IMPROVING COGNITIVE FUNCTION FOLLOWING EXERCISE-INDUCED DEHYDRATION: ROLE OF SPORTS DRINK SUPPLEMENTATION

A dissertation submitted to
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CHAPTER I

INTRODUCTION

Strenuous Exercise-Induced Reduction in Cognitive Performance

Approximately 16% of Americans aged 15 years or older engage in sports or exercise activities on an average day, with 60% of those individuals exercising for an hour or more each session (Bureau of Labor Statistics, 2008). Additionally, greater than 3 million individuals in the United States work in positions that require regular strenuous activity, including military service members and firefighters (National Fire Protection Association, 2010; Department of Defense, 2011). Studies show that exercise in moderation promotes a longer, healthier life, with some literature suggesting an increased performance in aspects of cognition temporarily (Brisswalter & Collardeau, 2002). Yet, it is important to understand the potential negative acute effects of strenuous and prolonged exercise to ensure optimal performance and safety for those involved in such activities (Center for Disease Control, 2011).

Few studies have examined the possible adverse effects of strenuous and prolonged physical exertion on cognitive function. Existing work suggests that high-intensity exercise for extended periods of time can be associated with acute reductions in attentional abilities and executive functioning, followed by a return to baseline after recovery (Gaoua et al., 2011; Bandelow et al., 2010; Welsh et al., 2002; Hocking et al.,
lengths of strenuous cycling and found reaction time decreased and errors increased upon completion. This suppression of mental abilities is important, as individuals regularly engaged in prolonged and strenuous physical exertion, such as firefighters and military personnel, likely require the use of continued focus and problem solving skills in order to safely and effectively perform their job-related duties (National Fire Protection Association, 2010; Department of Defense, 2011).

Mechanisms of Exercise-Induced Cognitive Dysfunction

Exercise, particularly in extreme temperatures, can induce physiological states that acutely suppress cognitive function. For example, heat exposure, hyperthermia, and dehydration are known to affect the brain’s ability to function normally and can adversely impact cognitive performance. Less commonly examined, hypoglycemia is another likely contributor to the acute suppression of cognitive function following strenuous and prolonged exercise. Blood glucose levels decline rapidly with exercise and low blood sugar is widely known to impair cognitive functioning (Mayo Clinic, 2010; National Institutes of Health, 2013; Frier, 2001; Golden et al., 1989; Draelos et al., 1995; Graveling, Dreary, & Frier, 2013). The current study sought to determine the independent contribution of hypoglycemia in exercise-induced cognitive dysfunction, while controlling for possible confounds. First, the current literature regarding exercise and hyperthermia/heat exposure and dehydration will be discussed, while later outlining the potential role of reduced blood glucose in this paradigm.
Heat Exposure and Hyperthermia

Much of the literature concerning cognitive function in response to thermal stress inaccurately interchanges the use of the terms hyperthermia and heat exposure; specifically, hyperthermia refers to an internal physiological state, whereas heat exposure describes an environmental condition. Although these terms describe different phenomena, they often co-occur and may combine to exacerbate cognitive dysfunction. Care was taken in the current document to accurately and clearly state specific and combined effects of hyperthermia and heat exposure.

Many physiological changes that occur in response to heat exposure may contribute to acute reductions in cognitive abilities, including those taking place within the brain. For example, cerebral blood flow decreases as blood is moved toward the skin to shed heat and sweating increases to cool the body (Kufe et al., 2003; Nybo et al., 2002; Princeton University, 2010). More extreme heat exposure, potentially present during strenuous exercise or work-related activity, has been linked to neural cell death, edema, and increased blood brain barrier permeability, which leaves the brain more susceptible to toxins (Kiyatkin & Sharma, 2009; Sharma & Johnson, 2007; Bondarenko & Chesler, 2001).

Hyperthermia refers to an increase in core temperature up to 40°C, as the body absorbs heat to the extent it can no longer disperse it and is often the body’s response to extreme temperature exposure (Knochel & Reed, 1994). When unable to compensate for increased body temperature, hyperthermia may manifest as heat illnesses such as heat exhaustion, heat stroke, heat cramps, heat rash, and heat fainting (i.e., heat syncope).
Research examining the adverse effects of hyperthermia on the brain shows structural changes in nerve and glial cells, electrical activity, and neural transmission speed that may compromise the integrity of the brain and its ability to function normally (Sharma & Hoopes, 2003; Hocking et al., 2001).

Despite these possible effects of heat exposure/hyperthermia on brain physiology, studies examining the effects of increased core temperatures on cognitive function have produced inconstant findings. Heat exposure of less than 60 minutes often produces an increase in nerve conduction speed and muscle temperature and may improve reaction time and simple task performance (Hancock & Vasmatzidis, 2003; Saltin et al., 1968; DeJesus et al., 1973). In contrast, prolonged heat exposure, often characterized as greater than 60 minutes, is associated with reduced performance on more complex cognitive tasks (Ramsey & Kwon, 1992). In general, attention, working memory, executive function, and memory are most vulnerable to thermal stress, with complex tasks appearing more susceptible to deficits (Lubit, 2008; Wetsel, 2011; Racinais, Gaous, & Grantham, 2008; Lieberman, 2007; Grocott et al., 2002). However, findings have been mixed and methodological differences and limited methodological control likely account for much of the discrepant outcomes regarding cognitive function in the current literature. These differences include the use of active versus passive heat induction, the presence or absence of cooling techniques employed on the body, and the extent and duration of heat exposure (Racinais, Gaous, & Grantham, 2008; Lieberman, 2007; Bandelow et al., 2010; Ramsey & Kwon, 1992; Pilcher et al., 2002; Riniolo & Schmidt, 2006; Parker et al.,
Thus, future studies should add to the current literature by increasing methodological control.

Dehydration

In addition to heat exposure and hyperthermia, dehydration has also been found to have adverse effects on the brain. Dehydration describes the physiological state in which the body loses more fluid than it consumes and is incapable of maintaining homeostasis (Mayo Clinic, 2011). Mild to moderate symptoms of dehydration include dry mouth, fatigue, thirst, dry skin, and headaches, with more severe symptoms ranging from a lack of sweating to low blood pressure, rapid heartbeat, and fever (Mayo Clinic, 2011). Severe cases of dehydration (over 5% loss of body weight) can include delirium, sometimes described as a “transient acute global cerebral dysfunction,” which is accompanied by severe, acute reductions in mental abilities (Wilson & Morley, 2003). Caselli and Brummer (2004) reported that functionally detrimental and even dangerous levels of dehydration can occur in as little as an hour of exercise. Given the prevalence of this level of exercise in the general population, and with approximately 4-million Americans engaging in greater than or equal to an hour of exercise daily, understanding this phenomenon and its potential adverse effects is important (Bureau of Labor Statistics, 2008).

There are many challenges in accurately studying the neurocognitive effects of dehydration, including appropriate induction of dehydration (e.g., fluid deprivation, exercise, and caffeine intake), utilizing sensitive measures of cognitive function, and minimizing the impact of multiple potential confounds such as subject gender, age,
mood, and expectations (Lieberman, 2012). In addition, factors such as level of hydration at outset of experimental trials and recovery method differences all appear to be important contributors to the variability in test performance (Rogers et al., 2001; Gaoua, 2010).

However, existing studies suggest that severe dehydration is associated with increased ventricular volume in the brain of adults undergoing and following strenuous exercise (Dickson, et al., 2005; Kempton et al., 2010). Neuroimaging suggests that persons suffering from dehydration also have to recruit additional brain regions to achieve the same level of cognitive performance as controls, particularly on executive function tasks (Kempton et al., 2010). Kempton et al. (2009) found an association between ventricle volume and level of dehydration in healthy adolescents and young adults during exercise trials, suggesting more severe dehydration results in more severe neurophysiological changes.

Although the adverse cognitive effects of severe dehydration are consistent across studies, findings for mild to moderate levels of dehydration are more variable. Mild levels of dehydration, frequently operationalized as approximately 1.5% body weight loss, are known to affect mood but not cognition (Ganio et al., 2011; Armstrong et al., 2012; Tomporowski, 2003; Grandjean & Grandjean, 2007; D’Anci et al., 2009). A loss of approximately 2% body weight through exercise has been found to negatively impact performance on complex, but not simple cognitive tasks, with multiple studies demonstrating reduced performance across cognitive domains, including visual memory, psychomotor speed, and information processing speed (Epstein et al., 1980;
Tomporowski, 2007; Gopinathan, Pichan, & Sharma, 1988). Cognitive impairment on simple cognitive tasks is not typically observed until dehydration of 3 to 5% body weight loss is achieved (Bradley & Higenbottam, 2003). Yet the findings in the current literature continue to be inconsistent, as not all studies have found significant cognitive impairment in the presence of moderate dehydration (Lieberman, 2007). Further research is required to best understand this phenomenon, as dehydration and heat exposure/hyperthermia likely do not account for all observed physiological effects and stressors. Thus additional potential mechanisms should be explored.

**Hypoglycemia**

Although less commonly examined in the literature, a likely mechanism for the mixed results in the adverse effects of strenuous exercise on cognitive function is hypoglycemia. Hypoglycemia is a term used to describe temporarily low glucose levels in the blood and ultimately reduced glucose within the brain (Austin & Deary, 1999). Specifically, glucose levels between 70 to 130 milligrams per deciliter (mg/dL) are considered within the normal range before meals, with below 180 mg/dL acceptable for one to two hours post meal (Mayo Clinic, 2010). Low blood sugar can be the consequence of many factors, including limited production of insulin by the pancreas, as often the case for those with diabetes (Mayo Clinic, 2010; National Institutes of Health, 2013). Exercise can also impact blood glucose levels, as the body requires the use of glucose as fuel for activity (McMahon et al., 2007). Strenuous exercise can result in hypoglycemia, as the blood’s level of glucose may become depleted while it is utilized to allow for continued physical activity (Mayo Clinic, 2010; Center for Disease Control and
Prevention; 2013). This reduced level of glucose may manifest as physical symptoms, including shakiness, hunger, nervousness, sweating, dizziness, confusion, visual disturbance, and weakness (Mayo Clinic, 2010; National Institutes of Health, 2013; Center for Disease Control and Prevention; 2013). Reduced blood sugar and subsequent symptoms have been observed across a variety of individuals following strenuous exercise, including both professional and amateur athletes (Rapoport, 2010; Locksley, 1980; di Prampero, et al., 1986; & Billat, et al., 2001).

In addition to these somatic symptoms, hypoglycemia can lead to significant alterations within the brain. Chronic and severe hypoglycemia can result in functional brain failure and brain tissue death following glucose deprivation at the neuronal level (National Diabetes Information Clearinghouse, 2008; Mayo Clinic, 2010; Cryer, 2007; Auer, 1986; Cryer, 2008). Hypoglycemia can also produce hyperexcitation of neurons due to toxins produced by decreased brain glucose, leading to rupture of cell membranes and eventual neuronal death (Auer, 1986).

Chronic and acute hypoglycemic states appear to produce differing effects on cognitive function. Chronic hypoglycemia allows the brain to eventually acclimate to glucose deprivation and such persons often exhibit intact cognitive testing (Warren & Frier, 2005; Austin & Deary, 1999; Wysocki et al., 2003). In contrast, acute hypoglycemia, like that found following strenuous exercise, has been linked to deficits on tasks of attention, reaction time, and executive function (Frier, 2001; Golden et al., 1989; Draelos et al., 1995; Graveling, Dreary, & Frier, 2013).
Hypoglycemia as a Contributor to Exercise-Induced Cognitive Dysfunction

Examining the independent role of hypoglycemia in exercise-induced cognitive dysfunction is difficult, as strenuous exercise often coexists in the presence of heat exposure/hyperthermia and dehydration. To best isolate the independent contribution of hypoglycemia in this paradigm, experimental methods must hold the previously discussed mechanisms constant (i.e., exercise intensity/duration, heat exposure, and dehydration) in order to manipulate and isolate the cognitive effects of blood glucose levels.

One such methodology utilizes a dehydration/rehydration paradigm. In these studies, participants are asked to exercise to varying levels of dehydration and are then rehydrated with different beverage types (e.g. high sugar, low sugar, no sugar) to determine their specific benefits. Such studies rely on the quick spike in blood glucose levels following ingestion of simple carbohydrates (i.e. 15-30 minutes), which can then be correlated to other variables of interest (Foster-Powell, Holt, & Brand-Miller, 2002). This methodology has been successfully utilized in studies examining perceived exertion, mood, hydration level, physical performance, and power output, (O’Neal, et al., 2013; Miller, Mack, & Knight, 2009; Peltier, et al., 2011).

A recent study used a modified version of this approach in a naturalistic project involving soccer players. Bandelow et al. (2010) examined the relative contribution of exercise, heat exposure, and benefits of a glucose-containing sports drink versus water on cognitive function before, at halftime, and immediately following two soccer matches. During the first match, players consumed water ad libitum throughout exertion. During
the second match, they were encouraged to consume extra fluids, whether water or sports
drinks. The amount and type of beverages chosen were recorded and analyses examined
the specific contribution of blood glucose levels to cognitive test performance, utilizing
working memory and visuomotor functioning tasks. Results showed that elevated core
body temperature had a consistent and adverse effect on all aspects of cognitive function.
In contrast, dehydration levels showed a mixed relationship to cognitive function, though
moderate levels of dehydration (>2.5% weight loss) were consistently associated with
poorer performance on tests of more complex mental abilities. Higher blood glucose
levels also showed a complex relationship to cognitive function, with better performance
on simple tasks involving response speed and poorer accuracy on complex tasks of
working memory.

Although this study provides insight into the specific role of blood glucose levels
on working memory and visuomotor functioning, understanding is limited due to four
methodological problems. First, analyses found that increased core temperature had an
independent effect on blood glucose levels above the impact of sports drink ingestion
alone. Controlling for core temperature would benefit analyses by focusing solely on
outcome differences related to blood glucose changes. Second, data collection in this
previous study was naturalistic in manner across multiple soccer matches and weather
conditions. Thus, results may be confounded by differences in participants’ physiological
responses to varied environmental temperature changes across time points (Armstrong,
1998). Third, the sports beverage utilized also included nutritional components other than
carbohydrates (e.g. sodium, potassium, vitamin B12, etc.), which makes it difficult to
determine which element(s) benefitted cognitive function relative to water. Therefore, rehydration with comparable beverages, with the exception of carbohydrate content, would allow for more accurate examination of between-condition differences. Finally, methods were widely unstandardized, as participants hydrated with the beverage type of their choice and were permitted to utilize cooling techniques before and during exertion (i.e., use of an ice water bath for cooling, sitting in a fanned and spritzed tent pre- and during gameplay), which introduced additional methodological confounds. Future research in this area would better serve the limited existing literature by controlling for these variables in order to best isolate the influence of glucose and eliminate the confounds of environmental and behavioral factors. In addition, given executive functioning has been vulnerable to suppression in the context of acute hypoglycemia and following exercise, dehydration, and heat exposure/hyperthermia, this cognitive domain should be examined in this paradigm (Frier, 2001; Golden et al., 1989; Draelos et al., 1995; Graveling, Dreary, & Frier, 2013). By specifically measuring the independent contribution of blood glucose levels on cognitive function following exercise, results would likely benefit those engaged in these activities professionally, such as military personnel, firefighters, and athletes, in addition to the significant percentage of the population regularly engaged in strenuous and prolonged exercise.

Current Study

Blood glucose levels decrease following exercise and cognitive function is often suppressed while individuals are acutely hypoglycemic. The current study sought to determine the independent influence of blood glucose levels in the acute reduction of
cognitive performance following strenuous and prolonged exercise while holding exercise duration and intensity, heat exposure, and dehydration levels constant. To do so, blood glucose levels were manipulated through rehydration with sports beverages containing different levels of sugar across experimental trials.

Hypotheses

The current project sought to test several hypotheses in a highly controlled setting to determine the independent contribution of blood glucose levels to post-exercise cognitive function. Based on previous literature, the current study tested the following hypotheses:

Hypothesis 1: Blood glucose levels will decline following a 120-minute bout of exercise at high temperatures.

Hypothesis 2: Cognitive function will also decline following exercise at high temperatures.

Hypothesis 3: Rehydration following exercise will significantly improve cognitive function.

Hypothesis 4: Rehydration using a full-sugar beverage will produce greater improvements in cognitive function than a zero-sugar beverage.
CHAPTER II

METHODS

The study protocol was approved by the Institutional Review Board at Kent State University. All subjects provided written informed consent before participating.

Study Overview

Healthy adult males presented for a screening session and two counterbalanced experimental trials in a 100°F chamber. Each experimental trial consisted of BASELINE glucose and cognitive function measures, in addition to numerous physiological and psychological measures to serve as control variables during analyses. Participants then completed 120 minutes of exercise on a cycle ergometer, with glucose and cognitive function measured POST-EXERCISE. Next, participants rehydrated with a zero-sugar or full-sugar sports beverage, with measures of glucose and cognitive function repeated immediately POST-REHYDRATION. Finally, after a 15-minute recovery period during which the participants rested while not permitted to drink, they completed experimental measures a final time at POST-RECOVERY.

Participants

A total of 11 English-speaking males between the ages of 18 to 25 were recruited by fliers. Interested persons contacted the research team to obtain detailed study information. Potential participants were excluded if there was the presence or history of
medical, neurological, developmental, or psychiatric disorders or a history of heat illness. No participants were excluded based on these criteria.

One experimental trial was discontinued for safety reasons (i.e., core temperature exceeded safe limit of 39°C), though complete glucose and cognitive function data is available for 10 participants and analyses were conducted on this sample. However, missing data for one individual was found for heart rate and core and chest temperature data, as sensors did not stay in place due to excessive sweating. Similarly, core temperature data was missing for another individual for similar reasons. Given the focus of the current study, these individuals were not replaced and pairwise deletion was used during analyses.

The sample was restricted to Caucasian, non-Hispanic males due to the known differences in thermoregulation across genders and ethnic groups (Bar-Or, 1998; Mehnert et al., 2002; Kelley, 1999; (Kaciuba-Uscilko & Grucza, 2001). Participants averaged 21.9 ±1.97 years of age. Regarding estimated premorbid intellectual functioning, the sample’s mean Spot-the-Word test score was 47 ±2.94, which falls within the average range (Mackinnon & Christensen, 2007). Physically, the participants had a mean body fat percentage of 20.72 ± 4.38, which is in the average range for adult males (American Council on Exercise, 2009). Similarly, VO2max tests at screening yielded a mean score of 37.54±8.81, which is in the average range for untrained, healthy adult males (Heywood, 1998).
Measures

Screening Measures

Self-Report Screening Measures.

*Medical, Neurological, Developmental, and Psychiatric History Questionnaire*. This questionnaire was developed as a screening measure to ensure participant safety. It required individuals to outline potential medical, neurological, developmental, and psychiatric conditions and disorders that may have excluded them from participation in the study or confounded cognitive and physiological data. See Appendix A.

*Heat Illness Symptom Index (HISI)*. The HISI is a self-report questionnaire measuring thirteen common symptoms related to heat illness including swelling, feeling tired, nausea, and confusion. Symptoms are measured on a 10-point Likert scale, with responses ranging from “no symptoms” to “had to stop practice due to symptoms.” Internal consistency has been found to range from .82 to .92, while scaled scores were reportedly significantly correlated in a football sample to observed weight loss during a sports practice (p= 0.006), rating of perceived exertion (p= 0.005), and heat index rating (p= 0.02) (Coris et al., 2006). See Appendix B.

*Heat Injury and Acclimation Questionnaire (HIAQ)*. Previous research has shown that greater acclimation to heat correlates with more adaptive physiological response to heat and preserved task speed accuracy during heat exposure (Wing, 1965; Fox, 1967; Gardner et al., 1996; Cheung & McLellan, 1998; Ramsey et al., 1992;
Radakovic et al., 2007). The HIAQ is a recently developed self-report questionnaire designed to measure heat injury and acclimation in concussion research conducted with collegiate athletes at Kent State University. This measure asks participants to identify symptoms they have experienced on a hot day from a list of 22 items often associated with heat illness, such as extreme thirst, sweating, and nausea. These symptoms were chosen for inclusion as supported by the Center for Disease Control’s description of heat injury (Center for Disease Control, 2009). Additionally, the questionnaire requires individuals to assess the percentage of time they experience muscle cramps in the heat, if they have been previously diagnosed with heat stroke and/or heat exhaustion, and their country/state of origin. See Appendix C.

Physiological screening measures.

**VO2 max.** Aerobic fitness was measured by VO2 max assessment to determine level of exertion required to reach a moderate level of dehydration in 120 minutes of exercise during experimental trials. This measure assessed the maximum capacity of the individual’s body to transport and use oxygen during exercise. Exercise was performed on a mechanically-braked cycle ergometer (Monark Ergomedic 874E), with workloads gradually progressing in increments from moderate to maximal intensity. Expired air was collected and volume measured via Douglas bags. Oxygen uptake was determined at or near test completion. Results were presented as liters of oxygen uptake per minute (l/min). The participants were considered to have reached VO2 max upon hitting a
plateau or 'peaking over' in oxygen uptake (ACSM's Guideline for Exercise Testing and Prescription, 2000).

Cognitive screening measures.

Spot-the-Word Test (STW). The STW test is a self-administered measure developed to estimate premorbid intelligence. Participants were asked to select the real word in a list of 60 word pairs consisting of one actual word and one non-word. Studies suggest the STW test is significantly correlated to other tests of premorbid intellectual ability, with estimates ranging to .83. Additionally, correlation coefficients between the two forms of the STW test ranged to .88. Thus, the literature supports its reliability and validity as a measure of premorbid intelligence (Baddeley, Emslie, & Nimmo-Smith, 1993; Mackinnon & Christensen, 2007). See Appendix D.

Experimental Measures

Self-report experimental measures.

Profile of Mood States- Short form (POMS-SF). Dehydration and other adverse physiological stressors have been shown to have a negative impact on an individual’s report of mood state (D’Anci et al, 2009; Choma, Sforzo, & Keller, 1998). Such mood changes can then impact cognitive function (Herrmann, Le Masurier, & Ebmeier, 2008; Nebes et al., 2003). The POMS-SF is a 37 item, condensed version of the original POMS which preserves the measure’s six domains of mood disturbance. The questionnaire consists of a five-point Likert scale, with mood-related items that provide answers
ranging from “not at all” to “extremely”. The POMS-SF yields six subscales including fatigue-inertia, vigor-activity, tension-anxiety, depression-dejection, anger-hostility, and confusion-bewilderment. In terms of psychometrics of the shortened mood measure, internal consistency has been found to range from .76 to .95 for the subscales and from .87 to .92 for the total score of the POMS-SF. Additionally, correlations between POMS-SF and original POMS total mood disturbance and subscale scores are estimated to exceed .95 (Curran, Andrykowski, & Studts, 1995). Correlations with the other mood measures supported the convergent and discriminant validity of the POMS-SF (Baker et al., 2002). See Appendix E.

*Thermal sensation scale.* Thermal sensation was measured using the Gagge Thermal Sensation Scale and the Modified Gagge Thermal Sensation Scale, both valid and reliable measures of subjective whole body thermal sensation (Gagge, Stolwijk, & Hardy, 1967; Glickman-Weiss et al., 1994). Participants were asked to quantify their thermal sensation utilizing these scales. See Appendices F and G.

*Rating of perceived exertion (RPE).* The Borg RPE is a tool used to measure an individual’s sensation of exertion during physical activity. Participants were asked to rate their perceived exertion based on Borg’s scale, ranging from “no exertion at all” (6) to “maximal exertion” (20) during the exercise bouts. Their described ratings were recorded. Borg (2005) found this rating of exertion scale to be highly correlated to an individual’s heart rate during physical activity (Borg, 2005; Center for Disease Control, 2011). See Appendix H.
Cognitive function experimental measures.

*Automated Neuropsychological Assessment Metrics- 4th Edition (ANAM4)*. The ANAM4 is a computerized cognitive test battery first developed by the Department of Defense with subtests designed to assess a variety of cognitive domains. Specific subtests utilized include the Running Memory Continuous Performance Task (RMCPT), a measure of sustained attention and concentration, and Logical Relations (LR), a measure of abstract reasoning and executive function. RMCPT necessitates that the individual, once presented with single characters on the screen, press “designated buttons to indicate if the displayed character matches or does not match the preceding character”. LR requires the individual to “evaluate the truth of the statement (e.g., “& comes after #”),” describing the order of two symbols displayed on the screen (e.g., “& #”) (ANAM4 Test Manual). The user is then asked to determine if the statement is true or false.

Analyses involving cognitive function variables utilized the ANAM4’s throughput scores, which have been well-supported in the literature to measure efficiency through a combination of reaction time and accuracy (ANAM4 User Guide, 2008). These subtests are significantly correlated to other empirically-supported neuropsychological tests measuring these constructs (Roebuck-Spencer et al., 2006; Kane et al., 2007).

Physiological experimental measures.

*Blood glucose*. Traditional, at-home blood glucose measuring tools were utilized to quantify blood glucose levels. Researchers were trained to use a lancet to prick the side of the participant’s non-dominant pointer finger, putting a drop of blood on a test
strip and then placing the strip into a meter that will display blood glucose levels. The meter displayed whole blood glucose readings in milligrams of glucose per deciliter of blood (mg/dl) and readings were recorded for each participant (Mayo Clinic, 2010).

*Heart rate.* Polar heart rate monitors (Accurex Plus, Polar Electro, Inc., Woodbury, NY) were utilized to continuously measure participant heart rate throughout the exercise bouts. Recordings were taken every 5 minutes.

*Metabolic performance.* Metabolic performance has been positively linked to cognitive function and those experiencing poorer metabolic fitness have demonstrated significant cognitive decline over time as compared to healthy controls (Barnes et al., 2003; Brooks et al., 1984). Participants’ metabolic performances were assessed by way of a Parvo metabolic measurement system (Parvo, Metabolic Cart, Sandy, Utah), which analyzes expired air samples via an indirect automated open circuit system to determine oxygen consumption. This system is frequently used as a reliable measure of gas exchange (Crouter et al., 2006; Cooper et al., 2009). The accuracy of O2 and CO2 analyzer is 0.1%, and the accuracy of flow/measurement is ±2% with Precision ‘Yeh’ Algorithm (Parvo, Metabolic Cart, Sandy, Utah).

*Core temperature (Tcore).* Tcore (°C) was measured using a rectal thermistor. Participants inserted the rectal thermistor 13 cm beyond the anal sphincter (ER 400-12, O.E. Meyer Co., Sandusky, Ohio). Tcore data was collected using an interface (iNet-100HC, Omega Engineering, Inc., Stamford, Connecticut) connected to a personal computer and continuously recorded.
Skin temperature (Tsk). Skin temperature (°C) was measured with skin thermistors (Model 409B, Yellow Springs Instruments Inc., Dayton, Ohio). These thermistors were placed using waterproof tape on the participant’s right chest, forearm, thigh, calf, and tricep (Toner & McArdle, 1986). Tsk data was also collected using an interface (iNet-100HC, Omega Engineering, Inc., Stamford, Connecticut) connected to a personal computer and were continuously recorded.

Experimental instrumentation.

Environmental chamber. To ensure standardized heat exposure during experimental trials, a climatic and environmentally controlled chamber (Western Environmental, Franklin, OH) was utilized and set to 100°F during both experimental trials.

Ergometer. Exercise was completed using a cycle ergometer Excalibur 1300W (Lode Excalibur, Lode, Groningen, the Netherlands). Participants exercised at an intensity of 60% of their VO2 max.

Sports Drink Beverages

Participants were rehydrated with a full- or zero-sugar beverage, with the beverage order being randomized.

Powerade. The full-sugar beverage utilized in the current protocol was Powerade Fruit Punch. This sports drink was designed to replenish electrolytes lost in the process of
sweating. It includes 6% carbohydrates (22 grams per serving) derived from glucose and fructose (The Coca Cola Company, 2013).

Powerade Zero. In contrast, Powerade Zero Fruit Punch was used as the essentially comparable zero-sugar sports drinks. This beverage has been similarly designed to provide electrolytes and energy to the body following significant loss from sweating (The Coca Cola Company, 2013). However, rather than carbohydrates (less than one gram per serving), this beverage derives flavor from sucralose and acesulfame potassium. These chemicals have been found to be safe for consumption and, unlike other various sugar substitutes, have not been found to produce negative cognitive side effects (Tandel, 2011). Thus, this beverage is similar to Powerade Fruit Punch, with the exception of its lack of carbohydrate.

Procedures

Screening Procedures

Participants presented for a 30-minute screening session prior to the experimental trials. During this screening, participants completed a medical/developmental/neurologic/psychiatric history questionnaire, HISI, HIAQ, Metabolic Performance Test, STW, ANAM tests (LR and RMCPT), and POMS-SF. VO2max tests were performed to identify each participant's physical fitness level to determine the appropriate level of exertion required during exercise bouts. See Figure 1.
Pre-trial standardization.

Following completion of the screening session, eligible participants were provided pre-trial instructions to optimize standardization and post-exercise dehydration. Participants were asked to complete a dietary journal three days prior to each experimental trial. During the day prior to each experimental trial, participants were further asked to ingest three liters of water. The night prior to each trial, participants were given a standardized, low sodium dinner (i.e., low sodium frozen pizza), while permitted to supplement with fruits and vegetables. Participants were also asked to abstain from exercise, smoking, and illicit drug and alcohol use one day prior to experimental trials. These trials were separated by at least two days to best allow muscle recovery and completed at the same time of day to prevent diurnal effects. Upon presenting for each

<table>
<thead>
<tr>
<th>Measures</th>
<th>Approx. 50 Mins.</th>
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<tbody>
<tr>
<td>VO2</td>
<td></td>
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<tr>
<td>VO2Max</td>
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<tr>
<td>Max HR</td>
<td></td>
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<tr>
<td>BMI</td>
<td></td>
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<tr>
<td>Height</td>
<td></td>
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<tr>
<td>Weight</td>
<td></td>
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</tbody>
</table>

Figure 1. Screening Protocol
trial, participants were required to drink 32 ounces of water and were provided a standardized breakfast consisting of a banana and bagel. See Appendix I.

Experimental BASELINE.

Participants presented for two counterbalanced experimental trials (i.e. zero-sugar versus full-sugar drink), each lasting approximately three hours and separated by at least two days. Participants arrived in the morning, typically between 5:00 and 9:00 a.m.

While blood glucose levels and cognitive function were the measures of primary interest, the protocol assessed a number of variables to control for potential confounds and isolate the independent contribution of blood glucose levels to cognitive function. BASELINE measures of blood glucose, ANAM tests, and body weight were assessed, in addition to POMS-SF, metabolic performance, Gagge, Modified Gagge, and RPE collected in an environmentally-controlled chamber set at 100°F. Participants remained in this chamber for the duration of each experimental trial. See Figure 2.

<table>
<thead>
<tr>
<th>Measures</th>
<th>Approx. 10 Mins.</th>
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</thead>
<tbody>
<tr>
<td>RPE</td>
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<tr>
<td>GAGGE</td>
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<tr>
<td>Modified GAGGE</td>
<td></td>
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<tr>
<td>VO2/ Metabolic</td>
<td></td>
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<tr>
<td>Glucose</td>
<td></td>
</tr>
<tr>
<td>Weight (lbs)</td>
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</tbody>
</table>

*Figure 2. Baseline Protocol*
Experimental Exercise Bouts and POST-EXERCISE Measurements

Participants then cycled on a cycle ergometer at 60% of their VO2max in the environmental chamber for a total of 120 minutes, with a five minute break for every 25 minutes of exercise. Within each exercise block, temperature and heart rate were measured continuously, with metabolic performance, RPE, Gagge, and Modified Gagge scores collected during the last five minutes of each cycling block. During each five minute break, the participant’s POMS-SF, blood glucose, and weight were measured. Immediately following the completion of exercise, measures of blood glucose and ANAM test data were collected, in addition to potential confounding variables (i.e., POMS-SF, Gagge, and Modified Gagge) POST-EXERCISE. Participants were also weighed POST-EXERCISE in order to characterize percentage of weight loss through sweating from BASELINE, as a measure of dehydration level. See Figures 3 and 4.

Experimental Hydration Period

Following these POST-EXERCISE assessments, participants randomly received hydration of a zero-sugar or full-sugar sports beverage and were hydrated with the opposite beverage upon the second experimental trial. Participants were permitted to drink an unlimited amount of the beverage during this fifteen minute period of hydration. The quantity consumed by each participant was recorded. See Figure 5.
**Figure 3. Exercise Protocol**

<table>
<thead>
<tr>
<th>Measures</th>
<th>Approx. 10 Mins.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPE</td>
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<tr>
<td>VO2/Metabolic</td>
<td></td>
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<tr>
<td>Glucose</td>
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<tr>
<td>Weight</td>
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<tr>
<td>T&lt;sub&gt;SK CHEST&lt;/sub&gt;</td>
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<tr>
<td>T&lt;sub&gt;ARM&lt;/sub&gt;</td>
<td></td>
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<tr>
<td>T&lt;sub&gt;THIGH&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>T&lt;sub&gt;CALF&lt;/sub&gt;</td>
<td></td>
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<tr>
<td>T&lt;sub&gt;TRICEP&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>HR</td>
<td></td>
</tr>
</tbody>
</table>

*Note: Boxes in white represent when measures were taken.

**Note: HR and temperatures measured continuously throughout experimental trials.

**Figure 4. Post-Exercise Protocol**
Measures | 15 Mins.
--- | ---
GAGGE | 
Modified GAGGE | 
VO2 | 
Glucose | 
Weight | 

*Figure 5. Hydration Protocol*

Experimental Rehydration Period and POST-REHYDRATION Measurements

After 15 minutes of rehydration, participants were still permitted to drink for an additional 15 minutes while blood glucose and ANAM test data, in addition to metabolic performance, POMS-SF, Gagge, and Modified Gagge, were assessed at POST-REHYDRATION. The total amount of liquid consumed was recorded for each participant following this period. See Figure 6.

Measures | 15 Mins.
--- | ---
GAGGE | 
Modified AGGE | 
VO2 | 
Glucose | 
Weight | 

*Figure 6. Post-Rehydration Protocol*
**Experimental Recovery Period**

Following POST-REHYDRATION data collection, participants then rested in the heated chamber for an additional 15 minutes to ensure optimal glucose absorption, in which they refrained from further hydration and activity. At POST-RECOVERY, blood glucose and ANAM data were collected a final time, in addition to metabolic performance, POMS-SF, Gagge, and Modified Gagge measures. As stated previously, following the participant’s first experimental trial, they then each presented for an identical trial, with the exception of the sugar content of the rehydration beverage. That is, if rehydrated with the zero-sugar beverage at the first trial, he was then rehydrated with the full-sugar beverage upon the second trial. See Figure 7.

<table>
<thead>
<tr>
<th>Measures</th>
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</thead>
<tbody>
<tr>
<td>GAGGE</td>
<td></td>
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<tr>
<td>Modified GAGGE</td>
<td></td>
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<tr>
<td>VO2</td>
<td></td>
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<tr>
<td>Glucose</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 7. Post-Recovery Protocol*
Data Analyses

Preliminary Analyses

Descriptive statistics (i.e., means and standard deviations) were calculated for demographic and medical history variables of interest. See Tables 1, 2, and 3. In addition, cognitive variables were evaluated in regard to statistical assumptions, including

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Baseline</th>
<th>Post-Exercise</th>
<th>Post-Rehydration</th>
<th>Post-Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Glucose</td>
<td>115.3(19.6)</td>
<td>95.5(7.4)</td>
<td>163.8(13.8)</td>
<td>139.8(42.5)</td>
<td></td>
</tr>
<tr>
<td>2. POMS-SF</td>
<td>-2.60(11.5)</td>
<td>7.40(9.8)</td>
<td>4.60(9.0)</td>
<td>0.40(0.8)</td>
<td></td>
</tr>
<tr>
<td>3. Gagge Sensation</td>
<td>1.50(0.7)</td>
<td>2.00(1.1)</td>
<td>1.30(0.8)</td>
<td>0.90(1.3)</td>
<td></td>
</tr>
<tr>
<td>4. Gagge Comfort</td>
<td>0.90(1.37)</td>
<td>-0.30(1.16)</td>
<td>0.50(1.27)</td>
<td>0.70(1.57)</td>
<td></td>
</tr>
<tr>
<td>5. Modified Gagge</td>
<td>1.35(1.4)</td>
<td>2.90(2.5)</td>
<td>1.35(1.2)</td>
<td>0.95(0.8)</td>
<td></td>
</tr>
<tr>
<td>6. HR</td>
<td>86.33(14.8)</td>
<td>120.78(19.0)</td>
<td>100.67(17.5)</td>
<td>103.67(17.1)</td>
<td></td>
</tr>
<tr>
<td>7. VO2</td>
<td>4.85(1.3)</td>
<td>4.88(1.5)</td>
<td>4.91(1.1)</td>
<td>5.51(1.0)</td>
<td></td>
</tr>
<tr>
<td>8. Core Temperature</td>
<td>37.25(0.3)</td>
<td>37.84(1.2)</td>
<td>37.74(0.8)</td>
<td>37.37(0.8)</td>
<td></td>
</tr>
<tr>
<td>9. Chest Temperature</td>
<td>35.38(0.7)</td>
<td>36.59(1.4)</td>
<td>36.39(1.2)</td>
<td>36.14(2.1)</td>
<td></td>
</tr>
<tr>
<td>10. Forearm Temperature</td>
<td>35.40(1.2)</td>
<td>36.87(0.9)</td>
<td>36.69(0.7)</td>
<td>36.32(0.6)</td>
<td></td>
</tr>
<tr>
<td>11. Thigh Temperature</td>
<td>34.85(0.8)</td>
<td>36.50(1.0)</td>
<td>35.93(0.8)</td>
<td>35.19(0.8)</td>
<td></td>
</tr>
<tr>
<td>12. Calf Temperature</td>
<td>34.78(0.7)</td>
<td>32.55(12.1)</td>
<td>36.14(1.5)</td>
<td>35.34(1.5)</td>
<td></td>
</tr>
<tr>
<td>13. Tricep Temperature</td>
<td>39.14(1.2)</td>
<td>37.04(0.8)</td>
<td>37.37(0.9)</td>
<td>35.89(2.8)</td>
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<tr>
<td>14. LR</td>
<td>1.40(0.1)</td>
<td>1.43(0.2)</td>
<td>1.39(0.2)</td>
<td>1.42(0.2)</td>
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</tr>
<tr>
<td>15. RMCPT</td>
<td>1.89(0.1)</td>
<td>1.92(0.1)</td>
<td>1.91(0.1)</td>
<td>1.91(0.1)</td>
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</tr>
</tbody>
</table>
Table 2. Means (Standard Deviations) of Physical, Psychological, and Cognitive Variables during the Zero-Sugar Condition

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline</th>
<th>Post-Exercise</th>
<th>Post-Rehydration</th>
<th>Post-Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Glucose</td>
<td>127.1(23.14)</td>
<td>97.1(7.30)</td>
<td>95.7(14.77)</td>
<td>95.2(17.91)</td>
</tr>
<tr>
<td>2. POMS-SF</td>
<td>-4.30(8.5)</td>
<td>1.50(10.2)</td>
<td>-0.50(9.1)</td>
<td>-2.50(4.9)</td>
</tr>
<tr>
<td>3. Gagge Sensation</td>
<td>1.50(0.7)</td>
<td>1.80(0.9)</td>
<td>0.90(0.6)</td>
<td>1.30(0.7)</td>
</tr>
<tr>
<td>4. Gagge Comfort</td>
<td>0.50(0.85)</td>
<td>-0.30(1.16)</td>
<td>0.50(0.71)</td>
<td>0.80(0.92)</td>
</tr>
<tr>
<td>5. Modified Gagge</td>
<td>0.90(0.5)</td>
<td>1.65(1.4)</td>
<td>0.90(1.2)</td>
<td>0.80(0.3)</td>
</tr>
<tr>
<td>6. HR</td>
<td>82.11(13.7)</td>
<td>113.89(20.4)</td>
<td>87.56(11.5)</td>
<td>93.22(16.4)</td>
</tr>
<tr>
<td>7. VO2</td>
<td>5.48(2.7)</td>
<td>4.42(0.9)</td>
<td>4.18(0.7)</td>
<td>4.26(1.18)</td>
</tr>
<tr>
<td>8. Core Temperature</td>
<td>37.01(0.5)</td>
<td>37.94(0.5)</td>
<td>37.72(0.5)</td>
<td>37.02(1.2)</td>
</tr>
<tr>
<td>9. Chest Temperature</td>
<td>35.43(0.6)</td>
<td>35.75(1.0)</td>
<td>35.84(0.8)</td>
<td>35.71(1.4)</td>
</tr>
<tr>
<td>10. Forearm Temperature</td>
<td>35.47(0.8)</td>
<td>36.40(1.5)</td>
<td>36.16(1.1)</td>
<td>36.52(0.8)</td>
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<td>11. Thigh Temperature</td>
<td>35.02(0.8)</td>
<td>36.42(1.0)</td>
<td>36.18(1.1)</td>
<td>35.84(0.9)</td>
</tr>
<tr>
<td>12. Calf Temperature</td>
<td>34.78(0.6)</td>
<td>36.49(0.8)</td>
<td>35.53(1.1)</td>
<td>35.67(1.1)</td>
</tr>
<tr>
<td>13. Tricep Temperature</td>
<td>34.98(0.6)</td>
<td>37.04(0.8)</td>
<td>37.37(0.9)</td>
<td>36.40(0.9)</td>
</tr>
<tr>
<td>14. LR</td>
<td>1.40(0.2)</td>
<td>1.45(0.2)</td>
<td>1.38(0.2)</td>
<td>1.43(0.3)</td>
</tr>
<tr>
<td>15. RMCPT</td>
<td>1.91(0.1)</td>
<td>1.93(0.1)</td>
<td>1.93(0.1)</td>
<td>1.96(0.0)</td>
</tr>
</tbody>
</table>

Table 3. Means (Standard Deviations) of RPE Scores by Condition

<table>
<thead>
<tr>
<th>RPE Full-Sugar Scores</th>
<th>Baseline</th>
<th>Exercise 1</th>
<th>Exercise 2</th>
<th>Exercise 3</th>
<th>Exercise 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. RPE Full-Sugar Scores</td>
<td>0.30(0.7)</td>
<td>2.80(0.9)</td>
<td>3.40(0.8)</td>
<td>4.50(1.4)</td>
<td>5.90(2.3)</td>
</tr>
<tr>
<td>2. RPE Zero-Sugar Scores</td>
<td>0.30(0.5)</td>
<td>2.50(0.9)</td>
<td>3.30(1.4)</td>
<td>4.00(2.2)</td>
<td>4.00(2.2)</td>
</tr>
</tbody>
</table>

normality (i.e., as evaluated using histograms and skewness and kurtosis statistics), homogeneity of variance (i.e., by comparing within-group variances), and sphericity (i.e., by examining Mauchly’s test of sphericity), as applicable to repeated measures ANOVA. Cognitive variables (i.e., LR and RMCPT throughput scores) violated the assumption of sphericity and were transformed as appropriate, utilizing a logarithmic method. Other variables were not examined using the same approach, as these physiological indices
would not be expected to conform to a normal distribution (e.g. temperature changes due to heat exposure and exercise are not normally distributed) but were examined in regards to known physiological responses to these stressors. Pearson and Spearman correlations were conducted to examine the relationship between cognitive test performance and possible covariates, with significant correlations indicating the potential need to control for such confounds. Potential covariates examined included metabolic performance, VO2 max, estimated premorbid intelligence, POMS-SF, RPE, core temperature, and amount of liquid consumed during rehydration period. See Tables 4, 5, 6, and 7. In addition, POMS-SF, Gagge and Modified Gagge, RPE, heart rate, metabolic performance, and core and skin temperatures (i.e., chest, arm, thigh, calf, and tricep temperatures) were examined via repeated measures ANOVA to assess values over time. Specifically, main effects of condition were of primary interest, as differences between zero- and full-sugar conditions were not expected and their presence may impact cognitive function findings above and beyond the impact of blood glucose levels alone. See Table 8. Finally, paired samples t-tests were utilized to determine potential between-condition differences in the amount of beverage consumed by participants.

Table 4. Pearson and Spearman Correlations between LR Scores during the Full-Sugar Condition and Potential Covariates

<table>
<thead>
<tr>
<th></th>
<th>STW</th>
<th>POMS-SF</th>
<th>% Body Fat</th>
<th>VO2Max</th>
<th>Liquid Total</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. LR Baseline</td>
<td>0.29</td>
<td>0.07</td>
<td>0.15</td>
<td>0.38</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>2. LR Post-Exercise</td>
<td>0.41</td>
<td>-0.20</td>
<td>-0.13</td>
<td>0.16</td>
<td>0.14</td>
<td>-0.20</td>
</tr>
<tr>
<td>3. LR Post-Rehydration</td>
<td>0.43</td>
<td>0.02</td>
<td>0.20</td>
<td>0.02</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>4. LR Post-Recovery</td>
<td>0.33</td>
<td>-0.36</td>
<td>0.32</td>
<td>-0.16</td>
<td>-0.17</td>
<td></td>
</tr>
</tbody>
</table>

Note: No correlations were significant.
Table 5. *Pearson and Spearman Correlations between LR Scores during the Zero-Sugar Condition and Potential Covariates*

<table>
<thead>
<tr>
<th></th>
<th>STW</th>
<th>POMS-SF</th>
<th>% Body Fat</th>
<th>VO2Max</th>
<th>Liquid Total</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. LR Baseline</td>
<td>0.44</td>
<td>-0.05</td>
<td>0.19</td>
<td>0.27</td>
<td>-0.06</td>
<td></td>
</tr>
<tr>
<td>2. LR Post-Exercise</td>
<td>0.43</td>
<td>-0.44</td>
<td>0.24</td>
<td>0.12</td>
<td>-0.17</td>
<td>-0.09</td>
</tr>
<tr>
<td>3. LR Post-Rehydration</td>
<td>0.36</td>
<td>0.01</td>
<td>0.21</td>
<td>0.28</td>
<td>-0.01</td>
<td></td>
</tr>
<tr>
<td>4. LR Post-Recovery</td>
<td>0.28</td>
<td>-0.13</td>
<td>-0.17</td>
<td>-0.05</td>
<td>0.31</td>
<td></td>
</tr>
</tbody>
</table>

Note: No correlations were significant.

Table 6. *Pearson and Spearman Correlations between RMCPT Scores during the Full-Sugar Condition and Potential Covariates*

<table>
<thead>
<tr>
<th></th>
<th>STW</th>
<th>POMS-SF</th>
<th>% Body Fat</th>
<th>VO2Max</th>
<th>Liquid Total</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. RMCPT Baseline</td>
<td>0.39</td>
<td>-0.46</td>
<td>0.56</td>
<td>0.19</td>
<td>-0.18</td>
<td></td>
</tr>
<tr>
<td>2. RMCPT Post-Exercise</td>
<td>0.49</td>
<td>-0.35</td>
<td>-0.12</td>
<td>-0.07</td>
<td>0.17</td>
<td>-0.26</td>
</tr>
<tr>
<td>3. RMCPT Post-Rehydration</td>
<td>0.59</td>
<td>-0.13</td>
<td>0.26</td>
<td>0.16</td>
<td>-0.00</td>
<td></td>
</tr>
<tr>
<td>4. RMCPT Post-Recovery</td>
<td>0.59</td>
<td>-0.17</td>
<td>0.00</td>
<td>0.42</td>
<td>0.19</td>
<td></td>
</tr>
</tbody>
</table>

Table 7. *Pearson and Spearman Correlations between RMCPT Scores during the Zero-Sugar Condition and Potential Covariates*

<table>
<thead>
<tr>
<th></th>
<th>STW</th>
<th>POMS-SF</th>
<th>% Body Fat</th>
<th>VO2Max</th>
<th>Liquid Total</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. RMCPT Baseline</td>
<td>0.03</td>
<td>0.04</td>
<td>-0.22</td>
<td>-0.04</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>2. RMCPT Post-Exercise</td>
<td>0.63</td>
<td>-0.23</td>
<td>0.16</td>
<td>0.38</td>
<td>0.06</td>
<td>-0.52</td>
</tr>
<tr>
<td>3. RMCPT Post-Rehydration</td>
<td>0.49</td>
<td>-0.09</td>
<td>0.25</td>
<td>0.30</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>4. RMCPT Post-Recovery</td>
<td>0.19</td>
<td>-0.53</td>
<td>0.11</td>
<td>-0.05</td>
<td>0.19</td>
<td></td>
</tr>
</tbody>
</table>

Note: No correlations were significant.
Table 8: ANOVA values and Effect Sizes for Physical and Psychological Variables over Time and between Full- and Zero-Sugar Conditions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time</th>
<th>Condition</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F, p</td>
<td>$\eta^2$</td>
<td>F, p</td>
</tr>
<tr>
<td>1. Glucose</td>
<td>9.62, 0.00</td>
<td>0.52</td>
<td>29.89, 0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>23.01, 0.00</td>
</tr>
<tr>
<td>2. POMS-SF</td>
<td>4.90, 0.01</td>
<td>0.35</td>
<td>13.32, 0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.76, 0.53</td>
</tr>
<tr>
<td>3. Gagge Sensation</td>
<td>3.45, 0.03</td>
<td>0.28</td>
<td>0.08, 0.79</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.66, 0.20</td>
</tr>
<tr>
<td>4. Gagge Comfort</td>
<td>12.34, 0.00</td>
<td>0.58</td>
<td>0.10, 0.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.43, 0.73</td>
</tr>
<tr>
<td>5. Modified Gagge</td>
<td>5.59, 0.00</td>
<td>0.38</td>
<td>3.63, 0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.97, 0.42</td>
</tr>
<tr>
<td>6. RPE</td>
<td>39.34, 0.00</td>
<td>0.81</td>
<td>2.83, 0.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.84, 0.00</td>
</tr>
<tr>
<td>7. HR</td>
<td>13.98, 0.00</td>
<td>0.63</td>
<td>3.45, 0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.42, 0.74</td>
</tr>
<tr>
<td>8. VO2</td>
<td>1.47, 0.25</td>
<td>0.14</td>
<td>2.23, 0.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.30, 0.10</td>
</tr>
<tr>
<td>9. Core Temperature</td>
<td>3.10, 0.05</td>
<td>0.31</td>
<td>0.33, 0.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.77, 0.52</td>
</tr>
<tr>
<td>10. Chest Temperature</td>
<td>1.69, 0.20</td>
<td>0.17</td>
<td>3.65, 0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.62, 0.61</td>
</tr>
<tr>
<td>11. Arm Temperature</td>
<td>5.27, 0.01</td>
<td>0.40</td>
<td>0.74, 0.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.91, 0.45</td>
</tr>
<tr>
<td>12. Thigh Temperature</td>
<td>19.53, 0.00</td>
<td>0.71</td>
<td>0.67, 0.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.54, 0.66</td>
</tr>
<tr>
<td>13. Calf Temperature</td>
<td>0.32, 0.81</td>
<td>0.04</td>
<td>0.75, 0.41</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.03, 0.40</td>
</tr>
<tr>
<td>14. Tricep Temperature</td>
<td>0.16, 0.92</td>
<td>0.02</td>
<td>1.61, 0.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.97, 0.42</td>
</tr>
</tbody>
</table>

Hypothesis testing. Primary analyses required the examination of effects across time (BASELINE, POST-EXERCISE, POST-REHYDRATION, and POST-RECOVERY) and between conditions (zero- versus full-sugar beverage rehydration intervention) in blood glucose levels and cognitive test performance (LR and RMCPT). Repeated measures ANOVA were employed to test study hypotheses. This approach was selected as it is most frequently used in past studies examining cognitive function after physiological stress (Krausman, Crowell, & Wilson, 2002). First, repeated measures ANOVA compared differences in blood glucose levels across BASELINE, POST-EXERCISE, POST-REHYDRATION, and POST-RECOVERY time points and beverage
type. With regard to cognitive function (i.e. LR and RMCPT throughput scores from the
ANAM4), multiple repeated measures ANOVA investigated differences across
conditions and specific time points of interest in relation to study hypotheses, rather than
the omnibus effect across all possible comparisons (Keppel & Zedeck, 2001). Thus,
planned comparisons examined BASELINE to POST-EXERCISE, POST-EXERCISE to
POST-REHYDRATION, POST-REHYDRATION to POST-RECOVERY, and POST-
EXERCISE directly to POST-RECOVERY cognitive values.
CHAPTER III

RESULTS

Preliminary Analyses

Tests of Statistical Assumptions

Scores from cognitive testing were examined to ensure they met statistical assumptions. Histograms for both LR and RMCPT throughput scores indicated the assumption of normality was not met. Further, LR scores also violated the assumption of sphericity (Mauchly’s W = 0.22, p<0.001). Logarithmic transformations were performed for both of these measures and yielded normal distributions for LR and RMCPT scores.

Examination of Potential Covariates

Bivariate Pearson and Spearman correlations were then used to identify possible covariates of cognitive function to be used in primary analyses. Analyses revealed no significant confounds and no additional variables were utilized in primary study analyses. Please see Tables 4, 5, 6, and 7.

Changes in physiological and psychological states over time.

Blood glucose. Blood glucose levels were examined across the four experimental time points. Significant main effects emerged for time (F(3,27)=9.62,
p<0.01; η_p^2=0.52) and condition (F(1,9)=29.89, p<0.01; η_p^2=0.77), in the context of a significant interaction of time by condition (F(3,27)=23.01, p<0.01; η_p^2=0.72), consistent with their large effect sizes. As expected, post hoc analyses revealed that glucose levels significantly decreased at POST-EXERCISE (F(1,9)=16.93, p<0.01), increased at POST-REHYDRATION (F(1,9)=69.70, p<0.01), and decreased again at POST-RECOVERY (F(1,9)=6.50, p=0.03).

Examination of the condition main effect showed similar glucose levels between the two rehydration beverage conditions at POST-EXERCISE (F(1,9)=3.41, p=0.10), while participants in the full-sugar condition had significantly higher blood glucose levels at POST-REHYDRATION (F(1,9)=67.59, p<0.01) and POST-RECOVERY (F(1,9)=51.38, p<0.01) than those in the zero-sugar condition.

The interaction effect was significant from POST-EXERCISE to POST-REHYDRATION (F(1,9)=509.53, p<0.01), as individuals rehydrated with the zero-sugar beverage demonstrated stable glucose levels between these time points, while blood sugar levels increased for those in the full-sugar condition. See Figure 8.

POMS-SF. Repeated measures ANOVA examining mood (i.e., POMS-SF total scores, with higher scores indicative of greater mood-related symptoms and thus poorer mood) across the four experimental time points revealed significant main effects for time (F(3,27)=4.90, p<0.01; η_p^2=0.35) and condition (F(1,9)=13.32, p<0.01; η_p^2=0.60), in the absence of a significant interaction of time by condition (F(3,27)=0.76, p=0.53; η_p^2=0.08). Therefore, there were significant differences over experimental time points and between conditions, without significant differences in time by condition.
Note: 1= Baseline, 2= Post-Exercise, 3= Post-Rehydration, and 4= Post-Recovery.

*Figure 8. Glucose Over Time by Condition*

Post hoc repeated measures ANOVA determined that POMS-SF scores and reported mood-related concerns significantly increased over time (i.e., indicating poorer mood) from BASELINE to POST-EXERCISE ($F(1,9)=9.157$, $p=0.01$), remained stable from POST-EXERCISE to POST-REHYDRATION ($F(1,9)=4.07$, $p=0.07$), and also stable from POST-REHYDRATION to POST-RECOVERY ($F(1,9)=4.64$, $p=0.06$).

Thus, reported mood was worse following exercise in a heated chamber and did not significantly improve following ingestion of cold beverage or while resting in the heated chamber.

In clarifying the main effect of condition on mood symptoms, analyses showed that participants reported poorer mood during the full-sugar condition than the zero-sugar condition at POST-REHYDRATION ($F(1,9)=9.5$, $p=0.01$) and POST-RECOVERY.
(F(1,9)=8.58, p=0.02). There was a similar trend at POST-EXERCISE (F(1,9)=4.92, p=0.054); however, conditions would not be expected to exhibit differences in mood at this time point, as the beverage intervention had not yet been administered. See Figure 9.

Note: 1= Baseline, 2= Post-Exercise, 3= Post-Rehydration, and 4= Post-Recovery. Higher scores are indicative of greater mental health concerns.

*Figure 9. POMS-SF Full Score over Time by Condition*

Gagge Sensation. Subjects reported Gagge Sensation scores across the four experimental time points. Analyses found a significant main effect for time (F(3,27)=3.45, p=0.03), in the absence of a significant main effect for condition (F(1,9)=0.08, p=0.79) or interaction of time by condition (F(3,27)=1.66, p=0.20). Therefore, there were significant differences in Gagge Sensation scores over time, without significant differences by condition or time by condition.
Regarding the significant main effect for time, post hoc repeated measures ANOVA found that Gagge Sensations scores were stable from BASELINE to POST-EXERCISE (F(1,9)=2.67, p=0.14), with significantly cooler thermal sensation reported from POST-EXERCISE to POST-REHYDRATION (F(1,9)=11.29, p<0.01), and stable reported sensation from POST-REHYDRATION to POST-RECOVERY (F(1,9)=0.00, p=1.0). Thus, participants reported stable thermal sensation following exercise, reported feeling cooler after rehydration with a sports beverage, and reported stable thermal sensation at recovery.

Gagge Comfort. Analyses examining recorded Gagge Comfort scores across the four experimental time points were conducted with results showing a significant main effect for time (F(3,27)=12.34, p<0.01), in the absence of a significant main effect for condition (F(1,9)=0.10, p=0.76) or interaction of time by condition (F(3,27)=0.43, p=0.73). Therefore, there were significant differences in Gagge Comfort scores across experimental time points, without significant differences by condition or time by condition.

Regarding the significant main effect for time, post hoc repeated measures ANOVA found that Gagge Comfort scores significantly decreased from BASELINE to POST-EXERCISE (F(1,9)=18.00, p<0.01), indicative of decreased level of comfort, with significantly increased comfort from POST-EXERCISE to POST-REHYDRATION (F(1,9)=18.58, p<0.01), and stable comfort from POST-REHYDRATION to POST-RECOVERY (F(1,9)=3.46, p=0.10). Consistent with what would be expected during
strenuous exercise in extreme heat, participants expressed less comfort following exercise, greater comfort following rehydration, and similar comfort following recovery.

Modified Gagge. Repeated measures ANOVA revealed a significant main effect for time (F(3,27)=5.59, p<0.01), in the absence of a significant main effect for condition (F(1,9)=3.63, p=0.09) or interaction of time by condition (F(3,27)=0.97, p=0.42) for Modified Gagge scores. Therefore, there were significant differences in Modified Gagge scores over experimental time points, without significant differences by condition or time by condition.

Regarding the significant main effect for time, post hoc repeated measures ANOVA found that Modified Gagge scores significantly increased from BASELINE to POST-EXERCISE (F(1,9)=7.15, p=0.03), indicative of feeling warmer, with significantly decreased/cooler sensation from POST-EXERCISE to POST-REHYDRATION (F(1,9)=10.22, p=0.01), and stable sensation from POST-REHYDRATION to POST-RECOVERY (F(1,9)=0.48, p=0.51). Participants expressed increased warmth following exercise and cooler sensation following rehydration, with stable sensation following recovery.

RPE. Ratings of perceived exertion were examined from BASELINE across the four exercise time points. Repeated measures ANOVA revealed a significant main effect for time (F(4,36)=39.34, p<0.01; $\eta^2_p=0.81$) and the interaction of time by condition (F(4,36)=4.84, p<0.01; $\eta^2_p=0.35$), in the absence of a significant main effect for condition (F(1,9)=2.83, p=0.13). Therefore, there were significant differences over experimental time points and for time by condition.
Post hoc analyses determined that RPE scores significantly increased over time (i.e., indicating greater perceived exertion) from BASELINE to the first exercise bout (0 to 25 minutes; \( F(1,9)=76.75, p<0.01 \)), from the first to second exercise bout (30 to 55 minutes; \( F(1,9)=8.65, p=0.02 \)), from the second to third exercise bout (60 to 85 minutes; \( F(1,9)=13.5, p<0.01 \)), and from the third to final exercise bout (90 to 115 minutes; \( F(1,9)=12.25, p<0.01 \)). Thus, as expected, participants reported increased perceived exertion across exercise bouts.

Although RPE scores were not different between beverage conditions, examination of the interaction effect (\( F(1,9)=12.25, p<0.01 \)) found those in the full-sugar rehydration condition endorsed greater RPE from the third to fourth exercise, while RPE in the zero-sugar condition were stable between these times. Similar to the POMS-SF results reported above, differences in condition reporting were not expected at this time point, as the beverage intervention had yet to be administered. See Table 8.

Heart rate. Analyses examining heart rate across the four experimental time points were conducted after excluding one case due to missing data. Results indicate a significant main effect for time (\( F(3,24)=13.98, p<0.01 \)), in the absence of a significant main effect for condition (\( F(1,8)=3.45, p=0.10 \)) or interaction of time by condition (\( F(3,24)=0.42, p=0.74 \)). Therefore, there were significant differences over experimental time points, without significant differences by condition or time by condition.

Regarding the significant main effect for time, post hoc repeated measures ANOVA found that heart rate significantly increased from BASELINE to POST-EXERCISE (\( F(1,8)=25.44, p<0.01 \)), decreased from POST-EXERCISE to POST-
REHYDRATION ($F(1, 8)=18.50, p<0.01$), and was stable from POST-REHYDRATION to POST-RECOVERY ($F(1, 8)=0.78, p=0.40$). Heart rate was more rapid immediately following exercise, decreased following rehydration, and eventually stabilized after recovery.

Metabolic performance (i.e., VO2). Regarding metabolic performance across the four key experimental time points, repeated measures ANOVA revealed no significant main effects (i.e., time ($F(3, 27)=1.47, p=0.25$); condition ($F(1, 9)=2.23, p=0.17$)) or an interaction effect ($F(3, 27)=2.30, p=0.10$). Participants had stable metabolic performances across time and there were no significant differences noted regarding metabolic performance and beverage condition.

Core temperature. Two participants were excluded from the analyses examining core temperature across time points due to missing data. Results demonstrated a significant main effect for time ($F(3, 21)=3.10, p=0.05$), in the absence of a main effect for condition ($F(1, 7)=0.33, p=0.59$) or interaction of time by condition ($F(3, 21)=0.77, p=0.52$).

Post hoc analyses revealed a significant increase in core temperature from BASELINE to POST-EXERCISE ($F(1, 7)=11.01, p=0.01$), with stable temperatures across the remaining time points (POST-EXERCISE to POST-REHYDRATION ($F(1, 7)=1.29, p=0.29$) and POST-REHYDRATION to POST-RECOVERY ($F(1, 7)=1.59, p=0.25$). Thus, core temperature increased following exercise and remained elevated until the conclusion of the study period, without significant differences in core temperature dependent on rehydration beverage type.
Chest temperature. As stated previously, skin temperature was measured utilizing thermistors applied to the chest, arm, thigh, calf, and tricep. For these skin measurements, one participant was excluded due to missing data as a result of excessive sweating that caused difficulties with thermistor tape adhesion. Analyses examining chest temperature showed no significant main effects (i.e., time (F(3,24)=1.69, p=0.20); condition (F(1,8)=3.65, p=0.09)) or an interaction effect of time by condition (F(3,24)=0.62, p=0.61). Thus, participants had similar chest temperatures across BASELINE, POST-EXERCISE, POST-REHYDRATION, and POST-RECOVERY and conditions (i.e., zero- and full-sugar beverage rehydration).

Forearm temperature. Results following analyses examining forearm temperature over time indicate a significant main effect for time (F(3,27)=5.27, p=<0.01), in the absence of a main effect for condition (F(1,9)=0.74, p=0.42) or interaction of time by condition (F(3,27)=0.91, p=0.45). Therefore, there were significant differences over experimental time points, without significant differences by condition or time by condition. In terms of the main effect for time, post hoc analyses found that forearm temperature significantly increased from BASELINE to POST-EXERCISE (F(1,9)=7.40, p=0.03) and remained elevated from POST-EXERCISE to POST-REHYDRATION (F(1,9)=0.25, p=0.63) and from POST-REHYDRATION to POST-RECOVERY (F(1,9)=0.00, p=0.99). Thus, forearm temperature rose significantly following exercise and remained at this elevated level for the rest of the study period.
Thigh temperature. Similarly, in examination of thigh temperature, analyses showed a significant main effect for time ($F(3, 27) = 19.53, p < 0.01$), in the absence of a significant main effect for condition ($F(1, 9) = 0.67, p = 0.44$) or interaction of time by condition ($F(3, 27) = 0.54, p = 0.66$). Therefore, participants’ thigh temperatures significantly changed over time, without differences noted between beverage conditions. Regarding the main effect for time, post hoc repeated measures ANOVA yielded higher thigh temperatures from BASELINE to POST-EXERCISE ($F(1, 9) = 43.15, p < 0.01$) and decreased temperatures from POST-EXERCISE to POST-REHYDRATION ($F(1, 9) = 5.58, p = 0.05$) and POST-REHYDRATION to POST-RECOVERY ($F(1, 9) = 5.65, p = 0.05$). Thigh temperature, then, increased following exercise, while going on to decline throughout the remaining time points.

Calf temperature. Analyses determined there were no significant main effects for time ($F(3, 27) = 0.36, p = 0.81$) or condition ($F(1, 9) = 0.75, p = 0.41$) or an interaction effect ($F(3, 27) = 1.03, p = 0.40$) when testing for differences in calf temperature. Participants’ calf temperatures were stable over time, with those in the zero- and full-sugar condition demonstrating similar temperature readings between conditions as well.

Tricep temperature. Repeated measures ANOVA examined tricep temperature across the experimental design, with no significant main effects (i.e., time ($F(3, 27) = 0.16, p = 0.92$); condition ($F(1, 9) = 1.61, p = 0.24$)) or an interaction effect ($F(3, 27) = 0.97, p = 0.42$) found. Thus, participants presented as stable across time points and between rehydration beverage conditions with respect to tricep temperature.
Summary of Psychological and Physiological States over Time

As expected, blood glucose levels decreased following exercise in the heated chamber and were influenced by the beverage intervention (i.e. increased with full sugar, further decrease with zero-sugar beverage). Interestingly, rehydration with the full sugar beverage produced poorer mood scores than the zero-sugar beverage. Patterns for the remaining physiological and psychological variables were largely consistent with expectations (i.e. core temperature increased after exercise and remained elevated in the heat). However, minor unexpected differences emerged across conditions (e.g. differences in RPE after exercise but prior to administration of beverage).

Hydration status. Participants lost an average of 2.57% body weight (±0.3%), consistent with a moderate level of dehydration (Grandjean & Grandjean, 2007). This level of dehydration has been associated in the literature with reduced performance on complex cognitive tasks (Tomporowski, 2003; D’Anci et al., 2009). Repeated measures ANOVA demonstrated a significant main effect for weight loss from BASELINE to POST-EXERCISE (F(1,9)=15.83, p=0.003), with no significant difference between full-and zero-sugar rehydration drink conditions (F(1,9)=0.53, p=0.49) or interaction of condition by time (F(1,9)=1.10, p=0.32). Therefore, participants reached a moderate level of dehydration, consistent with study aims, with no significant differences in dehydration level observed between conditions.
Quantity of Liquid Consumed during Experimental Trials

Paired samples t-tests examined the differences between conditions regarding the amount of liquid consumed during the rehydration phase of data collection. There were no significant difference between the zero- (during hydration period: M= 987.5 mL ±197.3) and full-sugar (during hydration period: M=990.0 mL ±224.1) conditions in the amount of liquid consumed during the hydration period (t(9)=−0.03, p=0.98). Similarly, no differences emerged in the combined total beverage consumed (t(9)=0.96, p=0.36; zero-sugar condition M=1332.5mL ±403.3; full-sugar condition M=1228.0±107.2). Thus, there were no condition differences in the amount of liquid consumed during experimental trials.

Cognitive function.

Executive Function. Repeated measures ANOVA examined LR scores across time points and between beverages. Regarding time, LR scores were stable from BASELINE to POST-EXERCISE (F(1,9)=2.01, p=0.19), significantly decreased from POST-EXERCISE to POST-REHYDRATION (F(1,9)=9.44, p=0.01; large effect size $\eta_p^2=0.51$), and were stable from POST-REHYDRATION to POST-RECOVERY (F(1,9)=1.82, p=0.21). When further examining POST-EXERCISE to POST-RECOVERY directly by way of repeated measures ANOVA, LR performances were also stable (F(1,9)=0.35, p=0.57) between these two time points. Thus, executive function performances were stable at POST-EXERCISE, poorer at POST-REHYDRATION, and then stable at POST-RECOVERY.
In terms of conditional differences, scores were similar across conditions at each time point (BASELINE TO POST-EXERCISE (F(1,9)=0.02, p=0.91), POST-EXERCISE to POST-REHYDRATION (F(1,9)=0.00, p=0.99, POST-REHYDRATION to POST-RECOVERY (F(1,9)=0.00, p=0.96) for the zero- and full-sugar rehydration beverages. Further, comparison of POST-EXERCISE directly to POST-RECOVERY scores also shows no differences between conditions (F(1,9)=0.16, p=0.70). Additionally, there were no significant interaction effects for time by condition (BASELINE TO POST-EXERCISE (F(1,9)=0.17, p=0.92), POST-EXERCISE to POST-REHYDRATION (F(1,9)=0.89, p=0.37), POST-REHYDRATION to POST-RECOVERY (F(1,9)=0.33, p=0.58), and POST-EXERCISE to POST-RECOVERY (F(1,9)=0.01, p=0.94)). See Figure 10 and Table 9. Therefore, executive function scores were similar across conditions and across condition by time.

Attention. Repeated measures ANOVA were employed to determine differences in RMCPT values across key time points and between rehydration beverage interventions. Regarding time, RMCPT scores significantly increased from BASELINE to POST-EXERCISE (F(1,9)=5.43, p<0.05; large effect size $\eta_p^2 = 0.38$), and were stable from POST-EXERCISE to POST-REHYDRATION (F(1,9)=0.31, p=0.59), and stable from POST-REHYDRATION to POST-RECOVERY (F(1,9)=2.68, p=0.14). Upon examining scores from POST-EXERCISE directly to POST-RECOVERY (F(1,9)=0.99, p=0.35), RMCPT scores were not statistically different. Thus, attention improved following exercise and did not significantly change across the remaining time points.
Note: 1= Baseline, 2= Post-Exercise, 3= Post-Rehydration, and 4= Post-Recovery.

Figure 10. LR Scores Over Time by Condition

Table 9: ANOVA values and Effect Sizes for LR Scores Over Time and Between Full- and Zero-Sugar Conditions

<table>
<thead>
<tr>
<th>Time Condition</th>
<th>Time F, p</th>
<th>Condition F, p</th>
<th>Interaction F, p</th>
<th>η²</th>
<th>η²</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Baseline to Post-Exercise</td>
<td>2.01, 0.19</td>
<td>0.02, 0.91</td>
<td>0.17, 0.92</td>
<td>0.16</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>2. Post-Exercise to Post-Rehydration</td>
<td>9.44, 0.01</td>
<td>0.00, 0.99</td>
<td>0.89, 0.37</td>
<td>0.51</td>
<td>0.00</td>
<td>0.09</td>
</tr>
<tr>
<td>3. Post-Rehydration to Post-Recovery</td>
<td>1.82, 0.21</td>
<td>0.00, 0.96</td>
<td>0.33, 0.58</td>
<td>0.17</td>
<td>0.00</td>
<td>0.04</td>
</tr>
<tr>
<td>4. Post-Exercise to Post-Recovery</td>
<td>0.35, 0.57</td>
<td>0.16, 0.70</td>
<td>0.01, 0.94</td>
<td>0.04</td>
<td>0.02</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Examination of potential differences in beverage condition found that scores were similar from BASELINE TO POST-EXERCISE (F(1,9)=0.32, p=0.58) and POST-EXERCISE to POST-REHYDRATION (F(1,9)=1.14, p=0.31) between the two conditions. However, individuals in the zero-sugar beverage condition demonstrated better RMCPT scores from POST-REHYDRATION to POST-RECOVERY (F(1,9)=6.45, p=0.03; $\eta^2_p=0.37$) when compared to the full-sugar rehydration condition. Similarly, directly analyzing RMCPT scores from POST-EXERCISE to POST-RECOVERY (F(1,9)=5.31, p=0.05; $\eta^2_p=0.42$) yielded greater values for the zero-sugar condition, when compared to the full-sugar rehydration condition. There were no significant interaction effects for time by condition (BASELINE TO POST-EXERCISE (F(1,9)=0.37, p=0.56), POST-EXERCISE to POST-REHYDRATION (F(1,9)=0.73, p=0.42), POST-REHYDRATION to POST-RECOVERY (F(1,9)=0.48, p=0.51), and POST-EXERCISE to POST-RECOVERY directly (F(1,9)=3.18, p=0.11)). See Figure 11 and Table 10. Therefore, attention scores were not significantly different between conditions by time. However, while attention performances were similar between conditions from BASELINE to POST-EXERCISE and POST-EXERCISE to POST-REHYDRATION, those in the zero-sugar condition demonstrated better performances than those in the full-sugar condition following recovery.
Note: 1= Baseline, 2= Post-Exercise, 3= Post-Rehydration, and 4= Post-Recovery.

*Figure 11.* RMCPT Scores over Time by Condition

**Table 10:** ANOVA values and Effect Sizes for RMCPT Scores over Time and Between Full- and Zero-Sugar Conditions

<table>
<thead>
<tr>
<th>Time Condition</th>
<th>Time F, p</th>
<th>$\eta^2$</th>
<th>Condition F, p</th>
<th>$\eta^2$</th>
<th>Interaction F, p</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Baseline to Post-Exercise</td>
<td>5.43, 0.05</td>
<td>0.38</td>
<td>0.32, 0.58</td>
<td>0.04</td>
<td>0.37, 0.56</td>
<td>0.04</td>
</tr>
<tr>
<td>2. Post-Exercise to Post-Rehydration</td>
<td>0.31, 0.59</td>
<td>0.03</td>
<td>1.14, 0.31</td>
<td>0.11</td>
<td>0.73, 0.42</td>
<td>0.08</td>
</tr>
<tr>
<td>3. Post-Rehydration to Post-Recovery</td>
<td>2.68, 0.14</td>
<td>0.42</td>
<td>6.45, 0.03</td>
<td>0.42</td>
<td>0.48, 0.51</td>
<td>0.05</td>
</tr>
<tr>
<td>4. Post-Exercise to Post-Recovery</td>
<td>0.99, 0.35</td>
<td>0.10</td>
<td>5.31, 0.05</td>
<td>0.37</td>
<td>3.18, 0.11</td>
<td>0.36</td>
</tr>
</tbody>
</table>
Hypotheses Testing

The primary goals of the current study were to better understand possible changes in blood glucose levels and cognitive test performance over time and across conditions. These findings are highlighted below:

*Hypothesis 1:* Blood glucose levels will decline following a 120-minute bout of exercise at high temperatures.

Post hoc repeated measures ANOVA revealed that blood glucose decreased from BASELINE to POST-EXERCISE ($F(1,9)=16.93$, $p<0.01$), in the absence of a significant main effect for condition or an interaction of time by condition. Blood sugar levels were significantly lower POST-EXERCISE than at BASELINE, supporting Hypothesis 1.

*Hypothesis 2:* Cognitive function will also decline following exercise at high temperatures.

In an attempt to replicate past findings, executive function and attention scores were examined from BASELINE to POST-EXERCISE. As noted above, repeated measures ANOVA found no change in LR after exercise and RMCPT scores actually increased following strenuous exercise in a heated chamber. Therefore, Hypothesis 2 was not supported.

*Hypothesis 3:* Rehydration following exercise will significantly improve cognitive function.

To examine possible benefits of rehydration, LR and RMCPT scores were examined from POST-EXERCISE to POST-REHYDRATION. Performance on LR actually declined from POST-EXERCISE to POST-REHYDRATION and remained
stable at this reduced level of performance from POST-REHYDRATION to POST-RECOVERY. In contrast, RMCPT scores were stable from POST-EXERCISE to POST-REHYDRATION and POST-REHYDRATION to POST-RECOVERY. Data do not support Hypothesis 3.

*Hypothesis 4:* Rehydration using a full-sugar beverage will produce greater improvements in cognitive function than a zero-sugar beverage.

In terms of LR performances, scores were similar between full- and zero-sugar conditions. However, cognitive test performances were better in the zero-sugar condition on the RMCPT from POST-REHYDRATION to POST-RECOVERY, when compared to the full-sugar condition, which is counter to Hypothesis 4.
CHAPTER IV

DISCUSSION

Review of Study Goals and Rationale

While acute exercise bouts have been shown to improve aspects of cognitive function, prolonged and strenuous exercise has been linked to temporary suppression in cognitive performance, particularly on tests of attention and executive function. Dehydration and heat exposure/hyperthermia are known contributors to this acute reduction in cognitive performance (Patel et al., 2007; Tomporowski, 2003; Grandjean & Grandjean, 2007; Warren & Frier, 2005; Austin & Deary, 1999; Wysocki et al., 2003). Findings from a recent study (Bandelow et al., 2010) suggest that reduced blood glucose levels are another important contributor to these cognitive difficulties, but no tightly-controlled study has examined this possibility.

The current study examined the independent contribution of blood glucose levels to cognitive changes following strenuous, prolonged exercise in the heat. To do so, the study protocol was designed to carefully control for the effects of exercise, dehydration, and heat exposure, while experimentally manipulating blood glucose levels through the use of rehydration with different sports beverages (i.e. full- versus zero-sugar). It was hypothesized that: 1) blood glucose levels would significantly decrease following
exercise in the heat; 2) cognitive performance would worsen following exercise; 3) rehydration would improve cognitive performance following expected exercise-induced cognitive suppression; and 4) rehydration with a full-sugar beverage would demonstrate greater improvement in cognitive function above zero-sugar rehydration. Although findings for blood glucose levels were consistent with these hypotheses, cognitive function did not decline after exercise and attention test performance was actually better when consuming the zero-sugar beverage. Several aspects of these findings will be discussed below.

Effectiveness of Study Methods in Producing Intended Physiological States

In order to examine the unique contribution of blood glucose levels to exercise-induced cognitive decline, the current study sought to control for a wide range of physiological indices. With few exceptions, no between-condition differences emerged on key variables such as thermal sensation, heart rate, and metabolic performance. Similarly, the exercise period produced the desired level of dehydration (i.e., mean of 2.57% body weight loss) and RPE scores increased across exercise bouts. Similarly, measures of internal and external temperature were generally consistent with expectations (i.e., increased through exercise, with stable values across the remaining time points in the absence of between-condition differences). Taken in combination, these findings suggest that the experimental manipulation successfully produced the intended effects for exercise, thermal response, and dehydration to test the study hypotheses.
Cognitive Outcomes

With regards to cognitive performances, results were generally inconsistent with study hypotheses. While moderate dehydration typically produces reduced cognitive performance on complex tasks, findings from past studies are inconsistent (Lieberman, 2007). Patterns of performance on tests of attention and executive function will be discussed separately below.

Attention Test Performance

Two important findings emerged upon examining exercise-related attention performance in the presence of heat stress, dehydration, and manipulated blood glucose. First, though much of the current literature supports reduced cognitive function after prolonged exercise, the current study found better attention performances following exercise. Second, those rehydrated with the zero-sugar beverage had significantly better attention scores than those in the full-sugar condition, despite expectations that increased blood glucose would improve attention scores following rehydration and recovery.

Better Attention after Exercise

Although the literature is mixed, some studies argue for a decline in attention in the presence of strenuous and prolonged exercise, dehydration, reduced blood glucose, and heat stress (Wetsel, 2011; Racinais, Gaoua & Grantham, 2008; Epstein et al., 1980; Tomporowski, 2003; Gopinathan, Pichan, & Sharma, 1988; Bradley & Higenbottam, 2003; Frier, 2001; Golden et al., 1989; Draelos et al., 1995; Graveling, Dreary, & Frier, 2013; Warren & Frier, 2005). In contrast, the current study found improved attention
following exercise in the presence of these physiological stressors, with this elevated performance level persisting through rehydration and recovery. Despite careful methodological control, several aspects of the current study may account for this pattern of findings. First, although core temperature increased during exercise in the heat for both the full- and zero-sugar conditions (i.e., 37.84°C and 37.94°C respectively), average measurements remained below 38 to 40°C, which is a level known to consistently impair cognitive function in past studies (Sharma & Hoopes, 2003; Stubblefield et al., 2003; Wetsel, 2011; Racinais, Gaoua & Grantham, 2008; Epstein et al., 1980). At those levels of hyperthermia, the body is unable to compensate for increased temperature, compromising the integrity of the brain and negatively impacting aspects of cognitive functioning (Sharma & Hoopes, 2003; Hocking et al., 2001; Knochel & Reed, 1994; Epstein et al., 1980). This core temperature range is often considered physically dangerous and was not the goal of the current study due to potential safety concerns and aims to examine typical core temperatures during exercise. However, it is possible that higher core temperatures would have produced deficits in attention test performance and future studies are needed to clarify this possibility.

Another potential explanation for the unexpected improvement in attention performance involves an interaction between dehydration levels and cognitive test complexity. Participants reached an average of 2.57% body weight loss, consistent with the goal of inducing moderate dehydration. Previous literature has generally found a decline in at least complex cognitive tasks with a 2 to 3% level of dehydration (Tomporowski, 2003; Gopinathan, Pichan & Sharma, 1988; Epstein et al., 1980;
Lieberman, 2007; Szinnai et al., 2005; Bradley & Higgenbottom, 2003). While the RMCPT is a valid measure of attention and appropriate for the current study, it requires relatively little working memory ability for completion (Tomporowski, 2003; Lieberman, 2007; Szinnai et al., 2005; ANAM4 Test Manual). Working memory is a complex form of attentional abilities that involves manipulation of information in short-term memory and has been more consistently found vulnerable to decline following strenuous exercise (Lezak, Howieson & Loring, 2004; Lubit, 2008; Wetsel, 2011; Racinais, Gaous, & Grantham, 2008; Lieberman, 2007; Grocott et al., 2002). It is possible that a more complex task with a higher working memory burden would demonstrate greater susceptibility to the environmental and physiological stressors of the current study.

In addition, consistent with expectations and the goals of the study methodology, blood glucose levels significantly decreased during exercise. However, it is important to note that blood glucose levels remained within normal limits for both conditions across all time points (i.e., full-sugar means: BASELINE= 115.3, POST-EXERCISE= 95.5, POST-REHYDRATION= 163.8, and POST-RECOVERY= 139.8; zero-sugar means: BASELINE= 127.1, POST-EXERCISE= 97.1, POST-REHYDRATION= 95.7, and POST-RECOVERY= 95.2) and no individual participant reached a level of hypoglycemia in the current paradigm (i.e. below 70 milligrams per deciliter (mg/dL) is considered hypoglycemic) (Mayo Clinic, 2010). Previous studies have found cognitive decline seen in the presence of severely, acutely reduced blood glucose levels, specifically 2.6 to 3.0 millimoles per liter (mmol/l), or 46.8 to 54 mg/dl (Warren & Frier, 2005). The current study produced a significant decline in blood glucose, though not to
the severe level of hypoglycemia found in patient studies and it is possible that lower levels of blood glucose would have produced different effects.

In addition to these possible explanations for improved attention following exercise, previous studies also identify alternative mechanisms not available through the current study methodology. As noted above, some past studies have found cognitive benefits from acute exercise and it is possible that those mechanisms counteract the adverse stressors of the current study (Brisswalter & Collardeau, 2002; Grego et al., 2005; Kashikara et al., 2009). For example, research has shown that the release of adrenaline is correlated with improvements in attention immediately following the meeting of an undetermined “adrenaline threshold” (Brisswalter & Collardeau, 2002). Similarly, Nideffer (1976) proposed an attentional control theory, stating that improvement of attention is often the result of increased physical arousal, such as that observed during or following strenuous exercise (Krausman, Harrison, & Wilson, 2002; Kahneman, 1973; Nideffer, 1976). This pattern has been attributed to increased release of attentionally-beneficial neurotransmitters during exercise (Krausman, Harrison, & Wilson, 2002; van der Kooji & Glennon, 2007; Silvetti, et al., 2013; Meesusen & DeMeirleir, 1995; Lambourne & Tomporowski, 2010; Chang, Etnier, & Barella, 2009; Wilson & Morley, 2003). Although arousal was not specifically examined in the current study, RPE has been positively correlated with arousal, and the study’s participants reported increased exertion across exercise time points, potentially relating to increased physiological arousal at POST-EXERCISE (Krausman, Harrison, & Wilson, 2002). Further, electroencephalography (EEG) studies show improved P300 amplitude and
latency in persons exercising less than two hours and a decrease after that time. Thus, it is possible that the 120 minute exercise protocol of the current study falls below a threshold regarding exercise duration and attention deficits. Similarly, a recent study found cognitive suppression only in persons with an increase in blood lactate above a specific threshold (i.e., above 4 mmol/l), a high level of blood lactate not necessarily reached through the current protocol (Perciavalle, et al., 2013; Kashikara et al., 2009; Goodwin et al., 2007).

Further, the current exercise modality (i.e., stationary cycling) was chosen as it is a sustainable mode of exertion over the course of 120 minutes under extreme environmental conditions. However, it is possible that exercise modality may influence effects on cognitive function. One study in particular noted an improvement in cognitive performance was associated with cycling, while cognitive function declined in the context of treadmill running (Lambourne & Tomporowski, 2010). Future research would benefit from further exploration of possible between-exercise-modality differences in cognitive performance.

A final explanation involves an inability to directly measure brain temperature. Increased brain temperature has been associated with greater reported fatigue and poorer cognitive performance (Maughan, Shirreffs, & Watson, 2007; Kiyatkin, 2011; Kiyatkin, 2007; Kiyatkin, 2005; Nybo, Secher, & Nielsen, 2002). Though core and skin temperatures changed as part of the study, it is possible that brain temperatures remained below the yet to be determined threshold for cognitive impairment. The currently utilized technique for brain temperature measurement is invasive and dangerous, involving
implantation of an intracranial catheter and probe, achieved through drilling into the individual’s skull (Li et al., 2012). While a potentially useful measure, this technique is beyond the scope of the current study.

**Poorer Attention with Full- Versus Zero-Sugar Rehydration**

Counter to hypothesis, attention test performance was worse after drinking a full-sugar sports drink than a zero-sugar version. The exact mechanism(s) responsible for this unanticipated result is/are unclear. However, several possible explanations exist and will be discussed below.

Past research on the combined effects of exercise and blood sugar levels on cognitive function are inconsistent. Bandelow et al. (2010) found higher blood glucose levels correlated with improved reaction time after exercise, but with the risk of increased errors. The current study used ANAM4 throughput scores, which is comprised of both speed and accuracy indices. However, post hoc analyses show no differences in accuracy between full-sugar and zero-sugar conditions in the current study, suggesting that higher blood glucose levels were actually associated with slower reaction time. Although opposite of the findings from Bandelow et al. (2010), past studies have also found exercise and physiological stressors correlated with slower reaction time (Tomporowski, 2003).

It is possible that differences in cognitive tests utilized across studies may help account for the inconsistent findings. As noted above, one specific difference between the previous literature and the current study involves the measure used to assess attention. Bandelow et al. (2010) examined a complex working memory task, while the RMCPT is
a simpler test of attention. Although simple and complex cognitive differences have not been previously measured within an exercise and blood glucose manipulation paradigm, complex tasks are more readily susceptible to suppression than cognitive tests with simple demand in the context of various physiological stressors present during intense exercise (Lubit, 2008; Wetsel, 2011; Racinais, Gaous, & Grantham, 2008; Lieberman, 2007; Grocott et al., 2002; Epstein et al., 1980; Tomporowski, 2007; Gopinathan, Pichan, & Sharma, 1988). This might account for the current findings, as a simpler task (i.e., RMCPT) may be less susceptible to decline in accuracy than complex tasks, like that measured by Bandelow et al. (2010), in the presence of drastic blood glucose fluctuations.

Another possible explanation for the potential detrimental effects of full-sugar rehydration on cognitive function involves the rapid changes in blood sugar during the full-sugar condition. While in the full-sugar condition, participants exhibited a significant and rapid increase in blood glucose measurement (i.e., 95.5 to 163.8 mg/dL in approximately 15 minutes), followed by a significant decrease at POST-RECOVERY (i.e., 163.8 to 139.8 mg/dL), while those in the zero-sugar condition showed fairly stable levels (BASELINE= 127.1, POST-EXERCISE= 97.1, POST-REHYDRATION= 95.7, and POST-RECOVERY= 95.2). Previous research has shown rapid changes in blood glucose levels to be associated with fatigue and reduced cognitive function (Johns Hopkins Medicine, 2013; Hopkins et al., 2010). It is possible that this rapid increase in blood glucose levels may lead to poorer cognitive function during the full- versus zero-sugar condition. Consistent with this possibility, reported mood scores were worse at
POST-REHYDRATION and POST-RECOVERY during the full-sugar condition compared to the zero-sugar condition. Poor mood has been correlated with poorer attention and may account for the worse attention scores found during the full-sugar condition (Chepenik, Cornew, & Farah, 2007; Levin, et al., 2007; Phelps, 2006; Pessoa, 2008; Watkins & Brown, 2002; Channon & Green, 1999). The literature suggests decreased blood glucose is associated with poorer mood in healthy adults; however, recent research indicates that, in addition to increased fatigue and cognitive difficulties, rapidly changing blood glucose, as seen in the full-sugar condition, may be linked to poorer mood as well (Gold, et al., 1995; Woyshville, et al., 1999; Hopkins et al., 2010).

Finally, glycemic load may also contribute to worse attention after ingestion of full- versus zero-sugar sports drink. Glycemic load refers to the amount of carbohydrate in a food/beverage that can be utilized to raise blood glucose levels (Glycemic Research Institute, 2010). Some studies have shown foods with lower glycemic loads are associated with better performances on aspects of cognitive function, including attention (Gilsenan, de Bruin, & Dye, 2009; Benton, Maconie, & Williams, 2007). Thus, as the full-sugar condition included a beverage with a higher glycemic load, it may have led to a poorer performance on attention tasks following rehydration and recovery. Clearly much additional work is needed to help clarify the complex relationship among blood glucose levels, exercise, and attention test performance.

Executive Function Test Performance

Results for performances on a test of executive function generally ran counter to expectations as well. Most notably, performance on this measure did not decline
following prolonged exercise in the heat, while actually declined after ingestion of a full-sugar sports beverage. Several possible explanations for this pattern of findings will be presented below.

No Decline in Executive Function After Exercise

Contrary to study hypotheses, LR scores did not decline from BASELINE to POST-EXERCISE. Past studies suggest that executive function is vulnerable to dehydration at a level of 2 to 3% body weight loss, such as the achieved dehydration level of 2.57% body weight loss in the current sample (Tomporowski, 2003; Gopinathan, Pichan & Sharma, 1988; Epstein et al., 1980; Lieberman, 2007; Szinnai et al., 2005; Bradley & Higgenbottom, 2003). A likely explanation is that the mechanisms that improved performance on the attention test described earlier (e.g. release of adrenaline, increased physical arousal, release of cognitively beneficial neurotransmitters) were able to stabilize executive function test performance by counterbalancing the negative impact of environmental and physiological stressors (Brisswalter & Collardeau, 2002; Grego et al., 2005; Kashikara et al., 2009; Krausman, Harrison, & Wilson, 2002; Kahneman, 1973; Nideffer).

Similarly, a better understanding of the broad construct of executive function may also shed insight into this null finding. This cognitive domain is comprised by widely-differing cognitive abilities, including planning, reasoning, concept formation, organizing, and monitoring one’s performance (Leezak, Howieson, & Loring, 2004). The current literature examining executive function performance in exercise paradigms often assesses different aspects of this complex construct and it is possible that specific mental
abilities are differentially affected by environmental and physiological stressors, while they may also represent varying degrees of complexity (Lambourne & Tomporowski, 2010). Future studies may benefit from utilizing measures sensitive to other aspects of executive function, in addition to more complex reasoning abilities.

Similarly, the LR test requires a simple motor response, as the participant is charged with right or left clicking to computer screen prompts (ANAM4 User Guide, 2008; ANAM4 Test Manual). However, past studies examining exercise and cognition often utilize executive function measures containing a more significant motor component, such as the Trail Making Test Part B, in which individuals must quickly draws lines from numbers and letters across a page (Lieberman, 2007). As a result, it is possible that inconsistent findings across studies may also be partly attributable to motor function in addition to any effects on cognitive function. Future work may choose to focus on these potential mechanisms for greater clarity into the varying results in the current literature.

Poorer Executive Function Scores Following Rehydration

Performance on a measure of executive function remained stable after exercise, though worsened following ingestion of a full-sugar sports drink. A likely explanation involves the same processes that led to the increased attention and stable executive function scores at POST-EXERCISE (Krausman, Harrison, & Wilson, 2002; Kahneman, 1973; Nideffer, 1976; Brisswalter & Collardeau, 2002). More specifically, arousal levels would decrease after cessation of exercise and could lead to poorer performance on this test of executive function, as participants were still exposed to heat stress. Similarly, the current protocol did not directly assess task engagement, which could also lead to
suppressed cognitive test performance as well (Nelson et al., 2003; Bianchini et al., 2001).

A final possibility is the potential effects of fatigue. Fatigue is commonly a byproduct of strenuous and prolonged exercise and has been correlated with poorer cognitive test performance, particularly on complex executive function tasks (Bush et al., 2005; Mittenberg et al., 2002). In the presence of reduced post-exercise physical arousal, the adverse effects of fatigue may have had a significant negative impact on LR scores. Future research may examine these factors to clarify the unexpected relationship between increased blood glucose levels and poorer executive function.

Study Limitations and Future Directions

The current findings run counter to expectations and much additional work is needed to better understand this phenomenon. As noted above, although the current paradigm achieved desired blood glucose, body temperature, and dehydration levels/changes, these effects may have fallen below the threshold needed for clear and consistent adverse effects on cognitive function. Similarly, mental abilities may differ in their vulnerability to these physiological stressors and future research would benefit from a similar protocol examining additional and more complex aspects of cognitive function (Lubit, 2008; Wetsel, 2011; Racinais, Gaous, & Grantham, 2008; Lieberman, 2007; Grocott et al., 2002; ANAM4 User Guide, 2008; ANAM4 Test Manual).

Future research should also expand the number of physiological measures to clarify possible mechanisms. For example, studies should investigate the role of neurotransmitters and hormones, such as dopamine and adrenaline, across cognitive
domains (Krausman, Harrison, & Wilson, 2002; van der Kooji & Glennon; 2007; Silvetti, et al., 2013; Meesusen & DeMeirleir, 1995; Lambourne & Tomporowski, 2010; Chang, Etnier, & Barella, 2009). This literature may also benefit from using more sophisticated measures of blood glucose and dehydration levels, such as the enzymatic hexokinase method and serum osmolality tests (i.e., freezing point depression method) (Armstrong, Ganio, & Casa, 2012; Bandelow et al, 2010).

In addition to methodological/measurement considerations, the current study focused on healthy young males that were screened for conditions that would make them most vulnerable to the effects of environmental stressors on cognitive function (Scarmeas & Stern, 2003; Kemperman, Kuhn, & Gage, 1997; Hultsch, Hammer, & Small, 1993). Use of different exclusion criteria may produce groups with greater cognitive vulnerability, such as those with below average intelligence, subjects with known medical conditions that may impact physiological response to the current paradigm’s stressors (i.e., diabetes), and less physically fit individuals (Rivera-Brown & Frontera, 2012; Mayo Clinic, 2011; Labelle et al., 2013). Similarly, thermal regulation varies across ethnic groups and genders (Grandjean & Grandjean, 2007). Replicating results in other samples may lend to optimal intervention and prevention of cognitive decline in exercise across demographic influence (Bar-Or, 1998; Mehnert et al., 2002; Kelley, 1999; Kaciuba-Uscilko & Gruca, 2001).

**Real World Implications of Study Findings**

The current results extend previous work and may have important real world implications. First, consistent with expectations and the current literature, blood glucose
levels significantly decreased following exercise and were readily modified by ingestion of a full-sugar sports drink. Clinicians, trainers, and persons engaged in prolonged and strenuous exertion should be mindful of the possibility of reduced blood glucose. In addition, sports drink supplementation may limit the effects of low blood glucose, such as shakiness, hunger, nervousness, while promoting safety (Mayo Clinic, 2010; National Institutes of Health, 2013; Center for Disease Control and Prevention; 2013).

Although the full-sugar beverage had the desired effects on blood glucose levels, this beverage may actually have its own significant undesirable side effects, including poorer mood. Specifically, rehydration with the full-sugar beverage was associated with worse mood at POST-REHYDRATION and POST-RECOVERY. While studies have shown reduced mood in conjunction with hypoglycemia, the current results may further support growing evidence for negative mood reactivity to rapid changes in blood glucose levels (Johns Hopkins Medicine; Hopkins et al., 2010). This counterintuitive finding is not widely known and a better understanding is needed.

A final implication involves the strong necessity for further research in this area. Findings for the cognitive effects of extreme environmental and physiological stressors are inconsistent across studies. However, many persons may be vulnerable to the possible adverse effects, including military personnel, firefighters, and professional athletes, in addition to the significant portion of the population exercising daily. Such persons may be at elevated risk for reduced task performance or even safety risk.
Summary and Conclusions

The current study sought to clarify the contribution of blood glucose levels to cognitive function after acute exercise in the heat. Counter to expectations, cognitive test performance improved after exercise and was worse after ingestion of a full- versus zero-sugar sports drink. Similarly, reported mood scores were worse during the full- versus zero-sugar condition as well. Future studies are needed to clarify physiological mechanisms for these findings, including blood lactate and neurotransmitter levels, among many others. Despite multiple study limitations, these counterintuitive results contain important implications for those engaging in regular strenuous physical activity under extreme conditions.
APPENDICES
APPENDIX A

MEDICAL, SOCIAL, DEVELOPMENTAL, AND PSYCHIATRIC HISTORY QUESTIONNAIRE
APPENDIX A
MEDICAL, SOCIAL, DEVELOPMENTAL, AND PSYCHIATRIC HISTORY QUESTIONNAIRE

Thank you for volunteering to be a participant for a study to be conducted in the Applied Physiology Research Laboratory. Some of the tests used in our experiments require that you perform very strenuous exercise, while other times may be under difficult environmental conditions. Consequently, it is important that we have an accurate assessment of your past and present health status to assure that you have no medical conditions that would make the tests especially dangerous for you. Please complete the health history as accurately as you can.

THIS MEDICAL HISTORY IS CONFIDENTIAL AND WILL BE SEEN ONLY BY THE INVESTIGATORS AND KENT STATE UNIVERSITY HEALTH CENTER PERSONNEL

Name__________________________________________ Date____/____/____
Date of Birth____/____/____ Present Age_____yrs
Ethnic Group:  ____White
____ African American
____ Hispanic
____ Asian
____ Pacific Islands
____ American Indian
____ Other_____________

MEDICATION

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

Check this box [ ] if you have not taken any medication.

MEDICATION________________ REASON FOR TAKING THIS
________________________________________________________________________
________________________________________________________________________
MEDICATION __________________
REASON FOR TAKING THIS
________________________________________________________________________
________________________________________________________________________

MEDICATION __________________
REASON FOR TAKING THIS
________________________________________________________________________
________________________________________________________________________

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.______________________________________________________________________

PROBLEMS AND SYMPTOMS

Place an X in the box next to any of the following problems or symptoms that you have had:

General
[ ] Mononucleosis
   If yes, when______________________________
[ ] Excessive fatigue
[ ] Recent weight loss while not on a diet
[ ] Recent weight gain
[ ] Thyroid disease
[ ] Fever, chills, night sweats
[ ] Diabetes
[ ] Arthritis
[ ] Sickle Cell Anemia
[ ] Heat exhaustion or heat stroke
[ ] Recent sunburn

Heart and Lungs
[ ] Abnormal chest x-ray
[ ] Pain in chest (persistent and/or exercise related)
[ ] Heart attack
[ ] Coronary artery disease
[ ] High blood pressure
[ ] Rheumatic fever
[ ] Peripheral vascular disease
[ ] Blood clots, inflammation of veins (phlebitis)
[ ] Asthma, emphysema, bronchitis
[ ] Shortness of breath
  [ ] At rest
  [ ] On mild exertion
[ ] Discomfort in chest on exertion
[ ] Palpitation of the heart; skipped or extra beats
[ ] Heart murmur, click
[ ] Other heart trouble
[ ] Lightheadedness or fainting
[ ] Pain in legs when walking
[ ] Swelling of the ankles
[ ] Need to sleep in an elevated position with several pillows

G-U SYSTEM
[ ] Get up at night to urinate frequently
[ ] Frequent thirst
[ ] History of kidney stones, kidney disease

Nervous System
[ ] Alcohol problem
[ ] Alcohol use
  If yes, how many drinks ingested per week? ________________
[ ] Frequent or severe headaches
[ ] Stroke
[ ] Attacks of staggering, loss of balance, dizziness
[ ] Persistent or recurrent numbness or tingling of hands or feet
[ ] Episode of difficulty in talking
[ ] Prolonged periods of feeling depressed or “blue”
[ ] Difficulty in concentrating
[ ] Suicidal thoughts
[ ] Have had psychiatric help

Explain any items checked (when, severity, treatment)
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
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? (Grandparents, parents, siblings, uncles, and aunts)
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Do you currently smoke cigarettes?  
YES  NO

Do you currently use any smokeless tobacco products?  
YES  NO

MENTAL HEALTH HISTORY

Do you have a history of treatment for mental health disorders?  
YES  NO

If yes, please describe treatment (when, where, what, and with whom), diagnoses given, and current status.
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

DEVELOPMENTAL HISTORY

Place an X in the box next to all that apply.
[ ] Delays in learning to crawl
[ ] Delays in learning to walk
[ ] Delays in learning to talk
[ ] Diagnosis of a learning disorder
[ ] Diagnosis of ADHD

If you endorsed any of these items, please explain.
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Are there any other reasons not mentioned above that you feel you should not participate in this research study?  
YES  NO
APPENDIX B

HEAT ILLNESS SYMPTOM INDEX
APPENDIX B

HEAT ILLNESS SYMPTOM INDEX

Please rate the severity of each of the following 13 symptoms experienced following a practice session based on the scale below.

0 = no symptoms
3 = mild symptoms
5 = moderate symptoms
7 = severe symptoms requiring a break from practice
10 = had to stop practice due to symptoms

<table>
<thead>
<tr>
<th>Symptom</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<tbody>
<tr>
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<td>2. Swelling</td>
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<td>3. Cramps</td>
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<tr>
<td>4. Nausea</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>5. Dizziness</td>
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<tr>
<td>6. Thirst</td>
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<tr>
<td>7. Vomiting</td>
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<td>8. Confusion</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>9. Muscle Weakness</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>10. Heat Sensations on Head or Neck</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>11. Chills</td>
<td></td>
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<tr>
<td>12. Stopping Sweating</td>
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<tr>
<td>13. Feeling Lightheaded</td>
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<td></td>
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</tr>
</tbody>
</table>


APPENDIX C

HEAT INJURY AND ACCLIMATION QUESTIONNAIRE
APPENDIX C

HEAT INJURY AND ACCLIMATION QUESTIONNAIRE

Exercising in the heat has different effects on different people. We are interested in how the heat affects you.

1. While exercising on a hot day, have you ever had the following (circle all that apply):
   Extreme thirst
   Getting tired faster than normal
   Muscle cramps
   Urge to defecate
   Dizziness
   Feeling like you might black out
   Nausea/vomiting
   Got so hot you stopped sweating
   Had hot and dry skin (i.e. no sweating)
   Stumbling or loss of coordination
   Very low blood pressure
   Extreme Sweating
   Feeling lightheaded
   Looking pale
   Muscle weakness
   Passing out
   Muscle weakness
   Muscle weakness
   Feeling like you might black out
   Headache
   Diarrhea
   Couldn’t urinate
   Become confused
   Very fast heart rate
   Passing/blacking out

2. Do you get muscle cramps when you exercise in the heat?   Yes   No
   If yes, what percent of the time: _____%

3. Have you ever been told that you had:
   heat exhaustion   Yes   No   If yes, when?   Before HS   HS   College
   heat stroke   Yes   No   If yes, when?   Before HS   HS   College

4. Would you say that exercising in the heat affects your performance:
   More than most people   About the same   Less than most people

5. What state did you grow up in? ____________________
   Or, if not from US, what country? ________________
APPENDIX D

SPOT-THE-WORD TEST
APPENDIX D

SPOT-THE-WORD TEST

Each pair of words below contains 1 real word and 1 fake word. Please circle the word from each pair that you believe is the real word.

broxic – oasis
pinnace – strummage
mannerism – whitten
daffodil – gombie
bellissary – cyan
vellicle – sampler
necromancy – ghoumic
narwhal – epilair
venady – monad
plargen – savage
clegger – minim
knibbet – mandrake
canticle – gammule
threnody – epigrot
brastome – banshee
shako – strubbage
paraclete – elezone
froopid – clod
rouse – choffid
goblet – prelly
flexipore – viscera
agipect – almond
tarantula – hostent
treding – rafters
legify – archaic
obsidian – plassious
restance – zombie
pimple – brizzler
frellid – static
hilfren – domain

livid – trasket
thrash – lisid
holomator – dross
orifice – serple
phalanx – distrivial
chloroleptic – lapidary
archipelago – zampium
grody – toga
moxid – tangible
moralist – florrisal
quince – bostry
lignovate – epicene
gibbon – wonnage
hipple – osprey
element – pargler
viridian – psynoptic
glorvant – onyx
plankton – whippen
akimbo – periasty
centaur – tritomial
vinady – bargain
prinodal – mango
reticule – flexent
frembulous – ontology
loxeme – legerdemain
hoyden – clinotide
aboriginal – hostasis
clavanome – bestiary
zando – albatross
APPENDIX E

PROFILE OF MOOD STATES- SHORT FORM
APPENDIX E

PROFILE OF MOOD STATES- SHORT FORM

Below is a list of words that describe feelings people have. Please read each one carefully. Then circle ONE answer to the right, which best describes HOW YOU HAVE BEEN FEELING DURING THE PAST 24 HOURS.

The numbers refer to these phrases:
0= not at all
1= a little
2= moderately
3= quite a bit
4= extremely

1. Tense 0 1 2 3 4
2. Angry 0 1 2 3 4
3. Worn out 0 1 2 3 4
4. Unhappy 0 1 2 3 4
5. Lively 0 1 2 3 4
6. Confused 0 1 2 3 4
7. Peeved 0 1 2 3 4
8. Sad 0 1 2 3 4
9. Active 0 1 2 3 4
10. On Edge 0 1 2 3 4
11. Grouchy 0 1 2 3 4
12. Blue 0 1 2 3 4
13. Energetic 0 1 2 3 4
14. Hopeless 0 1 2 3 4
15. Uneasy 0 1 2 3 4
16. Restless 0 1 2 3 4
17. Unable to concentrate 0 1 2 3 4
18. Fatigued 0 1 2 3 4
19. Annoyed 0 1 2 3 4
20. Discouraged 0 1 2 3 4
21. Resentful 0 1 2 3 4
22. Nervous 0 1 2 3 4
23. Miserable 0 1 2 3 4
24. Cheerful 0 1 2 3 4
25. Bitter 0 1 2 3 4
26. Exhausted 0 1 2 3 4
27. Anxious 0 1 2 3 4
28. Helpless 0 1 2 3 4
29. Weary 0 1 2 3 4
30. Bewildered 0 1 2 3 4
31. Furious 0 1 2 3 4
32. Full of pep 0 1 2 3 4
33. Worthless 0 1 2 3 4
34. Forgetful 0 1 2 3 4
35. Vigorous 0 1 2 3 4
36. Uncertain about things 0 1 2 3 4
37. Bushed 0 1 2 3 4
APPENDIX F

GAGGE THERMAL SENSATION SCALE
# APPENDIX F

## GAGGE THERMAL SENSATION SCALE

<table>
<thead>
<tr>
<th>Sensation</th>
<th>Comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Very Hot</td>
</tr>
<tr>
<td>3</td>
<td>Hot</td>
</tr>
<tr>
<td>2</td>
<td>Warm</td>
</tr>
<tr>
<td>1</td>
<td>Slightly Warm</td>
</tr>
<tr>
<td>0</td>
<td>Neutral</td>
</tr>
<tr>
<td>-1</td>
<td>Slightly Cool</td>
</tr>
<tr>
<td>-2</td>
<td>Cool</td>
</tr>
<tr>
<td>-3</td>
<td>Cold</td>
</tr>
<tr>
<td>-4</td>
<td>Very Cold</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sensation</th>
<th>Comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Very Comfortable</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Just Comfortable</td>
</tr>
<tr>
<td>0</td>
<td>Just Uncomfortable</td>
</tr>
<tr>
<td>-1</td>
<td></td>
</tr>
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<td>-2</td>
<td></td>
</tr>
<tr>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>-4</td>
<td>Very Uncomfortable</td>
</tr>
</tbody>
</table>
APPENDIX G

MODIFIED GAGGE THERMAL SENSATION SCALE
### APPENDIX G

**MODIFIED GAGGE THERMAL SENSATION SCALE**

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>Nothing at all</td>
</tr>
<tr>
<td>0.5</td>
<td>Moderately Warm</td>
</tr>
<tr>
<td>1.0</td>
<td>Warm</td>
</tr>
<tr>
<td>2.0</td>
<td>Very Warm</td>
</tr>
<tr>
<td>3.0</td>
<td>Very, very warm</td>
</tr>
<tr>
<td>4.0</td>
<td>Somewhat Hot</td>
</tr>
<tr>
<td>5.0</td>
<td>Hot</td>
</tr>
<tr>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>Very Hot</td>
</tr>
<tr>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td>Very, Very Hot</td>
</tr>
<tr>
<td>*</td>
<td>Unbearably Hot</td>
</tr>
</tbody>
</table>
APPENDIX H

RATING OF PERCEIVED EXERTION
## APPENDIX H

### RATING OF PERCEIVED EXERTION

<table>
<thead>
<tr>
<th>RPE</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>complete rest</td>
</tr>
<tr>
<td>1</td>
<td>very, very easy</td>
</tr>
<tr>
<td>2</td>
<td>easy</td>
</tr>
<tr>
<td>3</td>
<td>moderate</td>
</tr>
<tr>
<td>4</td>
<td>somewhat hard</td>
</tr>
<tr>
<td>5</td>
<td>hard</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>very hard</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>extremely hard (almost maximal)</td>
</tr>
<tr>
<td></td>
<td>exhaustion</td>
</tr>
</tbody>
</table>

APPENDIX I

PARTICIPANT INSTRUCTIONS
As a volunteer to participate in the Rehydration and Cognition study, we ask you adhere to the following instructions in order to ensure optimal safety and create standardization across participants.

**Instructions for 3 days (72 hours) prior to each experimental trial:**

We ask that you complete a **3-day dietary journal** (form attached), prior to each experimental trial. Please be as accurate as possible, noting the type and amount of each food consumed.
**Instructions for 24 hours prior to each experimental trial:**

We will provide a 32 oz. cup prior to the first experimental trial. We ask that starting 24 hours prior to each experimental trial, you drink 3 liters, or 3-32 oz. cups of water over this 24 hour period. The morning of each experimental trial, prior to reporting to the Mac Annex, we ask that you drink an additional 32 oz. of water. This will help the dehydration process and best ensure safety. Breakfast will be provided to you immediately prior to each experimental trial (i.e., bagel and banana).

Prior to the first experimental trial, you will be provided a low sodium dinner to be consumed the night before each experimental trial. In addition to the provided meal (i.e., low-sodium frozen pizza), you are permitted to eat as many fruits and vegetables as you would like, just be sure to make note of these additions on the dietary journal form.

Finally, we ask that you abstain from strenuous exercise, smoking, and illicit drug and alcohol use 24 hours prior to each experimental trial.

With any questions, please contact Lynn Kakos at [lreese3@kent.edu](mailto:lreese3@kent.edu). Thanks for your participation in this exciting study!

**Rehydration and Cognition Dietary Journal**

Participant Name ____________________________

Date of Experimental Trial 1 ____________ Food Journal Start Date ____________

Journal Day 1 Trial 1 Date _______________

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### Rehydration and Cognition Dietary Journal

Journal Day 2 Trial 1 Date ____________

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Rehydration and Cognition Dietary Journal

Journal Day 3 Trial 1 Date ________________

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Rehydration and Cognition Dietary Journal

Participant Name _____________________________

Date of Experimental Trial 2 ____________ Food Journal Start Date ____________

Journal Day 1 Trial 2

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Rehydration and Cognition Dietary Journal

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REFERENCES
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*Computational Biology, 6(10); e1000960.*

*Developmental Review, 26; 277-90.*


