⁻¹). There was no significant difference between AL and FR conditions (p = 0.33). As expected, there was a significant main effect for time (p = 0.02). The condition x time interaction was also significant (p < 0.001). Post-hoc testing revealed that HR was significantly greater during the NF condition compared to the FR condition at 10min and then every time point between 20-50min (p<0.05). Heart rate was also significantly greater during the NF condition compared to the AL condition at each time interval between 35-50min. No significant differences were observed at any time interval between AL and FR conditions.
Figure 1: Heart rate responses to exercise under three different fluid replacement strategies (M ± SE)

* denotes significant difference between NF and FR
** denotes significance between FR vs. AL and NF
Core Temperature

Figure 2 displays the $T_c$ response during exercise in the NF, AL, and FR conditions. Overall, the main effect for condition was significant with $T_c$ being greater during the NF condition compared to the AL condition (NF: 37.64 ± 0.11, AL: 37.42 ± 0.13 °C; $p = 0.03$) but not the FR condition (37.30 ± 0.24 °C; $p = 0.06$). There was no significant difference between AL and FR conditions ($p = 0.42$). As expected, there was a significant main effect for time ($p < 0.001$). The condition x time interaction was also significant ($p < 0.001$). Post-hoc testing revealed that $T_c$ was significantly greater during the NF condition compared to the FR and AL conditions at 30-50min ($p < 0.05$). No significant differences were observed at any time interval between AL and FR conditions.
Figure 2: Core temperature responses to exercise under three different fluid replacement strategies (M ± SE)

** denotes significance between FR vs. AL and NF
Mean Skin Temperature

Figure 3 displays the $T_{sk}$ response during exercise in the NF, AL, and FR conditions. Overall, the main effect for condition was significant ($p = 0.03$) with $T_{sk}$ being greater for the NF condition compared to the FR condition (NF: $36.01 \pm 0.13$, FR: $35.70 \pm 0.12 \, ^\circ C; \, p < 0.001$) but not the AL condition ($35.76 \pm 0.16 \, ^\circ C; \, p = 0.07$). There was no significant difference between AL and FR conditions ($p = 0.69$). As expected, there was a significant main effect for time ($p < 0.001$). The condition x time interaction was also significant ($p = 0.04$). Post-hoc testing revealed that $T_{sk}$ was significantly greater during the NF condition compared to the FR condition at 10min and then every time point between 20-50min ($p < 0.05$). Skin temperature was also significantly greater during the NF condition compared to the AL condition at 45 and 50min. No significant differences were observed at any time interval between AL and FR conditions.
Figure 3: Mean skin temperature responses to exercise under three different fluid replacement strategies (M ± SE)

* denotes significant difference between NF and FR
** denotes significance between FR vs. AL and NF
Perceptual Measurements

Thermal Sensation Scale

Figure 4 displays the thermal sensation response during exercise in the NF, AL, and FR conditions. Overall, the main effect for condition was significant (p < 0.001) with TSS being greater for the NF condition compared to both the AL (NF: 6.11 ± 0.15, AL: 5.73 ± 0.21; p = <0.01) and FR conditions (5.80 ± 0.20; p = 0.01). There was no significant difference between AL and FR conditions (p = 39). As expected, there was a significant main effect for time (p < 0.001). The condition x time interaction was also significant (p < 0.001). Post-hoc testing revealed that thermal sensation was significantly greater during the AL condition compared to the FR condition at every time point from 15-50min (p < 0.05). Thermal sensation was also significantly greater during the NF condition compared to the FR condition at 20-25min and then every time point between 40-50min (p < 0.05). No significant differences were observed at any time interval between AL and FR conditions.
Figure 4: Thermal sensation scale responses to exercise under three different fluid replacement strategies (M ± SE)

# denotes significant difference between NF and AL
** denotes significance between NF vs. AL and FR
Rating of Perceived Exertion

Figure 5 displays the RPE response during exercise in the NF, AL, and FR conditions. Overall, the main effect for condition was significant (p = 0.002) with RPE being greater for the NF condition compared to both the AL (NF: 14.51 ± 0.48, AL: 13.02 ± 0.61; p <0.01) and FR conditions (13.62 ± 0.55; p = 0.05). There was a significant difference between AL and FR conditions (p = 0.05). As expected, there was a significant main effect for time (p < 0.001). The condition x time interaction was also significant (p < 0.001). Post-hoc testing revealed that RPE was significantly great during the NF condition compared to the AL condition at 15min and then every time point between 25-50min (p<0.05). Rating of perceived exertion was also significantly greater during the NF condition compared to the FR condition at each time interval between 35-50min. Rating of perceived exertion was greater in the FR condition compared to the AL condition from 25-35min (p < 0.05).
Figure 5: Rating of perceived exertion responses to exercise under three different fluid replacement strategies (M ± SE)

# denotes significant difference between NF and AL
** denotes significance between FR vs. AL and NF
χ denotes significant differences between AL vs. NF and FR
χχ denotes significant differences between all conditions
Cognitive Variables

Letter-Digit Recognition

Table 3 displays the results of the letter-digit recognition task for each fluid intake protocol. No pre-test measures were significantly different amongst conditions. In the AL condition, mean response time was significantly less in the post-test measurement compared to the pre-test measurement (p = 0.05). No other significant differences were observed.

Match-to-Sample

Table 3 displays the results of the match-to-sample task for each fluid intake protocol. No pre-test measurements were significantly different amongst conditions. In the AL condition, median response time was significantly less in the post-test measurement compared to the pre-test measurement (p = 0.01). No other significant differences were observed.

Pattern Comparison

Table 3 displays the results of each variable measured and fluid intake protocol. Significant differences were observed between pre-test values of NF and FR mean (p = 0.03) and median (p = 0.02) response time. Mean response time was significantly decreased in the post-test measurement during the NF (p = 0.05), AL (p = 0.01), and FR (p = 0.05) conditions. There were significant decreases in median
response time for the post-test measurement compared to the pre-test measurement in NF (p = 0.01), AL (p = 0.02), and FR (p = 0.04) conditions.

Visual Vigilance Task

Table 3 displays the results of each variable measured and fluid intake protocol. No pre-test measurements were significantly different amongst conditions. There were no significant differences reported in any pre vs. post tests for any of the fluid intake conditions.

Trail Making Test

Table 3 displays the results of each variable measured and fluid intake protocol. No pre-test measurements were significantly different amongst conditions. There were no significant differences reported in any pre vs. post tests for any of the fluid intake conditions.
<table>
<thead>
<tr>
<th>Cognitive Assessment</th>
<th>Assessment Variables</th>
<th>No Fluid</th>
<th>Pre</th>
<th>Post</th>
<th>p value =</th>
<th>Ad Libitum</th>
<th>Pre</th>
<th>Post</th>
<th>p value =</th>
<th>Fluid Replacement</th>
<th>Pre</th>
<th>Post</th>
<th>p value =</th>
</tr>
</thead>
<tbody>
<tr>
<td>Letter-Digit Recognition</td>
<td>Correct Response (%)</td>
<td>98.06 ± 2.23</td>
<td>98.06 ± 3.00</td>
<td>1.00</td>
<td>98.89 ± 1.64</td>
<td>98.06 ± 2.23</td>
<td>0.08</td>
<td>97.50 ± 3.22</td>
<td>99.17 ± 1.51</td>
<td>0.17</td>
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<td></td>
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<tr>
<td></td>
<td>Mean Response Time (msec)</td>
<td>1577.52 ± 275.54</td>
<td>1562.03 ± 285.66</td>
<td>0.83</td>
<td>1531 ± 301.54</td>
<td>1444.27 ± 24.86</td>
<td>0.05*</td>
<td>1580.08 ± 255.32</td>
<td>1506.42 ± 206.16</td>
<td>0.06</td>
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<tr>
<td></td>
<td>Median Response Time (msec)</td>
<td>1481.92 ± 238.81</td>
<td>1495.83 ± 249.18</td>
<td>0.80</td>
<td>1462.33 ± 288.10</td>
<td>1368.25 ± 222.93</td>
<td>0.10</td>
<td>1554.79 ± 251.80</td>
<td>1477.67 ± 199.51</td>
<td>0.07</td>
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<tr>
<td>Match-to-Sample</td>
<td>Correct Response (%)</td>
<td>95.56 ± 3.85</td>
<td>91.04 ± 9.89</td>
<td>0.24</td>
<td>95.28 ± 3.89</td>
<td>93.89 ± 4.89</td>
<td>0.27</td>
<td>95.45 ± 4.02</td>
<td>91.82 ± 9.93</td>
<td>0.27</td>
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<tr>
<td></td>
<td>Mean Response Time (msec)</td>
<td>1262.19 ± 397.19</td>
<td>1192.10 ± 320.00</td>
<td>0.28</td>
<td>1208.48 ± 319.18</td>
<td>1275.95 ± 396.31</td>
<td>0.37</td>
<td>1174.18 ± 284.98</td>
<td>1163.83 ± 121.11</td>
<td>0.86</td>
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<td></td>
<td>Median Response Time (msec)</td>
<td>1140.00 ± 286.68</td>
<td>1084.79 ± 267.03</td>
<td>0.30</td>
<td>1208.21 ± 309.8</td>
<td>1137.08 ± 313.32</td>
<td>0.01*</td>
<td>1093.96 ± 239.93</td>
<td>1073.59 ± 82.61</td>
<td>0.67</td>
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<td>Pattern Comparison</td>
<td>Correct Response (%)</td>
<td>96.81 ± 2.61</td>
<td>96.67 ± 3.10</td>
<td>0.87</td>
<td>95.83 ± 3.45</td>
<td>96.39 ± 2.64</td>
<td>0.42</td>
<td>96.94 ± 3.00</td>
<td>96.39 ± 3.16</td>
<td>0.31</td>
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<td></td>
<td>Mean Response Time (msec)</td>
<td>1170.23 ± 312.35</td>
<td>1110.00 ± 281.16</td>
<td>0.05*</td>
<td>1169.62 ± 388.86</td>
<td>1041.58 ± 263.99</td>
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<td>1072.71 ± 226.21</td>
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<td>Median Response Time (msec)</td>
<td>1089.96 ± 277.07</td>
<td>1009.92 ± 237.75</td>
<td>0.01*</td>
<td>1079.54 ± 349.21</td>
<td>975.96 ± 234.97</td>
<td>0.02*</td>
<td>988.92 ± 198.07</td>
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<td>0.04*</td>
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<td>Visual Vigilance</td>
<td>Mean Reciprocal Time (1/msec)</td>
<td>3.04 ± 0.36</td>
<td>2.97 ± 0.46</td>
<td>0.32</td>
<td>3.06 ± 0.42</td>
<td>3.12 ± 0.44</td>
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<td>3.06 ± 0.32</td>
<td>3.05 ± 0.35</td>
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<td>Correct (Number)</td>
<td>87.25 ± 2.22</td>
<td>84.58 ± 6.14</td>
<td>0.14</td>
<td>86.67 ± 4.46</td>
<td>86.75 ± 3.08</td>
<td>0.95</td>
<td>87.58 ± 3.73</td>
<td>87.50 ± 2.68</td>
<td>0.92</td>
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<td>Premature Errors (Number)</td>
<td>0.92 ± 0.90</td>
<td>1.17 ± 1.3</td>
<td>0.63</td>
<td>1.17 ± 1.11</td>
<td>1.67 ± 0.99</td>
<td>0.26</td>
<td>1.00 ± 1.34</td>
<td>1.50 ± 1.68</td>
<td>0.11</td>
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<tr>
<td>Trail Making Test</td>
<td>Mean Reciprocal Time (1/msec)*100</td>
<td>6.74 ± 0.99</td>
<td>6.81 ± 0.84</td>
<td>0.69</td>
<td>7.05 ± 0.88</td>
<td>7.06 ± 0.83</td>
<td>0.88</td>
<td>7.03 ± 0.81</td>
<td>7.22 ± 0.69</td>
<td>0.70</td>
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<tr>
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<td>Accuracy (% correct)</td>
<td>92.75 ± 4.57</td>
<td>92.38 ± 3.96</td>
<td>0.66</td>
<td>93.59 ± 3.16</td>
<td>92.49 ± 3.75</td>
<td>0.30</td>
<td>93.77 ± 3.65</td>
<td>92.67 ± 4.57</td>
<td>0.12</td>
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</tbody>
</table>

Table 3: Pre vs. Post Results for the cognitive battery

* denotes significant difference between pre vs. post trials
CHAPTER IV
DISCUSSION

The purpose of this study was to quantify the effect of different hydration strategies on physiological and cognitive variables after an exercise bout in the heat. To further investigate the efficacy of an AL hydration strategy, two other trials were included to provide relation to the extremes of various hydration strategies (no intake and complete rehydration). The NF condition lost 1.54 % body mass, which is lower than the 2% marker for potential performance decrements previously established (ACSM, 2007). The FR and AL conditions were largely effective in preserving body mass, losing only 0.13 % and 0.29 %, respectively. Previous research has found AL hydration strategies potentially leading to ‘voluntary dehydration’ (Passe et al., 2007). Therefore, the current subjects largely utilized a more aggressive AL fluid replacement hydration strategy than other research has observed.

The fluid replacement protocols elicited different thermoregulatory stimuli. Compared to the NF condition, the FR strategy resulted in earlier and more pronounced differences within the physiological variables (HR, T_c, and T_sk) than the AL condition. However, the AL strategy was never significantly different than FR at any time points and experienced significant differences from NF from approximately 30-35min until the cessation of exercise. Figure 1 demonstrates the NF group experienced cardiovascular drift, possibly indicating a heightened thermoregulatory stress compared to AL and FR.
These physiological responses are consistent with Sawka et al. (1985) who found a graded effect of physiological stress in accordance with magnitude of dehydration on $T_c$ and heart rate. Although Sawka et al. (1985) observed changes at larger variations within body mass loss (0%, 3%, 5%, and 7%); the results of the current study indicate differences are observable at smaller intervals. Previous research has identified a potential increase in $T_c$ of 0.10 - 0.25 °C per percent body mass loss (Sawka, Montain, Lazka, 2001). However, during the NF trial, $T_c$ increased at a greater rate ($\approx 0.67 °C \cdot \%BM^{-1}$). This is concomitant with previous research which seems to indicate that exercise in a hot environment leads to accelerated rates of $T_c$ increase.

It appears the vital component responsible for the observed thermoregulatory responses amongst conditions in the current study is exercise intensity. Armstrong et al. (1997) had subjects exercise at light intensity at near identical ambient conditions (33 °C; 56%) at a light intensity (treadmill walking at 36 %VO$_{2max}$) for 90min. There were no differences in $T_c$ during any time points from a hydration strategy which withheld fluid intake and an ad libitum protocol in which the subjects were euhydrated before exercise. Subjects who were hypohydrated prior to exercise increased ad libitum intake, and therefore had an increased stimulation of the thirst mechanism (Armstrong et al., 1997). The greater intensity in the current study may have increased the thirst mechanism within the subjects, and therefore the drive to drink was greater, hence a more effective AL hydration strategy was utilized by the subjects.
Although no significant differences existed between AL and FR in the thermal sensation scale, significant differences were observed during 25-40min in RPE. Both self-reported measures followed the physiological trends of both AL and FR being significantly different than NF at the terminal portion of exercise. One potential rationale for this finding is the concept of AL hydration strategy. The thirst mechanism has been previously shown to be stimulated with preexercise hypohydration, and therefore, the thirst mechanism is responsive to alterations to the homeostatic fluid balance (Maresh et al., 2004; Dugas et al., 2009). The hypothesis that AL hydration, controlled by the thirst mechanism, is sufficient to preserve performance during exercise is gaining considerable traction. Therefore, the perceptual advantages observed in the AL trial may be present given the FR condition deviating from the ‘optimal’ hydration strategy, albeit by ingesting too much fluid (Dugas et al., 2004).

The cognitive measurements were analyzed in a pre vs. post manner, which differs from some previously referenced studies which evaluated and compared only the post-test results (Ganio et al., 2011; Gopinathan et al., 1988; Sharma et al., 1986). However, this method allows the analysis of pre-test measurements along with effects of the acute bout of exercise with different fluid replacement strategies in a warm environment. Further, the cognitive battery was designed to include cognitive assessments previously altered by hydration status (Table 1). Previous research has not independently assessed the pattern comparison test. Instead, the
pattern comparison was mentioned as a function of the match-to-sample task (Ganio et al., 2011; Lieberman et al., 2008).

Overall, no significant decrements in cognition were observed. The pattern-comparison test elicited the greatest response to exercise in a warm environment. Significant decreases in mean (NF and AL) and median response time (for all conditions) indicates the speed of response was improved with exercise. Importantly, the greater response speed was present without any consequences in accuracy (Table 2). Median response time was also significantly decreased in the AL trial during the match-to-sample test. As previously stated, pattern comparison assesses a function of the match-to-sample task. Therefore, the results of this study indicate that an AL hydration strategy may increase pattern recognition and working memory compared to the NF and FR conditions. Further, the NF condition observed greater cognitive enhancements (decreased both mean and median response time during the pattern comparison test) compared to the FR condition (decreased median response time). Therefore, the NF hydration strategy in this study may marginally increase pattern recognition and working memory compared to the FR condition.

A recent meta-analysis of hydration and cognition concluded that research indicates a small positive effect of exercise on cognition (Chang et al., 2012). Moderate intensity exercise seemingly has a significant effect on cognition with assessments administered directly following exercise, which is consistent with the results of the present study. Exercise duration also was significantly implicated in
cognitive performance. Exercise lasting greater than 20mins has shown to increase cognition (Chang et al., 2012).

Exercising duration may be integral to the cognitive responses. Grego et al., (2005) experienced an optimal time for cognition during the second hour of a three hour cycling bout at moderate intensity. These results may be explained by the inverse-U hypothesis of Yerkes & Dobson (1908), which states that the arousal levels are greatest after an initial stimulus, but then decrease when the stimulus is too great. In an exercise construct, modeled by Grego et al., (2005), the exercisers reached maximal arousal after an exercise stimulus lasting 80min.

Cian, Koulmann, Barraud, Raphel, Jiminez, and Melin (2000) potentially further demonstrated the role of arousal in cognitive function. Cian et al. (2000) manipulated hydration status four ways: euhydration, hyperhydration, dehydration-heat, and dehydration exercise. Various cognitive alterations existed between conditions. However, after a short (15-20min) exercise bout at 85% VO$_{2peak}$, there were no significant differences among the manipulated hydration statuses despite subjects experiencing a greater sense of tiredness and a decrease in mood during the dehydration trials. It is possible in the Cian et al. (2000) study the increase in exercise may have increased arousal simultaneously, and therefore equalized the cognitive profiles of each hydration group.

Initially it was postulated that cognitive decrements in the heat resulted from a redistribution of resources outward to counteract increasing thermoregulatory stress, limiting available resources for the central governor (Grego et al., 2005).
There is a potential link between arousal and brain activity. Grego et al. (2005) found decreases in a central flicker fusion task at 2hr into exercise. The central flicker task changes in relation to arousal and results are used to trace cognition. Previous research has found cycling to reach central fatigue around 2hr into exercise (Lepers et al., 2002). Therefore, it is plausible to suggest arousal and central fatigue occurred in conjunction, linking cognitive function and the level of activation of the central governor.

Although no direct correlation has been shown and was not measured in the current study, the idea of central arousal may present a viable explanation for the observed results. Our results seem consistent with the aforementioned hypothesis that optimal cognitive function is observed approximately 1hr into exercise. All conditions observed mild increases in overall cognition. Further, many cognitive variables were trending ($p = 0.10 – 0.06$) towards significance. Increasing the current exercise duration may have propagated these trends below the significance threshold, greatly enhancing cognitive function. The increase in cognitive function may be limited to the AL and FR conditions, given the upward trend in heightened thermoregulatory stress during the NF condition.

In conclusion, the results of this study indicate that an AL hydration strategy during a sub-hour exercise bout in a warm environment is as effective at facilitating thermoregulation and control of physiological stress as a FR fluid replacement strategy. Further AL hydration strategy provides enhanced thermoregulatory protection compared to NF as evidenced by the decreased $T_c$, $T_{sk}$, and HR. The AL
hydration strategy seemed preferable to an FR strategy, given the significantly less RPE and enhanced cognitive post-exercise scores compared to the FR condition. The significant cognitive enhancements observed in the pre- vs. post-test measurements in the pattern comparison and match-to-sample cognitive assessments indicate that the cognitive functions of working memory and pattern recognition demonstrate plasticity with an exercise stimulus. These results also demonstrate the efficacy of an AL hydration strategy in replacing an equivalent volume of fluids as the FR hydration strategy.
REFERENCES


Appendix A

Human Subjects Institution Review Board Approval
Date: April 26, 2012

To: Chris Cheatham, Principal Investigator
    Matt Wittbrodt, Student Investigator for Thesis

From: Amy Naugle, Ph.D., Chair

Re: HSIRB Project Number 11-10-04

This letter will serve as confirmation that the change to your research project titled “The Effect of Ad Libitum Hydration on Cognitive Function After Exercise in a Hot Environment” requested in your memo received April 25, 2012 (Add $60 compensation for each participant; add documentation and signature of each participant acknowledging receipt of compensation) has been approved by the Human Subjects Institutional Review Board.

The conditions and the duration of this approval are specified in the Policies of Western Michigan University.

Please note that you may only conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: October 19, 2012
Appendix B

Human Subjects Institutional Review Board Informed Consent
Informed Consent

Western Michigan University
Department of Health, Physical Education and Recreation

Principal Investigator:  Christopher C. Cheatham, Ph.D.
Student Investigator:    Matt Wittbrodt, B.S.

Title of Study:         The effect of *ad libitum* hydration on cognitive function after exercise in a hot environment

You have been invited to participate in a research project titled “The effect of *ad libitum* hydration on cognitive function after exercise in a hot environment.” This project will serve as Matt Wittbrodt’s thesis project for the requirements of the Master of Science in Exercise and Sports Medicine (Exercise Physiology Concentration) degree. This consent document will explain the purpose of this research project and will go over all of the time commitments, the procedures used in the study, and the risks and benefits of participating in this research project. Please read this consent form carefully and completely and please ask any questions if you need more clarification.

What are we trying to find out in this study?

When we exercise our working muscles produce heat, which causes an increase in body temperature. In response, the body tries to remove the heat. When resting, the pathways can easily remove the excess heat. However, when the body temperature increases beyond a normal amount, much more energy is needed to remove the heat. A response to this is a decrease in brain functioning, which could potentially have negative effects when applied to a sporting or decision making situation. The extent that this occurs relates to how much body weight is loss through sweating. One way to improve the body weight loss is by drinking fluids. Therefore, fluid intake has a role within our brain function after exercise. We are trying to find out how well the brain functions when the exerciser only drinks when they are thirsty.

Who can participate in this study?

In order to be eligible to participate, you must be a male between the ages of 18 and 35 years and meet the following criteria:
• You must be healthy, free of disease and free of medication use which may affect the cardiovascular or metabolic responses during exercise;
• You must be free of any orthopedic injuries or conditions that would make exercise difficult;
• You must be classified as “Low-Risk” for cardiovascular disease based on the American College of Sports Medicine’s Risk Stratification guidelines;
• You must be recreationally active;
• You must not be classified as being obese.

If you agree to participate and sign this consent form, these criteria will be determined by having you complete several health history questionnaire forms. The determination of whether or not you are classified as being obese will be determined from measurements of your height and weight, or measurement of skinfold thickness.

**Where will this study take place?**

This study will take place in the Human Performance Research Laboratory which is located on the first floor of the Student Recreation Center at Western Michigan University.

**What is the time commitment for participating in this study?**

If you choose to be part of this study, you will be asked to come to the laboratory on six separate days. The first day will take approximately one hour and a half. The next two sessions will take around 30 minutes, and the last three sessions will take around 2.5 hours.

Thus, the total time commitment is approximately ten hours.

Overall, we would like to have you finish the study within five to six weeks of starting it.

**What will you be asked to do if you choose to participate in this study?**

We will ask you to come to our laboratory six times. The first visit is the “Orientation / Graded Exercise Test” visit, the second and third visits are to get you used to the cognitive tests, and the final three (4th, 5th, 6th visits) are “Heat Stress Tests”. The first heat stress test will have you exercise without any fluids. The other two heat stress tests will either i) force you to drink a specific amount of fluids or ii) drink as much fluid as you want. Before each visit to the laboratory, we will ask you to not drink any alcohol or caffeine the day before and day of your visits to the laboratory.
We also ask that you come well hydrated and pay attention to your food intake before the first heat stress test. During heat stress test two and three, we will also ask that you follow a similar diet to the first test. We will also ask that you not exercise the day before and the day of your visits to the laboratory. Lastly, we will ask you to wear a t-shirt, shorts, and athletic shoes to each visit to the laboratory.

Orientation / Graded Exercise Test Visit

If you choose to participate in the study and sign the informed consent form, we will have you complete two health history questionnaires and measure your height and weight. We will use this information to determine if you are eligible to continue participating in the study.

We will then measure your percent body fat using a skinfold caliper. We will measure the thickness of your skin and the layer of fat underneath it at seven different places on your body. We will then enter these numbers into a math equation to determine your percentage body fat. We will then introduce you to the cognitive tests, and have you practice them once.

We will then have you perform a maximal exercise test on a stationary bicycle to determine your fitness level (how much oxygen your body uses). We will strap a heart rate monitor around your chest. We will also explain how to use the Borg Ratings of Perceived Exertion (RPE) Scale. This is a scale with numbers and words describing how hard the exercise is. To use the scale, you simply point to a number. We will then hook you up to the “Metabolic Measurement Cart” so that we can measure how much oxygen your body uses during exercise and how much carbon dioxide your body produces. To do this, you will breathe through a clean, sanitized mouthpiece (similar to a snorkel mouthpiece) and you will wear a pair of noseclips so that you can only breathe through your mouth. The air you blow out during exercise goes into the “Metabolic Measurement Cart” and the amount of oxygen and carbon dioxide is measured.

We will then begin the exercise test. You will bike on the stationary bicycle for three minutes at a very easy intensity. We will then make the exercise more difficult every one minute by increasing the resistance you must bike at. When the stationary bicycle is at a level which you can’t bike at, the exercise test will be over. This is called volitional fatigue and is the point during exercise when you feel like you can exercise no longer. In other words, the exercise is just too hard to continue. This feeling might occur due to leg fatigue, overall fatigue, hyperventilation (rapid
breathing), or other factors relating to maximal exercise. This exercise test usually takes between 8 and 15 minutes. After the test is over we will have you pedal easy at a very low exercise intensity so that you can cool-down. During this test we will record your heart rate every 30 seconds and ask that you indicate how hard the exercise feels every 1-2 minutes.

**Cognitive Test Visits**

One of the main things we are measuring in this study is how well your brain works after exercise. We will measure this using a common laptop computer and software. The purpose of these two visits is to have you practice the tests on the laptop so you are used to them when the testing starts. For these sessions, you will not have to dress for exercise. We will ask that you do not exercise within 2 hour before the session.

**Heat Stress Test Visits**

The fourth, fifth, and sixth visits to the laboratory are for the heat stress tests. The tests will be the same each visit, but with different fluid intakes. The first visit will have you exercise without any fluids, while the next two will allow you to drink fluids, but at different amounts. The order you will complete the fifth and sixth sessions will be random. During one of the visits you can drink water to your liking, and the other you will be required to drink a pre-determined amount of liquid.

When you get to the laboratory for the heat stress tests, we will again measure your body weight and also ask you to provide a urine sample. **The urine sample gives us a way to verify your hydration status.** You will then take the cognitive test before getting ready to exercise. After the cognitive tests, you will then be given instructions on how to insert the rectal temperature probe and you will then insert the probe yourself in a private restroom. We will then attach some small wires to your skin so that we can measure the temperature of your skin. We will also hook you up to the metabolic measurement cart and the heart rate monitor so that we can measure how much oxygen your body is using and your heart rate. Once you are hooked up to all the instruments, we will ask that you sit in a comfortable chair in our environmental chamber for 20 minutes. The temperature in the chamber will be 88°F. After the 20 minutes of seated-rest, you will exercise in the 88°F air on a **stationary bicycle** at a moderate intensity for 50 minutes. After that, the heat stress test is finished and we will disconnect you from all the equipment. We will move you to another room where you will complete the cognitive tests again. After that, we will ask you to give another urine sample and measure your body weight.
What information is being measured during the study?

This section will describe the measurements that we are going to take during your participation in the study.

Health Status/Medical History: We will be collecting information about your health status from the health history questionnaires.

Height, Weight, Percent Body Fat: We will be measuring your height, your weight, and the percentage of your body weight that is fat.

Core Temperature: Core temperature is the temperature inside your body. Core temperature will be measured using a rectal temperature probe. We will measure core temperature throughout the heat stress tests (second and third visits to the laboratory). To measure core temperature using a rectal temperature probe, you will be given a temperature probe with a small piece of tape on it. In a private restroom, you will be asked to insert the probe into your rectum approximately 5-6 inches (up to the piece of tape). The other end of the probe will come out the top of your shorts in the back. Before you insert the probe, we will ask you to place some lubricating jelly on the tip of the probe so that it goes in more comfortably.

Metabolic Rate / Oxygen Consumption: During each visit to the laboratory, we will measure how much oxygen your body uses and how much carbon dioxide your body produces using a metabolic measurement system. To do this, you will breathe through a clean, sanitized mouthpiece (similar to a snorkel mouthpiece) and you will wear a pair of noseclips so that you can only breathe through your mouth. The air you blow out during exercise goes into the “Metabolic Measurement Cart” and the amount of oxygen and carbon dioxide in the air you breathe out is measured.

Cognition: Your brain function will be measured many times throughout this study. During the heat stress tests, you will be measured both before and after the exercise. This will be measured using a program installed on a laptop computer.

Urine Specific Gravity: Every heat stress test you will submit two urine samples, one before exercise and one after. Urine specific gravity is used to measure how dehydrated you are after exercise.

Heart Rate: Your heart rate, or how many times your heart beats every minute will be measured throughout each visit to the laboratory. We will measure heart rate by strapping a heart rate monitor around your chest.
Skin Temperature: During the heat stress tests, we will measure the temperature of your skin at four places on your body. To do this, we will attach small wires to the top of your skin using tape and/or a small amount of a glue that is designed to be used on the skin.

Thermal Sensation: Throughout the fourth, fifth, and sixth visits to the laboratory, we will ask you how you feel temperature-wise by asking you to point to a number on a chart.

What are the risks of participating in this study and how will these risks be minimized?

Measuring Height and Weight: There are no known risks associated with the measurement of height and body weight.

Assessing Percent Body Fat via Skinfold Thickness: You may experience some slight discomfort due to the pulling of the skin and the application of the skinfold calipers. However, this discomfort, if experienced, is minor and is only when we are doing the measurement. We will attempt to minimize the possibility of any discomfort by following proper standardized procedures. Also, the investigators are experienced at performing skinfold measurements.

Measurement of Heart Rate and Thermal Sensation: There are no known risks associated with the measurement of heart rate using a telemetry heart rate monitor or measuring your thermal status.

Cognition: There are no known risks associated with completing cognitive tests with the use of a common laptop computer.

Urine Samples: There are no known risks associated with submitting a urine sample. This will be completed in an isolated restroom with full privacy.

Exposure to Heat: Rest and/or exercise in the heat can cause light-headedness, a feeling of tiredness, an increase in your body temperature, and an overall feeling of discomfort. During the experiment, we will be constantly monitoring your body temperature. If your body temperature increases past a certain level, we will stop the experiment and move you to a cooler temperature. The temperature that we stop the experiment at is below any dangerous level to your body.

Maximal Exercise: Intense, maximal exercise can cause feelings of tiredness, weakness, dizziness, and nausea. When exercising, there is always a risk for musculoskeletal injuries (muscle strains, pulls, cramping). Lastly, there is always a
risk for a cardiac event (i.e. chest pain, heart attack). However, this risk is extremely low. The American College of Sports Medicine states that the risk of such an event in a younger healthy population is only 0.1 incidents out of every 10,000 maximal exercise tests. In order to minimize these risks, we will confirm that you are classified as “low-risk” using the health history questionnaires. Also, we will have you stretch before the exercise to reduce the risk for musculoskeletal injuries. Lastly, an investigator will always be next to the stationary bicycle and will be monitoring your heart rate and how you feel. The investigators all have experience in performing this test and are also first-aid and CPR certified.

Moderate-Intensity Exercise: Exercise may cause the feeling of fatigue, light-headedness, and an overall feeling of discomfort. There is also a risk for muscle soreness and musculoskeletal injuries (muscle pulls, strains). The exercise may be stressful but is generally easily tolerated by individuals and is not dangerous for healthy individuals. The investigators are trained in performing exercise tests and are familiar with emergency procedures. Also, we will be monitoring your heart rate and body temperature to make sure that your body is tolerating the exercise.

Core Temperature: The measurement of core temperature using a rectal probe may cause some slight discomfort. The insertion of the probe may cause some slight discomfort but this will be minimized by using a lubricating jelly on the tip of the probe. The slight discomfort may continue while the temperature probe is in place.

Skin Temperature: There are no known risks associated with measuring skin temperature by taping small wires to the surface of your skin.

Other Risk Considerations: Participation in this study requires approximately ten hours of your time and therefore may be an inconvenience to you.

Other Protection Considerations: The principal investigator has extensive experience performing the measurements outlined in this application. The principal investigator was trained during his doctoral work at Kent State University and during his post-doctoral work at the John B. Pierce Laboratory at the Yale University School of Medicine. The student investigator has been trained in all of the laboratory exercises and has extensive experience in exercise testing.

As in all research, there may be unforeseen risks to the participant. If an accidental injury occurs, appropriate emergency measures will be taken; however, no compensation or additional treatment will be made available to you except as otherwise stated in this consent form.
What are the benefits of participating in this study?

You may learn about your fitness level and percent body fat and how your fitness level and percent body fat compare to individuals of your same age. **We will have norm data available for immediate comparison.** Other than that, there may be no direct benefit to your participation in this study.

Are there any costs associated with participating in this study?

There are no monetary costs to you for participating in this study.

Is there any compensation for participating in this study?

There is no monetary compensation for participating in the study.

Who will have access to the information collected during this study?

Only the investigators will have access to your data. To maintain confidentiality, a personalized identification number will be assigned to you and be used to record data collected throughout the study. Your name will never be associated with your data. If the results of the study are published in a journal or presented at a conference, no names or other identifying information will ever be used.

The original data will be retained in a locked cabinet for a minimum of three years after the completion of the study in the department of Human Performance and Health Education at Western Michigan University.

What if you want to stop participating in this study?

You can choose to stop participating in the study at any time for any reason. You will not suffer any prejudice or penalty by your decision to stop your participation. You will experience NO consequences either academically or personally if you choose to withdraw from this study.

The investigator can also decide to stop your participation in the study without your consent.

Should you have any questions prior to or during the study, you can contact the primary investigator Christopher C. Cheatham at (269) 387-2542 or chris.cheatham@wmich.edu. You may also contact the Chair, Human Subjects Institutional Review Board at 269-387-8293 or the Vice President for Research at 269-387-8298 if questions arise during the course of the study.
This consent document has been approved for use for one year by the Human Subjects Institutional Review Board (HSIRB) as indicated by the stamped date and signature of the board chair in the upper right corner. Do not participate in this study if the stamped date is older than one year.

I have read this informed consent document. The risks and benefits have been explained to me. I agree to take part in this study.

Please Print Your Name

___________________________________  __________

Participant’s signature  Date
Appendix C

Health History Questionnaire
Health History Questionnaire

Health/Medical History Questionnaire

Thank you for volunteering to participate in research at the Human Performance Research Laboratory of Western Michigan University. It is important that we have an accurate assessment of your present health status to assure that you have no medical conditions or previous injuries that may make participation in this study especially dangerous for you. Please complete the health history questionnaire as accurately as you can.

THIS MEDICAL HISTORY IS CONFIDENTIAL AND WILL BE SEEN ONLY BY THE INVESTIGATORS.

Name:____________________________________________________Date:_______
Date of Birth:______________ Present Age:_____yrs
Ethnic Group:

€ Alaskan Native
€ Asian American
€ Black/African American
€ Hispanic
€ International/Non-US Resident
€ Multiracial
€ Native American/American Indian
€ Pacific Islander
€ White (Non-Hispanic)

HOSPITALIZATIONS AND SURGERIES

If you have ever been hospitalized for an illness or operation, please complete the chart below. Do not include childhood tonsillectomy or broken bones.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>OPERATIONS OR ILLNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Are you under long-term treatment for a protracted disease, even if presently not taking medication? € Yes € No
If yes, please explain: __________________________________________________________
____________________________________________________________________________
____________________________________________________________________________
____________________________________________________________________________
____________________________________________________________________________

MEDICATIONS

Please list all medications that you have taken within the past 8 weeks (include prescriptions, vitamins, over-the-counter drugs, nasal sprays, aspirins, supplements, etc.):

€ Check this box if you have not taken any medications.

<table>
<thead>
<tr>
<th>MEDICATION</th>
<th>REASON YOU ARE PRESENTLY TAKING THIS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PROBLEMS AND SYMPTOMS

Please place an “X” in the box next to any of the following problems or symptoms that you have had within the past year:

General

€ Mononucleosis    If yes, when ________________________
€ Recent weight loss while not on a diet
€ Recent weight gain
€ Thyroid disease
€ Fever, chills, night sweats
€ Diabetes
€ Arthritis
€ Heat exhaustion or heat stroke
€ Abnormal chest x-ray

Problems and Symptoms (cont’d)

€ Pain in chest (persistent and/or exercise related)
€ Heart attack
Medical History, page 3

- Coronary artery disease
- High blood pressure
- Rheumatic fever
- Peripheral vascular disease
- Blood clots, inflammation of the veins (phlebitis)
- Asthma, emphysema, bronchitis
- Shortness of breath € At rest € On mild exertion
- Discomfort in chest on exertions
- Palpitation of the heart; skipped or extra beats
- Heart murmur, click
- Other heart trouble Please explain______________________________
- Lightheadedness or fainting
- Pain in legs when walking
- Swelling of the ankles
- Need to sleep in elevated position with several pillows
- High cholesterol If yes, what was the last measured value?______________

Nervous System

- Frequent or severe headaches
- Stroke
- Attacks of staggering, loss of balance, dizziness
- Persistent or recurrent numbness or tingling hands or feet
- Episode of difficulty in talking

Musculoskeletal

- Recent soft tissue injury (deep bruises, charley horse, muscle strain)
- Recent or chronic joint sprain If yes, which joint(s)?______________________
- Unstable joint If yes, which joint(s)?______________________
- Limited range of motion If yes, which joint(s)?______________________
- Rheumatoid arthritis
- Back or neck pain, sacroiliac pain
- Pain radiating from back down limbs

Please give details for any items checked (when, severity, treatment):
______________________________________________________________
______________________________________________________________
______________________________________________________________
Other

Have you ever passed out during or after exertion? € Yes € No

Do you have a family history of coronary artery disease? € Yes € No

If yes, who?

Do you use (complete the information if your answer is yes):

Tobacco € Yes € No

Cigarettes _____ per day_____
Smokeless _____ per day_____
Pipe _____ per day_____
Cigars _____ per day_____

ALLERGIES

Please list all allergies you have (include pollen, drugs, alcohol, food, animals, etc.):

€ Check this box if you have no allergies

1. ________________________________
2. ________________________________
3. ________________________________
4. ________________________________

______________________________

I, ____________________________, have completed this medical/health history questionnaire honestly and completely as possible.

______________________________
Participant Signature Date

Reviewed and approved for participation:

______________________________
Principal or Student Investigator Date
**TABLE 2. AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire**

Assess your health needs by marking all *true* statements.

**History**

You have had:
- [ ] a heart attack
- [ ] heart surgery
- [ ] cardiac catheterization
- [ ] coronary angioplasty (PTCA)
- [ ] pacemaker/implantable cardiac defibrillator/rhythm disturbance
- [ ] heart valve disease
- [ ] heart failure
- [ ] heart transplantation
- [ ] congenital heart disease

If you marked any of the statements in this section, consult your healthcare provider before engaging in exercise. You may need to use a facility with a medically qualified staff.

**Symptoms**

- [ ] You experience chest discomfort with exertion.
- [ ] You experience unreasonable breathlessness.
- [ ] You experience dizziness, fainting, blackouts.
- [ ] You take heart medications.

Other health issues:

- [ ] You have musculoskeletal problems.
- [ ] You have concerns about the safety of exercise.
- [ ] You take prescription medication(s).
- [ ] You are pregnant.

**Cardiovascular risk factors**

- [ ] You are a man older than 45 years.
- [ ] You are a woman older than 55 years or you have had a hysterectomy or you are postmenopausal.
- [ ] You smoke.
- [ ] Your blood pressure is >140/90.
- [ ] You don’t know your blood pressure.
- [ ] You take blood pressure medication.
- [ ] Your blood cholesterol level is >240 mg/dL.
- [ ] You don’t know your cholesterol level.
- [ ] You have a close blood relative who had a heart attack before age 55 (father or brother) or age 65 (mother or sister).
- [ ] You are diabetic or take medicine to control your blood sugar.
- [ ] You are physically inactive (i.e., you get <30 minutes of physical activity on at least 3 days per week).
- [ ] You are >20 pounds overweight.

- [ ] None of the above is true.

You should be able to exercise safely without consulting your healthcare provider in almost any facility that meets your exercise program needs.

AHA/ACSM indicates American Heart Association/American College of Sports Medicine.
Appendix D

Perceptual Sensation to Heat Stress Test Charts
Borg RPE Chart

BORG SCALE OF PERCEIVED EXERTION

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
Gagge Thermal Sensation Scale

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>Unbearably Cold</td>
</tr>
<tr>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>Very Cold</td>
</tr>
<tr>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>Cold</td>
</tr>
<tr>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>Cool</td>
</tr>
<tr>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td>Neutral (Comfortable)</td>
</tr>
<tr>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>Warm</td>
</tr>
<tr>
<td>5.5</td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td>Hot</td>
</tr>
<tr>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>Very Hot</td>
</tr>
<tr>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>8.0</td>
<td>Unbearably Hot</td>
</tr>
</tbody>
</table>