THE EFFECT OF MODERATE EXERCISE INDUCED DEHYDRATION ON
COGNITIVE PERFORMANCE ON THE IMPACT TEST IN NCAA
DIVISION III COLLEGIATE WRESTLERS

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THE EFFECT OF MODERATE EXERCISE INDUCED DEHYDRATION ON COGNITIVE PERFORMANCE ON THE Impact TEST IN NCAA DIVISION III COLLEGIATE WRESTLERS

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ABSTRACT

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The purpose of this study was to determine whether moderate exercise-induced dehydration (DEH) has an effect on cognitive performance on the ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing) in Division III collegiate wrestlers. 21 NCAA Division III wrestlers representative of 10 collegiate weight classes participated in the study. Subjects completed the computer-based ImPACT test under euhydrated (EUH) conditions, and immediately following, a standard wrestling practice to induce moderate DEH (2.5-4% body weight loss). EUH status was confirmed using urine specific gravity and body weight (BW) measurements of subjects. Percent BW loss (% BW) was determined as the difference between pre and post-practice BW. ImPACT test scores were compared between EUH and DEH conditions to determine if a significant change in specific cognitive performance variables had occurred. Paired t-tests were used to determine significance (p<0.05) between conditions. Results indicated significant % BW loss (-2.9 ±0.4%, p<0.05) took place indicating moderate DEH status. Significant decreases in the visual memory and visual motor speed, and an increase in impulse control errors were observed after DEH. The results of this study indicated that moderate exercise-induced DEH may negatively affect the interpretation of the diagnostic modules within the ImPACT test.
ACKNOWLEDGEMENTS

First I would like to thank my family, not only for their support and guidance through this process, but throughout my entire life. My parents have served as excellent role models, and my motivation to work hard, to persevere, and to chase my dreams were all valuable morals that my parents constantly encouraged me to uphold. I offer my sincere thanks and gratitude to my family for their unconditional love and support, and I am proud to share this accomplishment with them.

I would like to thank my thesis committee consisting of Dr. Glenn Wright, Scott Doberstein, and Dave Malecek for their advice and continuous support. The dedication and the amount of time and effort that were put into this research are greatly appreciated. I know that I could not have completed this research without your guidance.

I would like to thank Dave Malecek for working with me and helping me schedule pilot and testing sessions with the wrestling team. I am grateful that he gave me permission to use the wrestling athletes as subjects. I have enjoyed working with him and am thankful for the opportunity to work with the team.

I would like to express my appreciation to the members of the wrestling team for agreeing to participate as subjects in my research. It was because of my personal experience with the wrestling team that I became interested in the topic of dehydration, and I am thankful that the athletes shared my enthusiasm for the research.

I would like to express gratitude towards the University of Wisconsin-La Crosse RSEL grant program for their funding that helped to make the completion of this research possible.
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INTRODUCTION

In athletics, success originates from a variety of factors ranging from appropriate and frequent training, adequate mental and physical rest, and proper nutrition. Of these, the factor that is frequently overlooked is proper nutrition, particularly hydration. Proper hydration has become a popular focus of study in medicine. The total human body mass is composed of 50-60% water (Maughan, 2003), therefore, it is crucial that athletes practice proper hydration techniques in order to replenish the water that is lost during athletic endeavors. If body water is not replenished, athletes subject themselves to dehydration (DEH) in conjunction with the possible physical and cognitive complications that may accompany it.

DEH occurs when fluid output exceeds fluid intake. DEH causes a decrease in homeostasis within the body whereby water leaves the cell, causing the cell to shrink, resulting in a decrease in cell function. The level of DEH is determined by the extent of water lost within the cell. When mild DEH, a loss of up to 2% of body weight (BW) occurs, about 30% of the water loss occurs within the cell. However, when DEH levels are moderate, a BW loss of 2.5-5%, water loss within the cell increases to about 52% of the total body water loss (Costill, Cote, & Fink, 1976). This indicates that as DEH level increases from mild to moderate, the extent of water lost from within the cell increases, ultimately resulting in a decrease in cell function.
A sport that frequently renders itself to various levels of DEH is the sport of wrestling. In order for an athlete to qualify for his/her desired weight class, it may be necessary for the wrestler to employ weight loss techniques in order to reach the preferred weight class. Although the National Collegiate Athletic Association (NCAA) and the National Federation of State High School Associations (NFHS) have established rules and regulations to prohibit rapid weight loss procedures that induce harmful and even fatal DEH from occurring, wrestlers continue to employ unsafe weight loss techniques.

Wrestlers are not only faced with the dangers that accompany DEH, but the risk of experiencing significant injuries as well. Due to the fast paced intensity and nature of the combat sport that provide little to no head protection, wrestlers subject themselves to cerebral concussions. Wrestlers do in fact wear head gear in order to prevent injuries to the ears; however, head gear does not offer appropriate protection for the prevention of concussions. This continuous hand-to-hand action in this combat sport creates situations in which concussions are ultimately inevitable. In men’s collegiate wrestling, concussions represent 3.3% of the total injuries reported (Daneshvar, Nowinski, McKee, & Cantu, 2007) and in high school wrestling, research has shown that concussions are responsible for 17-23.9% of injuries in a single wrestling season (Lincoln et al., 2011). In addition, when examining the collegiate injury rate per 1,000 athletic exposures, concussions account for 0.25% of injuries and were three times more likely to occur in a competition than in practice. In this longitudinal study, it was observed that concussions accounted for 6.6% of the injuries that occurred during competition and 4.5% of the injuries that occurred during practice in a single season (Daneshvar et al., 2007).
Currently, the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT, ImPACT Applications, Inc, Pittsburgh, PA) is a computerized post-concussion evaluation tool that can be utilized by medical personnel in order to determine whether an athlete has suffered a concussion. Using these neurocognitive tools, medical professionals can make vital decisions as to whether an athlete should seek further medical attention or take necessary precautions when dealing with a concussion. The ImPACT has proven to be both valid and reliable in subjectively assessing concussion and statistically analyzing whether or not it is safe for the athlete to return to play based on their baseline cognitive results when compared to measures in a concussed state (Iverson, Gaetz, Lovell, Collins, & Maroon, 2002; Iverson, Lovell, & Collins, 2004).

DEH, at any level has a negative effect on the physical function and performance. The relationship between DEH and physical performance has been extensively researched. The effect that any degree of DEH has on cognitive performance, however, has been studied, but the results of the research do not reach a definitive conclusion. Specific areas of cognitive function that are proposed to be affected by hydration status include sustained and selective attention time (Adan, 2012; D’Anci, Mahoney, Vibhakar, Kanter, & Taylor, 2009; Patel, Mihalik, Notebaert, Guskiwicz, & Prentice, 2007; Petri, Dropulie, & Kardum, 2006; Shirreffs, Merson, Fraser, & Archer, 2004; Suhr, Hall, Patterson, & Niinisto, 2004; Cian, Barraud, Melin & Raphael, 2001; & Cian, Koulmann, Barraud & Raphael, 2000), and visual motor tracking (Petri, Dropulic & Kardum, 2006; Suhr et al., 2004; Cian et al., 2001; Devlin, Fraser, Barras & Hawley, 2001; Cian et al., 2000; Gopinathan, Pichan & Sharma, 1988; Sharma, Sridharan, Pichan & Panwar, 1986; & Epstein, Keren, Moisseiev, Gasko & Yachin, 1980). Other cognitive variables that
showed negative effects following moderate DEH include short term memory (STM) (Cian et al., 2001; Cian et al., 2000; & Choma, Sforzo, & Keller, 1998; Gopinathan et al., 1988; Sharma et al., 1986), decision time (Ganio et al., 2011; Serwah & Marino, 2006, & Cian et al., 2001), and fatigue and mood (Ganio et al., 2011; Marttin, Judelson, Wiersma, & Coburn, 2011; D’Anzi et al., 2009; Patel et al., 2007; Grego et al., 2005; Cian et al., 2001; Cian et al., 2000; Choma et al., 1998; & Sharma et al., 1986).

Since the sport of wrestling subjects its athletes to both DEH and concussion, determining if there is a relationship between DEH and concussion based symptoms is highly beneficial to the athletes involved and the medical personnel that need to assess the athlete for a potential concussive event. If there is in fact a definite relationship between the two, this information would be beneficial in assisting medical professionals during these situations to determine which types of cognitive deficits may be related to the concussion injury itself, or possible cognitive deficits that may be identified within the degree of DEH that is frequently tolerated in the sport, or a combination of both factors. Consequently, the purpose of this study is to determine if moderate exercise induced DEH has an effect on cognitive performance on the ImPACT test in NCAA Division III collegiate wrestlers.
METHODS

Experimental Approach to the Problem

In order to determine if a change in cognitive performance occurred with moderated DEH in collegiate wrestlers, a one day repeated measures design was utilized. Subjects were evaluated for hydration status using urine specific gravity prior to baseline cognitive testing. If subjects were in a euhydrated (EUH) state, the baseline ImPACT was administered. After completion of the cognitive assessment, subjects underwent an exercise protocol in order to induce moderate DEH. Following the DEH procedure, subjects were evaluated again to determine the degree of DEH, and if they met the moderate level of DEH criteria, subjects were then administered the post exercise ImPACT. Results from the baseline EUH and DEH cognitive tests were then compared to determine if cognitive performance was affected by moderate exercise induced DEH.

Subjects

One week prior to the intra-squad dual meet, 22 male NCAA Division III collegiate wrestlers voluntarily participated in this study. Subjects were athletes of the University of Wisconsin-La Crosse 2012-2013 wrestling team and were representative of all 10 collegiate weight categories. Written informed consent (Appendix A) was obtained from all subjects before they were allowed to participate in this study, and all experimental procedures were approved by the Institutional Review Board for investigations involving human subjects at University of Wisconsin-La Crosse. Subjects were disqualified from participation if they had a history of heat illness, as DEH
procedures have the potential to make the heat illness symptoms reoccur. Additionally, subjects were disqualified from competition if they had experienced a concussion injury within the last six months. Subjects were asked to maintain a normal exercise regimen specific to the sport of wrestling, as the protocol designed to lose weight was similar to a standard wrestling practice, therefore, the subjects must be in appropriate physical condition to complete a wrestling practice. It was also requested that the subjects report to the testing site on the day of testing in a EUH state. Due to an injury that occurred during the practice, one subject was not able to complete the study. All data, therefore, is based on 21 subjects.

Table 1 displays the anthropometric data for the subjects involved in the study.

<table>
<thead>
<tr>
<th>Table 1. Subject Characteristics (n=21)</th>
<th>Mean ± Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>19.41 ± 1.18</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>179.16 ± 4.83</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>82.57 ± 11.57</td>
</tr>
<tr>
<td>EUH= Eubycrated</td>
<td></td>
</tr>
</tbody>
</table>

**Procedure**

Subjects reported to the University of Wisconsin-La Crosse Human Performance Lab in a EUH state that was confirmed with urinary measures that evaluated urine specific gravity ($U_{sg}$). A digital refractometer (Atago 4410 PAL-10S, Tokyo, Japan) was used to measure $U_{sg}$. If a subject did not meet the NCAA requirement of having $U_{sg}$ of $\geq 1.020$, he was disqualified from the study. Blood glucose levels were obtained from a fingertip capillary blood sample using a portable glucose monitor (One Touch Ultra Min.
Glucose Monitor, Life Scan, Inc., Milpitas, CA.) All EUH (baseline) measurements (demographics, blood glucose, $U_{sg}$) were taken 1-hour prior to the DEH procedure.

Once EUH data was collected, subjects were gathered in a designated room and the computer based ImPACT setup and testing procedure were explained. Subjects were informed that ad libitum water consumption was allowed until the EUH BW was measured. The subjects were then escorted by the principal investigator to the computer testing lab where subjects were administered the ImPACT test under EUH conditions. Subjects were encouraged to do their best on the 6 cognitive modules contained in the test. The ImPACT test procedures took approximately 30 minutes to complete, after which, subjects were escorted directly to the practice facility.

Each subject was provided a minimum weight loss goal of 2.5% reduction in BW and a maximum of 4% loss to attain during the DEH procedure. This range was chosen because it represents a moderate level of DEH. Additionally, it is common for wrestlers to lose 2.5-4% of BW in the 24-hour period preceding a wrestling match (Opplinger, Utter, Scott, Dick, & Klossner, 2006).

Subjects were weighed prior to practice to the nearest 0.1 kg (BWB-800 Tanita, La Crosse Scale, LLC, La Crosse, WI) and each subject was weighed wearing only clean and dry wrestling spandex, which were exchanged after the weigh-in for designated practice attire for each subject consisting of a designated cotton sports t-shirt and practice spandex. Subjects used the same pair of clean and dry spandex for the EUH and DEH weight measurements.

Controlled acute DEH was achieved during a 2-hour standard practice that generally occurs during the competitive season. During this 2-hour practice, subjects
were prohibited from drinking any fluid. The temperature of the practice facility was kept between 72-73°F for the duration of practice. If a subject was showing signs of heat stress or expressed that he was unable to continue without hydrating, he was eliminated from the study.

The 2-hour practice consisted of a warm-up, active technical drilling, live wrestling scenarios, conditioning, and a cool down. The warm-up lasted for 15 minutes and included jogging, dynamic stretching, and very basic and controlled wrestling maneuvers. Active technical drilling consisted of specific wrestling maneuvers and scenarios demonstrated by a coach and then practiced by the subjects with a partner in a controlled manner. The technical drilling session lasted for 40 minutes. The live wrestling scenarios lasted for 40 minutes and consisted of 3-5 minute bouts of wrestling that simulated actual competition, separated by 1-3 minutes of active rest. The conditioning session included drills that focused on anaerobic capacity and muscular endurance while stressing the lactic acid system. The conditioning portion of the practice lasted 15 minutes. The cool down session within the practice lasted 10 minutes and consisted of static stretching.

At the conclusion of the practice, subjects were weighed again wearing clean dry spandex. Immediately following weight measurements, DEH blood samples were taken via finger stick to measure DEH blood glucose levels. Subjects were instructed to not hydrate and remain in the practice facility until all subjects were weighed and blood samples collected.

Once measures of blood glucose and BW were completed, subjects were escorted by the principal investigator to the computer lab to administer the ImPACT test in a DEH
state. The total time that had elapsed between the end of practice and administration of the DEH ImPACT test was approximately 1 hour. Subjects were encouraged to once again perform to the best of their ability on the six cognitive modules within the test. During testing, subjects were not allowed to rehydrate for the purpose of maintaining a moderately DEH state. The ImPACT test lasted approximately 30 minutes, and after subjects were finished taking the test, they were provided immediately with their choice of water or a sports drink in order to rehydrate.

**Data Analysis**

The variables that were analyzed in this study were BW, blood glucose, and the six cognitive test variables within the ImPACT test under two different conditions, EUH and DEH. Data analysis was performed using IBM SPSS 19.1 (SPSS Inc., Chicago, IL). In order to compare EUH vs. DEH values, the data were first evaluated to see if they were normally distributed. Since the data from both conditions displayed normality for each variable, the parametric approach was used to compare each variable between EUH and DEH using paired sample t-tests. The alpha value, or probability of Type I error, that was used for this study was set at $p<0.05$ for each respective test.
RESULTS

Figure 1 displays BW under EUH and DEH conditions for all subjects. There was a significant difference between EUH and DEH BW (p=.000) indicating a significant weight loss (2.89 ± 0.4%) took place.

Figure 1. Body weight of subjects in the euhydrated (EUH) and dehydrated (DEH) conditions; *Significant difference; p < 0.05
Blood glucose under EUH and DEH conditions are presented in Figure 2. These data indicate a significant increase in blood glucose (p = 0.037) took place during the wrestling practice from EUH to DEH.

![Bar chart](image)

**Figure 2.** Blood glucose of subjects in the euhydrated (EUH) and dehydrated (DEH) conditions; *Significant difference; p < 0.05

ImPACT test results (Table 2) indicate that DEH resulted in a significant decrease in visual memory performance and significant increases in number of errors in the visual motor speed and impulse control assessments. The modules that analyzed verbal memory, reaction time, and the cognitive efficiency scale showed no significant change as a result of DEH.
Table 2. ImpACT test cognitive variable scores. Mean ± standard deviation

<table>
<thead>
<tr>
<th>Variable</th>
<th>EUH Test Score</th>
<th>DEH Test Score</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal Memory Performance</td>
<td>87.81 ± 12.077</td>
<td>85.29 ± 10.987</td>
<td>0.334</td>
</tr>
<tr>
<td>Visual Memory Performance</td>
<td>80.48 ± 11.66</td>
<td>73.14 ± 18.44</td>
<td>0.031*</td>
</tr>
<tr>
<td>Visual Motor Speed</td>
<td>41.29 ± 7.52</td>
<td>43.00 ± 7.46</td>
<td>0.316*</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>1.00 ± 0.00</td>
<td>0.86 ± 0.36</td>
<td>0.083</td>
</tr>
<tr>
<td>Impulse Control Errors</td>
<td>5.48 ± 3.87</td>
<td>8.62 ± 4.99</td>
<td>0.003*</td>
</tr>
<tr>
<td>Cognitive Efficiency Scale</td>
<td>0.19 ± 0.40</td>
<td>0.19 ± 0.40</td>
<td>1.00</td>
</tr>
</tbody>
</table>

* Significant difference; p < 0.05
DISCUSSION

This study was conducted in order to determine whether moderate exercise induced dehydration has an effect on the cognitive performance on the ImPACT test in collegiate wrestlers. To our knowledge, there have only been two groups that have investigated how dehydration affected performance on objective concussion tests (Weber, et al., 2013; Patel, Mihalik, Notebaert, Guskiewicz, & Prentice, 2007). However, both studies examined performance on cognitive measurement systems other than the ImPACT test.

Body Weight Measurements

Following a 2-hour bout of combined aerobic and anaerobic exercise, a moderate dehydration level of 2.89 ± 0.4% BW loss was induced. The comparison of EUH to DEH BW measurements indicated that BW loss was considered significant. DEH is typically categorized by the amount of BW lost in comparison to the total BW of the individual and research has supported the amount of body mass changes from pre-activity to post-activity as the most reliable indication of DEH occurring (Harvey, Meir, Brooks, & Holloway, 2008). The extent of DEH, specifically during activity, is indicated through the amount water lost during exercise, therefore, the DEH that occurred during this particular study is assumed to be due entirely to sweat loss. The loss in body mass from EUH to DEH measurements in this study indicates that moderate DEH had indeed occurred. Therefore, the significant body water lost through sweating due to exercise was likely an important factor that contributed to variability in EUH vs. DEH test scores.
Results from this study indicate that subjects demonstrated a significant change in specific cognitive variables on the ImPACT test following moderate DEH. Weber et al. (2013) suggest that athletes should be in a fully EUH state to ensure that weight cutting practices, specifically the DEH present as a result of the weight cutting practices, do not negatively influence clinical test measurements. In addition, Covassin, Weiss, Powell, and Womack (2007) found that fatigue has a negative effect on cognitive performance tests, specifically the ImPACT test when administered immediately after exhausting exercise. Because of this information, we made it a point to conduct the DEH ImPACT test 1-hour after the conclusion of the DEH procedure in order to account for and ultimately avoid the influence of exercise fatigue during the test. Since our results indicate our subjects were not in a fully EUH state during the administration of the ImPACT test following practice and the subjects had approximately 60 minutes of passive recovery from the practice session, it could be assumed that the changes in cognitive performance that occurred were the result of moderate DEH.

**Visual Memory Performance**

Results of data analysis demonstrated that visual memory performance significantly decreased after DEH had occurred. The cognitive variable of visual memory is comparable to the cognitive function of working memory, and more specifically, short term memory (STM) (ImPACT Applications Inc., 2011). The results from this study are consistent with the results of previous studies (Cian et al., 2001; Cian et al., 2000; & Choma, Sforzo, & Keller, 1998; Gopinathan et al., 1988; Sharma et al., 1986) that examined STM and tasks that employ the use of STM and memory recall after DEH had occurred. On the ImPACT test, the modules that measure visual memory performance
revolve around shape and symbol recognition and recall. For example, one module asks the subject whether the shape or design was shown previously in a sequence, while another module asks the subject to match the symbol or shape with its representative number shown to the subject previously. Subject performance on each module is based on number of correct answers. The results of this study are similar to results found in research where it was discovered that after DEH levels reached 2% or greater, significant detriments in STM tasks occurred, specifically in tasks that required subjects to remember sequences of numbers (Covassin et al., 2007; Gopinathan et al., 1988). The decrease in visual memory performance is in agreement with previous research conducted by Cian et al. (2000) and Cian et al. (2001) where visual recall, specifically numerical digit memorization, and design memorization and recall were negatively affected following DEH of 2% or more of BW loss.

It must be explained that within the computerized ImPACT program, when comparing pre and post-test scores, the specific cognitive module test score is "flagged red" to indicate when a clinically significant difference has occurred. When observing the results for visual memory performance, 67% if the subjects were identified by the ImPACT test as having experienced clinical deficits in visual memory performance after DEH.

**Visual Motor Performance**

Results indicated that visual motor performance was significantly different after DEH had occurred. Based on the individual data scores, an increase in visual motor speed was observed following the DEH procedure. The cognitive variable of visual motor speed can be compared to visual motor tracking, specifically hand-eye coordination and
visual perception and speed (ImpACT Applications Inc., 2011). The three modules that specifically measure visual motor performance concentrate on visual tracking of shapes, letters, and numbers as well as speed and accuracy of recognition and matching of associating variables. The results of our study, however, are not supported by results that have been observed in previous research. In fact, research has shown that after moderate DEH levels, visual motor performance, specifically in tasks that require visual tracking accuracy and hand-eye coordination, actually decreased significantly (Sharma et al., 1986; Cian et al., 2000; Cian et al., 2001; Devlin, Fraser, Barras, & Hawley, 2001; Petri et al., 2006). Military research that examined the effect of DEH on target shooting accuracy, visual tracking, and visual perception found that after moderate DEH was induced, the number of target hits were reduced by 17.5% on complicated tasks, and visual perception significantly decreased (Epstein, Keren, Moisseiev, Gasko, & Yachi, 1980).

After examination of the individual subject EUH and DEH ImpACT test scores, it was determined that although the differences in the scores was considered statistically significant, the ImpACT program did not consider the differences in scores clinically significant as only 48% of the subjects demonstrated decreases in visual motor speed scores. When examining the individual scores of each subject, it was noted that the subjects that demonstrated a significant difference from EUH to DEH test scores had a very large variation in scores, indicating that the statistical significant difference was based on the large variation of test scores from only 48% of subjects. The lack of clinical significance within our study can be supported by information found in research (Gopinathan et al., 1988) where moderate DEH of approximately 2.6% occurred did not
cause significant decreases in visual motor tracking. Gopinathan et al. (1988) indicated that perhaps the DEH induced was not significant enough to see clinically negative results, which may also explain the lack of clinical significance in our subjects.

**Impulse Control Errors**

After DEH, results showed that the number of impulse control errors significantly increased. Impulse control can be compared to the cognitive variable of decision time, as the concept behind the module that evaluates impulse control anticipation and recognition of visual stimuli, and the time it takes to correctly assess the stimuli and make appropriate recognition decisions (ImPACT Applications Inc., 2011). One aspect of the module that assesses impulse control instructs the subject to press a specific letter on the keyboard based on the colored symbol that is presented on the screen. The second part of the impulse control module involves word-color recognition similar to the Stroop effect (Algoum, Chajut, & Shlomo, 2004) where the color of the word may or may not be denoted by the word itself. If the subject incorrectly categorizes the symbol or color word, or if the subject inappropriately anticipates the presentation of the symbol or word, a subject impulse control error is recorded. Analysis of EUH and DEH test scores revealed that the increase in impulse control errors was both statistically significant and clinically significant as indicated by 57% of subjects experiencing significant increases in impulse control errors following moderate DEH.

Results from our study concur with previous research that examined the effects of DEH on decision time. Moderate DEH has been shown to be related to a deterioration of decision making abilities increasing the length of time to make a crucial decision (Serwah & Marino, 2006; Cian et al., 2001) and increasing visual working memory response

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latency, specifically decision making errors, especially when the subject is asked to complete a complex task (Ganio et al., 2011).

**Reaction Time**

After evaluation of the data, it was observed that reaction time did not show a significant change in comparison of EUH and DEH test scores. However, subtle decreases in reaction time were clinically observed within the ImPACT program. In fact, test results showed that 43% of the subjects had clinically significant improvements in reaction time after DEH, showing that there was an agreement between the stats and the software interpretation.

The results of our study and the trend that was observed that showed an improvement in reaction time was supported by previous research that examined reaction time after moderate DEH was induced, however, the degree of DEH was greater than the degree induced in our study. Research has demonstrated that after moderate DEH was induced, simple reaction time decreased, which is indicative of an improvement in choice reaction time (D'Anci et al., 2009; Serwah & Marino, 2006; Grego et al., 2004; Lebowitz et al., 1972). The results found in research conducted by Weber et al. (2013) however, indicate that after moderate DEH of 2.52% loss of BW, similar to the DEH that occurred in our study, reaction time was not significantly affected. Similar results were found in research by Patel et al. (2007) where differences in reaction time were not observed following moderate levels of DEH. If the degree of DEH within our study would have been greater, perhaps a more clinical and statistical significant difference would have been observed in reaction time.
Blood Glucose Measurements

Blood glucose showed a significant increase following the DEH procedure. We chose to examine EUH and DEH blood glucose values in our study because we wanted to control as many factors that may play a role in cognitive performance as possible so we could attribute any detriments that had occurred specifically to the DEH. Glucose is a major source of energy for the brain and central nervous system, and since relatively little glucose can be stored in the brain, neuronal functioning is dependent upon blood glucose supplies. Disruption in neuronal activity and a decrease in cognitive performance have been reported during times of glucose deprivation (Holmes, Hayford, Gonzalez, & Weydert, 1983). If blood glucose measurements would have shown a decrease following DEH, it could not be certain whether cognitive performance impairments were due to DEH or the decrease in blood glucose.

The increase in blood glucose that occurred following the bout of exercise matched the expected outcome of post-exercise blood glucose. Studies indicate that there is an increase in blood glucose immediately following exercise, specifically after anaerobic exercise (Hulton, Edwards, Gregson, MacLaren, & Doren, 2013; Almeida et al., 2011; Hordern et al., 2011; Ball, Burrows, & Sargeant, 1999). Because the results of our study are similar to the results from previous research in which an increase in blood glucose post-exercise was observed, it can be concluded that cognitive changes that were present in the DEH ImPACT were not the result of blood glucose decreases, but rather, more so the result of impairments caused by DEH.
Limitations

Due to logistical considerations, we could not perform the data collection on multiple days, as we were not allowed to do any data collection during the competitive season. In addition, the window between minimum weight assessment and hydration testing and the commencement of the competitive season was very small, so we had to take advantage of the time period we were allowed to conduct the study within.

Retrospectively, we realize that it may have been beneficial to have a control group in which subjects were administered the ImPACT under EUH conditions and a practice procedure that promoted rehydration during the practice and was allowed to reach EUH before the follow-up ImPACT test administration. However, due to the logistics of the athletic team and the team competitive season practice schedule, this control session was not feasible.

In addition, a wrestling athlete, like many athletes, is in a constant DEH state. Research has shown that it is very common for athletes in various sports to begin competition or training with some degree of fluid DEH (Maughan & Shirreffs, 2010; Galloway, 1999) and once an individual reaches a higher degree of DEH during an exercise bout, it is nearly impossible for a completely EUH state to be attained unless exercise ceases and appropriate rehydration is allowed (Maughan, 2003; Galloway, 1999). A wrestling athlete is known to be chronically DEH (Buford, Rossi, Smith, O’Brien, & Pickering, 2006; Alderman, Landers, Carlson, & Scott, 2004; Choma, Sforzo, & Keller, 1998) yet, he or she may proceed to induce further DEH due to the nature of the sport and in order to reach the desired weight class. Wrestlers are not usually encouraged to maintain EUH status during a practice because the practice session is
typically used as a weight cutting method (Lingor & Olson, 2010). Therefore, to ask a wrestling athlete to maintain a fully EUH state throughout a practice session would not simulate a true wrestling practice that occurs within a competitive season nor would it be entirely possible. However, despite the small window of opportunity, difficulties due to the wrestling team logistics, and the lack of a control group, it can be said that we were able to successfully simulate an actual wrestling practice that occurs within a competitive season and create the inevitable DEH situation through weight-cutting procedures that are performed by a typical wrestling athlete.

Conclusions

The results of our study indicated that moderate DEH in NCAA Division III collegiate wrestlers has a negative effect on cognitive performance determined by the ImPACT test. The results of a clinical concussion test such as the ImPACT test may be difficult to interpret specifically in wrestlers that are utilizing weight-loss tactics that put them in a DEH state. Results of our study indicate that in order to achieve an accurate concussion assessment on the ImPACT test, the athlete should be in a EUH state or as close as possible to a state of EUH when the test is administered. Additionally, our study supports the idea that the ImPACT test should be used as a post-concussion test utilized 24-48 hours after an athlete has sustained concussion instead of an immediate concussion assessment tool. The time that is required between the concussion incident and the post-concussion ImPACT test administration is necessary in order for the athlete to appropriately attain a EUH status and ensure that the athlete performs at the highest cognitive capacity as possible.
REFERENCES


APPENDIX A

INFORMED CONSENT
Protocol Title: The effect of moderate exercise induced dehydration on cognitive performance on the ImPACT test in NCAA Division III collegiate wrestlers

Principle Investigator: Laura Hudson
3427 Elm Drive Apt C
La Crosse, WI 45601
(715) 292-3711

• Purpose and Procedure
  o Assess if exercise induced dehydration has a negative effect on the cognitive performance on the Impact test in Division III collegiate wrestlers.
  o Develop accurate evaluation tools for athletic trainers to use when assessing a concussed or injured athlete to determine if cognitive function and performance is affected at all by moderate dehydration of loss of 2.5-4% body weight.
  o My participation will require a collection of a urine sample, a collection of a blood sample by means of a finger stick, completion of a neurocognitive testing battery in the form of the computer based ImPACT concussion test, measurement of body weight on a digital scale, and participation in a two hour dehydration procedure in the form of a standard wrestling practice.
  o The collection of a blood sample in the form of a finger stick will occur before the dehydration practice and after the dehydration practice is completed.
  o In order to participate in this study, I must not have experienced a concussion in the last six months and I must not have a history of heat related illness, specifically heat exhaustion or heat stroke.
  o My participation in this study requires that I have participated in the sport of wrestling within the last year and within the ages of 18-25 years.
  o The total time requirement to complete this study will be 4 hours which will include the two hours of wrestling practice used to induced moderate dehydration and two total hours to complete the baseline and post dehydration ImPACT test and previously mentioned data collection processes.
  o Testing will occur in the Human Performance Lab of Mitchell Hall for urine and blood sample collection, the Mitchell Hall wrestling facility for the dehydration procedure, and room 26 of Mitchell Hall for baseline and post dehydration ImPACT testing.

• Potential Risks
  o I may experience muscle soreness or fatigue from completing the two hour wrestling practice.
  o I may experience mental fatigue due to completion of the ImPACT test under euhydrated and moderately dehydrated conditions.
- Due to moderate dehydration, I may experience unwanted physical symptoms such as dry mouth, lethargy, lightheadedness, dizziness, or muscle cramping.
- To minimize the risks associated with moderate dehydration, medical personnel such as licensed and certified athletic trainers and additional capable athletic training students will be on site for every test session to respond to any complications I may experience in response to dehydration or exercise.
- The risk of serious or life threatening health complications for healthy individuals like myself, is near zero.
- In the unlikely event that any injury or illness occurs as a result of this research, the Board of Regents of the University of Wisconsin System, the University of Wisconsin-La Crosse, their officers, agents, and employees do not automatically provide reimbursement for medical care or other compensation. You have been informed that payment for treatment of any injury or illness must be provided by me or my third party payor, such as your health insurier. If any injury or illness occurs during the course of research, or for more information, you will notify the investigator in charge. You have been informed that you are not waiving any rights that you may have for injury resulting from negligence of any person or the institution.

For information about policies, the conduct of the study, or the rights of the research subjects, please contact the University of Wisconsin-La Crosse Institutional Review Board (IRB) for the Protection of Human Subjects (608-785-6892, irb@uwlox.edu). The IRB is a group of people who review the research to protect the rights of the research participants.

- **Rights and Confidentiality**
  - My participation is voluntary. I can withdraw from the study at any time without penalty or consequences.
  - The results of this study may be published in scientific literature or presented at professional meetings or conferences using grouped data only.
  - All information in this study will be kept confidential through the use of number codes. My data will not be linked to personally identifiable information.

- **Possible Benefits**
  - There are no anticipated direct benefits to the subjects as a result of participating in this study.
  - Indirect benefits of conducting this study include gaining a better understanding of what can be done to minimize dehydration in athletes in order to prevent cognitive performance deficits and developing accurate evaluation tools for athletic trainers to use when assessing a concussed or injured athlete to determine if cognitive performance is affected negatively by moderate dehydration.
Questions regarding study procedures may be directed to Laura Hudson (715-292-3711), the principal investigator, or the student advisor Dr. Glenn Wright, Department of Exercise and Sport Science, UW-L (608-785-8689). Questions regarding the protection of human subjects may be addressed to the UW-La Crosse Institutional Review Board for the Protection of Human Subjects (608- 785-8124 or irb@uwlaux.edu).

I HAVE READ AND UNDERSTAND ALL OF THE ABOVE, ASKED QUESTIONS, RECEIVED ANSWERS CONCERNING MY QUESTIONS, AND I WILLINGLY GIVE MY CONSENT TO PARTICIPATE IN THIS STUDY.

_________________________________________  __________________________________________
(Date)                                                                                     (Signature of Participant Giving Consent)

_________________________________________  __________________________________________
(Date)                                                                                     (Signature of Person Obtaining Consent)
APPENDIX B

REVIEW OF RELATED LITERATURE
INTRODUCTION

In athletics, success originates from a variety of factors ranging from appropriate and frequent training, adequate mental and physical rest, and proper nutrition. The factor that is frequently overlooked is proper nutrition, particularly hydration. Proper hydration has become a popular focus of study in the medical and athletic fields of interest. Athletes must practice proper hydration techniques in order to replenish the water that is lost through practice sessions, competitions, in addition to through everyday life processes that deplete water reserves. If body water is not replenished, athletes subject themselves to dehydration (DEH) in conjunction with the possible physical and cognitive complications that accompany it.

A sport that frequently renders its athletes to various levels of DEH is the sport of wrestling. In order for an athlete to qualify for his/her desired weight class and be considered competitive at that weight, it may be necessary for the athlete to employ weight loss techniques in order to reach the preferred weight class. Although the National Collegiate Athletic Association (NCAA) and the National Federation of State High School Associations (NFHS) have established rules and regulations in hopes of prohibiting rapid weight loss procedures that induce harmful and even fatal DEH from occurring, athletes that compete in the sport of wrestling continue to use unsafe weight loss techniques. Weight loss techniques used frequently by wrestling athletes often include dangerous and harmful techniques that occur in the week preceding a match, with the goal of being able to wrestle with a strength advantage in the desired weight class.

Unfortunately, athletes involved in the sport of wrestling are not only faced with the dangers that accompany dehydration. Due to the fast-paced, intense nature of the
combat sport that provides little to no protection through the use of protective head gear, athletes subject themselves to injury, specifically, concussions. Wrestlers wear head gear in order to prevent injuries to the ears during competition; however, the head gear does not prevent concussions. Due to the nature of the sport both in practice and competition, the athlete is subjected to situations in which concussions are ultimately inevitable.

Currently in sports medicine, there are specific post-concussion assessments that can be utilized by medical personnel in order to immediately evaluate whether an athlete has suffered a concussion. Using these tools, medical professionals can make vital decisions as to whether an athlete should seek further medical attention or if the athlete should instead take necessary precautions when dealing with a concussion. Recently, an instrument called the Immediate Post-Concussion Assessment and Cognitive Testing (ImpACT) has been created in order to establish a baseline of cognitive abilities and function before a concussion has occurred. These baseline scores provide a foundation of cognitive function that can be used to compare to the cognitive abilities and performance of an athlete after a concussion has been sustained. The ImpACT has proven to be both valid and reliable in assessing an athlete’s state of injury and statistically analyzing whether or not it is safe for the athlete to return to play (Iverson, Gaetz, Lovell, Collins, & Maroon, 2002; Iverson, Lovell, & Collins, 2004). Through the analysis of comparative measures, medical professionals now have numerical data to base critical return to play decisions upon instead of relying simply on subjective athlete information.

DEH, whether it is mild, moderate, or severe, has a negative effect on the physical function and performance. The relationship between dehydration and physical performance has been extensively researched, well documented, and fully accepted in
medical literature. The effect that any degree of DEH has on cognitive performance, however, has not been well researched. In response to the lack of research, the concept of DEH and the negative effect that it has on cognitive performance has not been completely accepted in the sports medicine field. Most studies that have examined the DEH and cognitive performance relationship have found specific areas of cognition that have been affected by moderate to severe DEH; however, additional research is still needed.

Since the sport of wrestling undoubtedly subjects its athletes to DEH and concussion injuries, finding out whether there is a correlation between DEH and cognitive performance is beneficial to the athletes involved. If there is a relationship between the two, perhaps this information would be beneficial in assisting medical professionals during concussion evaluations, specifically in the sport of wrestling.

In this review of literature, the concept of DEH and specific indications related to DEH will be reviewed. The sport of wrestling and the frequent DEH that occurs due to the demands of the weight classification system within the sport will be examined as well as the prevalence of concussions that typically occur within the sport. Additionally, concussion assessment tools, specifically the ImPACT will be discussed as well as the validity and reliability of comparative measures that allow for safety in return to play decisions. Finally, research regarding the relationship between DEH and the effect it has on specific cognitive functions will be reviewed. It is the hope that the information obtained in this review will drive the need for research to be conducted that will attempt to answer the question as to whether exercise induced DEH has an effect on cognitive performance.
INTRODUCTION TO DEHYDRATION

Water is arguably one of the most important components that make up the human body. In fact, water accounts for 50-60% of total body mass, and the turnover rate of water in the human body exceeds that of other body components (Maughan, 2003). DEH is defined as a deficit of body water, or when fluid output exceeds fluid intake. When the crucial cycle of body water turnover is altered, physical and cognitive functions may be altered. In a sedentary individual, the rate of daily fluid loss can exceed 3 liters (Leiper, Carnie, & Maughan, 1996), corresponding with about 5-10% of total body water content (Maughan, 2003). When comparing a sedentary individual to one that consistently exercises or undergoes heat exposure, dehydration in an active individual is almost unavoidable.

The main avenues of water loss from the human body are through urine (about 1400 ml), feccs (about 200 ml), insensible losses though lungs (about 400 ml), and loss through the skin such as sweating (about 500 ml), creating a total daily water loss about 2500 ml (Maughan, 2003). Although the human body is adapted to efficiently endure a high daily rate of water exchange, a water deficit of only 2% percent is enough to impair physical performance. If body water loss reaches 10-15% of total body mass, about 20-30% of total body water, the outcome of this situation is likely to be fatal (Maughan, 2003).

DEH has historically proven to be an important issue in the sports world. In both the 1995 International Association of Athletics Federation Conference and the 2003 International Olympic Committee (IOC) Conference, the topic of DEH was discussed and statements referring to the topic of proper DEH were publicized. In 2003, the IOC
Consensus Conference released a statement regarding hydration which concluded that “dehydration impairs performance in most events, and athletes should be well hydrated before exercise. Sufficient fluid should be consumed during exercise to limit dehydration to less than about 2% loss of body mass.” (IOC Consensus Statement, 2004 in Shirreffs, Casa, & Carter, 2007). The reason behind warning athletes about losing more than 2% of body mass was attributed to the ranking of DEH based on percent loss of body mass. A state of mild DEH is defined as loss of body weight (BW) of 1-2%. Moderate DEH, on the other hand, is loss of BW of 2-5%, and severe DEH is considered BW loss of over 5%. The change of body water is measured by the change in BW. This measure of BW loss is fully accepted in regards to actual body water loss because when an individual is in a caloric balance, a BW loss essentially is attributed to water loss (Adan, 2012). Mild to severe DEH causes physiological impairments within the body. Severe DEH, or more than 5%, can be linked to compromised cardiovascular function, muscle weakness and fatigue, renal dysfunction, headache, severe anxiety, coma, and death (Maughan, 2003). Symptoms of mild to moderate DEH of 1-5% range from dry mouth, fatigue, sleepiness, decrease in alertness, thirst, headache, decreased urine output, dizziness or lightheadedness, heart palpitations, rapid respiration, and fever (Wilson & Morley, 2003).

**Dehydration Indications**

DEH is known to produce physical symptoms as well as physical and physiological deficits. These physical deficits are specifically notable when looking at individual work capacity. Physiological detriments that result in unwanted physical symptoms, however, can be observed due to the increased cardiovascular strain associated with DEH, decreased venous return, and decreased stroke volume (Sanders,
Noakes, & Dennis, 1999). DEH also affects blood flow to the kidneys and other body tissues as well as the ability to sweat and dissipate heat (Horswill, 1991). The most notable DEH deficits include decreased cellular function, a change in brain function, and change in blood component measures, and loss of BW.

**Cellular Function**

DEH ultimately causes a loss in total body water due to sweat loss. This decrease in total body water affects the body at the cellular level. When the body undergoes DEH, a reduction of water within and between cells as well as within the blood plasma occurs (Kozlowski & Saltin, 1964). Different levels of DEH affect the extent to which water is taken from within the cell. For example, with mild DEH of about 2.2% loss of BW, 70% of the water loss comes from extracellular fluid, while 30% of the water is taken from the intracellular fluid within the cell. However, when moderate to severe DEH is undergone with 4.1-5.8% loss of BW, 48-50% of water loss comes from the extracellular volume while 50-52% comes from within the cell (Costill, Cote & Fink, 1976). This indicates that as the DEH level increases, the extent to which water is taken from the cell increases. DEH causes a decrease in homeostasis in addition to shrinkage of the cell, ultimately leading to a decrease in cell function.

DEH also has an effect on plasma volume (PV) in the blood. The decreased PV may lead to the reduced cardiac function causing the cardiovascular strain and decreased stroke volume and venous return which in turn reduces blood pressure (Jiminez et al., 2002; Alen, Smith, & Miller, 1977). In addition to decreased cardiovascular function, the reduction in PV may also contribute to decreased blood flow to the kidneys, skin, and muscles (Horswill, 1991).
Effect on Brain Function

Although DEH has a major effect on cellular water volume, the effects are also apparent in the mechanisms of brain function. Due to the decrease in blood flow caused by DEH, an inadequate amount of blood is able to circulate within the brain, decreasing the blood-oxygen levels which may contribute to neuro-cognitive deficits. Additionally, changes in the amount of electrolytes that occur when an individual is DEH may alter brain activity as well as the functioning of the neurotransmitter systems that are involved in cognitive processes (Lieberman, 2007; Wilson & Morley, 2003). Structural magnetic resonance imaging (sMRI) methods have been used previously in DEH studies. Research has shown that acute (Dickson et al., 2005; Kempton et al., 2009) or prolonged (Duning et al., 2005) DEH through physical exercise or restricted fluid intake causes reversible brain changes. Brain changes include reduced brain volume (Duning et al., 2005) and associated increases in ventricular volume (Kempton et al., 2009).

A study conducted by Kempton and colleagues (2011), used functional magnetic resonance imaging, sMRI, and arterial spin labeling to study to effects of acute DEH on brain function, structure, and blood flow. The study was used to investigate whether acute DEH had a direct effect on the cognitive domain of the brain, specifically in the volume of the lateral ventricles as previous research (Kempton, et al., 2009) suggested that these brain structures were the most sensitive to the effects of DEH. Results of this study showed that ventricular enlargement occurred following DEH, and that this enlargement was proportional to BW lost, which is consistent with previous research (Dickson et al., 2005; Duning et al., 2005; and Kempton et al., 2009). There was a significant correlation between the percent change in body mass and percent change in ventricular volume. This
correlation indicated that greater reductions in body mass result in greater increases in the volume of the lateral ventricles in the brain.

Research conducted by Kempton et al. (2009) is an accurate portrayal of the brain’s response to DEH regardless of the method of dehydration. When an individual becomes DEH, blood volume decreases, which causes a reduction in brain volume. This reduced brain volume is directly related to the increase in ventricular volume. Serum osmolality also increases as a result of acute DEH, creating an osmotic gradient. This causes water to leave the intracellular space due to changes that occur in the blood-brain barrier permeability and decreases in the blood flow in some areas of the brain (Maughan, Shirrefs, & Watson, 2007). When water leaves the cells, a subtle reduction in overall brain volume occurs. Furthermore, a secondary or compensatory increase in ventricular volume results from the decrease in overall brain volume (Dickson et al., 2005; Duning et al., 2005; Kempton et al., 2009).

DEH can have an effect on both endocrine and biochemical aspects of the brain. In response to DEH, vasopressin, an antidiuretic hormone is secreted. The increased plasma levels of vasopressin may actually be beneficial for learning and memory task execution within brain mechanisms (D’Anci, Constant, & Rosenberg, 2006; Patel, Mihalik, Notebaert, Guskiewicz, & Prentice, 2007). A state of DEH leads to an activation of the hypothalamic-pituitary-adrenocortical axis and to the production of stress hormones, particularly cortisol. The increase in cortisol levels may be responsible for the negative effects on cognitive functions including perception, spatial ability, and memory (D’Anci, Constant, & Rosenberg, 2006; Lieberman et al., 2005). Proper hydration can decrease cortisol levels as well as increase the levels of glycerol in the
body. In addition, proper hydration along with the increased ingestion of glycerol allows for adequate availability of glucose in the central nervous system (Cian, Koullmann, Barraud, & Rafael, 2000; Cian, Barraud, Melin, & Rafael, 2001; and Serwah & Marino, 2006). Glucose availability within the central nervous system is known to be advantageous for learning and memory systems within the brain (Adan & Serra-Grabulosa, 2010).

Structural brain changes are also evident in the results of the study done by Streitburger, e. al. (2012). Brain scans were conducted on each subject that displayed the brain during a baseline, DEH, and a rehydration. On average, subjects lost approximately 2.3% of their BW between the baseline scan and dehyrdration scan, indicating moderate DEH had occurred. Results showed a significant volume decrease in gray matter had occurred in the left caudate nucleus and right cerebellar posterior lobe following DEH procedures. In addition, all major brain compartments underwent changes as a result of DEH, specifically when looking at gray and white matter, especially in the ventricular system. Cerebrospinal fluid results obtained showed an increased volume in the lateral ventricles upon DEH, which was consistent with previous studies (Dickson et al., 2005; Duning et al., 2005; Kempten et al., 2009). DEH also caused a significant decrease in tissue volume to occur. Streitburger et al. (2012) reiterated that DEH causes decreased blood volume which may contribute to reduced brain volume along with an increase in volume of the ventricular system. Additionally, acute DEH increases serum osmolality, which generates an osmotic gradient resulting in an increased diffusion of water from extracellular stores into extracellular spaces. This process results in cell shrinkage,
specifically in the astrocytes, which play an important role in water transport (Simard & Nedergaard, 2004).

**Effect on Blood Measures**

DEH results in loss of water from the body, particularly within the cells and blood. Along with the decrease in body fluid comes an increase in the concentration of blood due to the decrease in the cell-plasma ratio. Blood measurements such as hematocrit (Hct), hemoglobin, and PV are key indicators that are used to signify DEH. In euhydrated (EUH) blood, the standard Hct level is 42-54% for males, while plasma accounts for 45-58% of red blood cells (Braunwald et al., 2001). When an individual experiences DEH, however, the Hct levels increase, corresponding with a decrease in PV.

Before examining the effects of DEH on Hct and plasma levels, it must be understood that even with exercise, Hct and plasma levels will be altered, revealing again an increase in percent Hct and a decrease in PV. A study conducted by Rotstein, Bar-Or, and Dlin (1982) demonstrated that Hct and calculated PV changes were affected by short, supramaximal tasks, such as the Wingait Anaerobic Test. The relative plasma decrease for both males and females following the exercise protocol was a 10-15% decrease. Similarly, in a study conducted by Green et al. (1984), it was discovered that after a bout of short term supramaximal cycling exercise, Hct concentration percentage increased approximately 10%. When examining total PV, the study demonstrated a decrease of 14% from pre to post-exercise volumes. Although the studies did not account for any DEH that may or may not have taken place, both demonstrated that exercise does have an effect on these blood markers. Due to the fact that the exercise bout was short term and
supramaximal, there is no reason to believe that DEH occurred in such a short period of time. In addition, PV and Hct quickly returned to baseline values once exercise ceased.

When looking at DEH and the effects on Hct and plasma levels, it is necessary to establish a relationship between the severity of DEH and the relative decrease in PV as well as the corresponding increase in Hct. A study conducted by Jimenez and colleagues (2002) found that regardless of whether the DEH occurred in response to heat stress or exercise, a 2.7% moderate loss of BW increased the plasma osmolality. After DEH was induced, calculations of PV changes by hemoglobin and Hct showed PV decreased by approximately 6% in both exercise trials. Results showed that moderate DEH had an effect on PV, especially when examining the increased concentration of blood in the form of Hct. This aspect is of importance because maintaining blood volume is crucial to ensure cardiovascular and thermoregulatory functions, specifically during exercise.

Changes in PV and Hct were also examined in a study conducted by Osterberg, Pallardy, Johnson, and Horswill (2010). Blood samples to measure Hct, blood glucose, and hemoglobin were taken before and after DEH procedures occurred. The Hct and hemoglobin were used to calculate change in PV. In regards to blood glucose levels, there appeared to be no difference between EUH and DEH values. For all trials, moderate DEH of 2-3% occurred and relative PV decreased on average 8%. Blood sample analysis from this study concluded that DEH decreases PV, thus increasing Hct. In addition, although exercise was the method used to induce DEH, blood glucose levels were not affected by the procedure.

In mild to moderate DEH, significant changes in both Hct and PV are observed. However, a study conducted by Karila and colleagues (2008) demonstrated that severe
DEH has significant effects on Hct and plasma volume. The subjects of the study were elite wrestlers, therefore, the nature of DEH was a relatively familiar practice to partake in. After a two week weight loss regimen, hemoglobin had increased significantly compared to pre-weight loss measures by 8%. Similar to previous studies (Jiminez et al., 2002; Osterberg et al., 2010) Hct increased significantly when compared to EUH measures by 12%. Results of this study suggest that severe DEH, even over a long duration, has significant effects on blood chemistry. Long term DEH, however, may constitute a more severe health risk in individuals, especially in those that participate in repeated long term DEH procedures.

Loss of Body Weight

DEH is typically categorized by the amount of BW lost in comparison to total BW of an individual. Although decreased brain function, decreased cellular fluid, decreased PV, and increased Hct concentrations are all indicators of hydration status, change in BW still proves to be the most accurate measure when determining the amount of DEH. A study conducted by Harvey, Meir, Brooks, and Holloway (2008) looked to determine the most accurate and reliable measure of DEH. Measures of Hct, urine specific gravity ($U_{sg}$), urine color, and BW were taken before and after a competitive event and all measures showed significant differences. Linear mixed effects models predicted that mass change was the best fitting in order to determine the extent of DEH occurring.

When examining the various methods to measure DEH, collecting urine samples may be problematic post-game as DEH may inhibit many athletes from producing a urine sample. Urine color is a questionable method of measuring DEH as urine color can be
affected by factors completely unrelated to DEH such as food, medications, illness, or ingestions of large volumes of hypotonic fluid (Oppliger & Bartok, 2002; Shirreffs, 2000). Hct analysis and blood collection are invasive and require expensive equipment, and the procedure is difficult to conduct immediately post-game. In addition, Hct and osmolality may be less sensitive to mild levels of DEH (Oppliger & Bartok, 2002). Research has supported the use of body mass changes as the most timely, accurate, and practical method of monitoring DEH in addition to being simple to administer without being invasive, making it the most accepted measure of DEH.

DEHYDRATION IN WRESTLING

Over 250,000 high school and college athletes participate in the sport of wrestling each year (NCAA, 2002; NFHS, 2002; Bartok et al., 2004). In order to maintain fairness and prevent injuries, wrestlers compete against opponents of a similar weight. In collegiate wrestling, there are 10 separate weight classes that range from 125-286 pounds (56.8-130 kg). The classification of weight classes in addition to the intense competition often causes most wrestlers to “cut weight” or decrease mass in order to qualify for a lower weight class and experience increased strength or leverage over another opponent (Alderman, Landers, Carlson, & Scott, 2004; Buford, Rossi, Smith, O’Brien, & Pickering, 2006).

During the 1997 collegiate wrestling season, three wrestlers died while practicing unsafe rapid weight loss (RWL) methods. The NCAA responded to the tragedies by mandating a wrestling weight certification program to establish permanent weight classes for each wrestler in attempt to eliminate the motivation to participate in extreme and detrimental weight loss procedures (Wenos & Amato, 1998; NCAA, 1998). The NCAA
also instituted such rules as wrestlers are not allowed to fall below 5% total body fat and total BW loss during a week should not exceed 1.5% of total BW (Kiningham & Gorenflo, 2001). Additionally, the NCAA instituted a decrease in time between weigh-ins and competition and prohibited the previously traditional weight loss techniques of vapor impermeable sweat suits and saunas (Alderman et al., 2004).

Both the NCAA and the NFHS have also established rules that require the preseason assessment of hydration status among wrestlers before establishing a minimum weight that the wrestler can compete at (Utter, 2007; Utter, 2001). To assess hydration status, the NCAA chose a $U_{sg}$ threshold of $\leq 1.020$ to identify a state of EUH, while the NFHS established a threshold of $\leq 1.025$ (Oppliger et al., 2006). Collegiate and high school wrestlers that are above the set threshold are not allowed to have their body composition assessed to determine the minimum wrestling weight (MWW). If a wrestler fails to meet hydration requirements at his or her desired weight class, the athlete is forced to compete at a higher weight class.

**Common Weight Loss Methods**

Despite the interjection of the NCAA and NFHS and the increased precautions taken to eliminate unsafe and fatal weight loss methods in the sport of wrestling, RWL techniques are still used by wrestlers of all ages and skill levels. A study conducted by Kiningham and Gorenflo (2001) examined the weight loss practices of high school wrestlers through a survey that assessed common weight loss procedures. Results showed that on average, wrestlers lost approximately 6 pounds during a competitive season, with over 27% of wrestlers admitting to the loss of 10 pounds or more. Even more alarming, the survey results concluded that 72% of wrestlers engaged in at least one potentially
harmful weight loss method during the wrestling season. Common methods of weight loss included laxatives, diet pills, diuretics, vomiting, fasting, gradual dieting, fluid restriction, excessive exercise, use of heated wrestling rooms, and use of rubber/plastic sweat suits.

Regardless of the level of competition, RWL methods appear to be accepted and practiced within the culture of wrestling. Collegiate weight loss methods were examined in the study conducted by Lingor and Olson (2010) in order to identify common methods used by collegiate wrestlers. The survey discovered that the methods of reducing food intake, excessive exercise, fluid restriction, fasting, sauna use, hot baths, rubber suits, forced vomiting, and diuretic and laxative use were the most prevalent methods utilized by collegiate wrestlers. The methods exercised by high school and collegiate level wrestlers undoubtedly subject the athlete to DEH, regardless of the method or the frequency of use. Unfortunately, the way in which each method is abused would be deemed an unsafe method due the nature of RWL that occurs as a result.

**Typical Weight Loss as a Result of Wrestling Weight Loss Methods**

Typical weight loss methods employed by a majority of wrestlers in the sport undoubtedly lead to RWL. Despite the rules and regulations that have been created to make the sport less harmful to the athletes, the RWL that wrestlers willingly subject themselves to in order to “make weight” still threatens the safety and hydration status. Although the MWW program created and enforced by collegiate and high school wrestling committees appears to have reduced the magnitude of weight change that is allowed by a wrestler, the process known as weight cycling still continues. Weight cycling, the continuous loss and regain of body mass, may occur up to 15-30 times over a
5 month period (Lingor & Olson, 2010; Ransone & Hughes, 2004; Brownell, Steen, & Wilmore, 1987). A study conducted by Lingor and Olson (2010) looked to quantify the acute weight loss that occurs as college wrestlers prepare for a competition and to examine the patterns and subsequent effects of weight cycling throughout a competitive season. Results showed that subjects lost an average of 5.3% of their initial weight in order to compete in their desired weight class for the first meet. However, for each additional weight cycle that was completed in order to prepare for remaining competitions, an average of 4.7% loss of BW occurred. With the drastic amount of weight loss that is occurring within the process of weight cycling, DEH simultaneously takes place.

In a study conducted by Marttinen, Judelson, Wiersma, and Coburn (2011), similar weight losses of 4-5.3% occurred the week before a competition. Results of the study also discovered that the majority of the weight loss occurred 24-48 hours prior to a competition. Although the NCAA technically states that wrestlers may lose 1.5% of total body mass each week, this study proved that many wrestlers manipulate the system to rapidly lose multiple weeks’ worth of body mass just days before a competition. Research that examined similar last minute weight loss tactics was conducted by Ransone and Hughes (2004). Subjects were asked to weigh in 24 hours before and 1 hour before a competition occurred as well as 24 hours after competition. A significant difference in weight measurements existed between BW 24 hours before competition compared to 1 hour before competition, showing that RWL occurs within this time frame. Additionally, there was a significant difference in BW 1 hour before a competition and 24 hours after a competition had taken place, showing that immediate weight gain occurs following
competition as RWL methods are no longer utilized after competition. These results correlate with previous studies that conclusively indicate that extreme and subsequently unhealthy weight loss methods are frequently used in the sport of wrestling, especially in the hours closest to actual competition (Schmidt, Corrigan, & Melby, 1993; Horswill, 1993).

**Measurement of Dehydration Status to Determine Minimum Weight**

In order to compete in a specific weight class, the wrestling athlete must be evaluated before the season begins to determine the appropriate and the most safe minimum weight class that each individual may compete in. The NCAA Competitive Safeguards Committee has approved hydrostatic weighing (HW), skinfolds (SF), and air displacement plethysmography for collegiate weight assessment (Turocy et al., 2011; Utter, 2001). At the high school level, MWW assessment is made using HW, SF, and bioelectrical impedance analysis (BIA) (Utter, 2007). Concerns over the past few years have risen in regards to the effects of DEH and how it influences MWW assessment techniques (Clark, Oppliger, & Sullivan, 2002). DEH ultimately decreases BW, reduces total body water, alters the distribution and compartmentalization of body water, lowers hydration levels of fat free mass, and changes the density of fat free mass (Clark et al., 1993; Oppliger & Bartok, 2002). In a study conducted by Bartok, Schoeller, Clark, Sullivan, and Landry (2004), the issue of DEH and the effects on MWW testing were examined. The results of the study determined how acute thermal DEH affected body composition methods and how the effects of DEH substantially have an impact on the total error in MWW estimation. DEH increased the total error for leg-to-leg BIA by 23% while increasing the total error for multi-frequency bioelectrical impedance spectroscopy.
by 33%. Even more surprisingly, DEH affected SF testing by increasing total error by 59%. More importantly, in a DEH state, all techniques of measurement had a total error approaching or exceeding 4 kg. A total error of 4 kg signifies that the predicted minimum weight is within 4 kg (8.8 lbs) 68% of the time and within 8 kg (17.6 lbs) 95% of the time, making the error levels unacceptable for MWW estimation as they span several weight classes. Results of the study made it clear that DEH significantly limits accurate and reliable body composition assessment for the otherwise valid methods of assessing MWW.

**Alternative Methods to Determine Hydration Status**

The effects of DEH are significant areas of concern for sport of wrestling. Through research, it was observed that some wrestlers arrive for MWW testing in a DEH state in order to qualify for a lower weight class. In fact, in research conducted by Clark and Oppliger (1998), unannounced reweighing of wrestlers days after MWW testing showed that almost 25% had gained more than 1.4 kg (3 lbs), with a maximum weight gain of 8 kg (18 lbs). In the hopes of prohibiting the act of DEH to reach an unsafe MWW class, the NCAA and NFHS added hydration testing to the MWW testing protocol. Ever after the instatement of hydration regulations, concerns still remain regarding the sensitivity and specificity of $U_{8}$ testing and the ability of wrestlers to conceal the effects of DEH during MWW testing.

The information obtained after looking at the effects of DEH on MWW assessment (Bartok, Schoeller, Clark, Sullivan, & Landry, 2004) in addition to the uncertainty in the accuracy of $U_{8}$ measurement and its sensitivity to changes in hydration status (Oppliger, Magnes, Popowski, & Gisolfi, 2005; Bartok et al., 2004;
Popowski, Oppliger, Lambert, Johnson, Johnson, & Gisolf, 2001), have motivated researchers to find a method of measuring hydration status that is valid, reliable, and easy to administer. It has been suggested that ultrasound velocity (UV) can be utilized to measure the change in water content of soft tissues (Sarvazyan, Tatarinov, & Sarvazyan, 2005) including muscle that consists of approximately 73% water (Wang, Deurenberg, Wang, Pietrobelli, Baumgartner, & Heymsfield, 1999). Utter et al. (2010) found that after DEH of ≥5%, a significant increase in UV existed in male collegiate wrestlers when examining the soleus. UV increased by 5 m·s⁻¹ in the soleus after weight loss of 5%, similar to results from a study by Topchyan, Tatarinov, Sarvazyan, and Sarvazyan (2006) where subjects lost 3.6% of BW and UV increased in the soleus by 2.18 m·s⁻¹. The changes in UV were also accompanied by similar increases in plasma osmolality, Uₚg, and urine osmolality, indicating DEH took place.

In attempt to determine additional ways to identify acute DEH in collegiate wrestlers, Utter and colleagues (2012) conducted a study that examined the validity of multi-frequency direct segmental bioelectrical impedance analysis (DSM-BIA) and its accuracy in measuring changes in hydration status. Results showed that at all five frequencies evaluated (5, 20, 50, 100, 500 kHz) had a significant increase in weighted impedance when acute DEH of 3.5% occurred. Research conducted by Utter and colleagues (2010) showed that along with an increase in weighted impedance, increases in plasma osmolality, Uₚg, and urine osmolality were also observed with acute DEH. The results of the study demonstrated that DSM-BIA may have a practical application as an alternative method to measuring Uₚg for assessing hydration status for MWW certification procedures.
The methods of UV (Utter et al., 2010) and DSM-BIA (Utter et al., 2012) demonstrate both accurate and reliable results in comparison to the currently accepted methods of hydration assessment. Although these methods do have practical applications in weight certification procedures, the actual use of the methods may be somewhat impractical to employ in most settings. The majority of high school programs and even most college programs will not have access to either of these methods simply because of the expensive equipment needed to conduct the assessments and the lack of trained individuals to conduct the assessments properly. Both UV and DSM-BIA would be excellent procedures to implement in athletic programs, especially to utilize in MWW certification for wrestling. However, because urine specific gravity, plasma osmolality, and urine osmolality showed a similar increase in DEH that coincided with the increase in UV (Utter et al., 2010) and the increase in DSM-BIA (Utter et al., 2012), it would be just as accurate to use the previously accepted measures of $U_{\text{sg}}$ and plasma osmolality to assess hydration status.

CONCUSSIONS

Annually, there are an estimated 1.7 million people that sustain a traumatic brain injury in the United States, and a reported 1.6 million are sport related concussions (Kerr, Marshall, Harding, & Guskiewicz, 2012). When examining the 1.7 million people and the traumatic brain injury cases, a majority of the injuries can be attributed to sports, specifically high risk, high impact, contact sports. Of the incidents considered “traumatic brain injuries”, the most common head injury sustained is a concussion. A concussion is induced by an impulsive force transmitted to the head resulting from a direct or indirect impact to the head, face, neck, or elsewhere. Direct blows usually occur when the
individual is struck in the head by another object. Direct blows can also occur when an
individual’s moving head strikes a fixed object resulting in impact deceleration of the
brain. A blow to the head can produce injury at the site of impact or on the opposite side
of the impact (Nelson, Jane, & Geick, 1984). Forces that result in a concussion include
acceleration/deceleration forces and particularly rotational type forces that produce
shaking of the brain within the skull. The shaking of the brain results in shearing forces
that disrupt diffuse axonal connections running between the cortex and the midbrain
(Kuland, 1982).

When examining an individual with a suspected concussion, it may be difficult to
notice obvious signs and symptoms that provide an indication of a concussive injury.
Many concussions remain undiagnosed due to the failure of athletes to appropriately
report symptoms. Symptoms of concussion are highly subjective to the individual,
therefore, it is important to evaluate all aspects of brain and nervous system function and
cognition in order to determine if an individual is suffering from a concussion. The
primary symptom of concussion is posttraumatic retrograde or anterograde amnesia. The
remaining symptoms fall into one of four main categories of cognitive, physical, emotion
and mood, and sleep habits. Cognitive symptoms include lack of concentration, feeling of
being “slow”, unclear thinking, and poor memory recall. Physical symptoms include
headache, fuzzy or blurry vision, nausea and vomiting, dizziness, sensitivity to light and
noise, balance detriments, and fatigue. Emotion and mood symptoms include irritability,
sadness, nervousness or anxiousness, increased emotional tendencies, and frequent
changes of emotional state. Sleep habits include sleeping more or less than usual and
insomnia.
Concussions in Wrestling

Public awareness of concussions has risen as a result of recent information regarding the short and long term consequences of concussions. In fact, from the 1988 to 2008, the number of reported concussions in the NCAA through its Injury Surveillance System displayed an average annual increase of 7.0%. (Daneshvar, Nowinski, McKee, & Cantu, 2011). Although the sport of football has received the majority of attention when it comes to these head injuries, any sport categorized as an impact sport automatically places participating athletes at similar risks for concussion. Wrestling is considered a highly intense impact sport in which athletes practice and compete wearing head gear that offers little to no protection of the head. In attempt to monitor the prevalence of concussions in sports considered “high impact,” the NCAA conducted a longitudinal survey evaluating reported concussion injuries during the 1988 through 2004 seasons. It was discovered that in men’s wrestling, concussions represented 3.3% of the total injuries reported. In addition, when examining the injury rate per 1,000 athletic exposures, concussions accounted for 0.25% of the injuries (Daneshvar et al., 2011).

Research has determined the prevalence of concussions in both the practice and competition settings in order to enhance athlete safety as well as concussion evaluation methods and procedures. Investigations have shown that concussions are three times more frequent in a competitive setting as opposed to a practice setting (Daneshvar et al, 2011). It was observed that in a high school setting, concussions accounted for 0.13% and 0.32% in practice and competition settings respectively when analyzing the rates of more than 1,000 athlete exposures (Daneshvar et al., 2011). Collegiate wrestling demonstrated an increased frequency of concussions experienced in competition compared to practice.
Research showed that when looking at rates of more than 1,000 athlete exposures, practice concussions accounted for 0.35% while competition concussions were 1%. This longitudinal study showed that concussions accounted for 6.6% of the injuries that occurred during a competition and 4.5% of the injuries that occurred during practice (Daeshivar et al., 2011).

The activities and specific maneuvers performed in the sport of wrestling can be analyzed based on the frequency that the maneuver may cause a concussion to occur. The maneuver most commonly associated with concussion were takedowns, which accounted for 58.7% of concussions. Takedowns were more likely to lead to a concussion (13.6%) than any other wrestling activities (6.7%). Player to playing surface contact situations were responsible for 53.2% of concussions while 44.1% of concussions were caused by player to player contact.

**Concussion Assessment and Evaluation**

Currently in sports medicine, specialized tests have been used to assess head injuries and determine if an individual has sustained a concussion. These tests, such as the Standardized Assessment of Concussion (SAC) and Standardized Concussion Assessment Tool (SCAT or SCAT2), are administered by the health professional to the injured athlete immediately following a suspected concussion. Through verbal symptom recognition, balance and coordination assessment, long and short term memory, orientation, and concentration evaluation, the medical professional must rate the athlete based on categorical scoring in order to determine if the athlete has sustained a concussion. These cognitive assessment tools are ideal for immediate sideline evaluation.
However, these tests tend to base the power of final scoring of the athlete and the
determination of concussion on subjective symptomatic measures.

Although performance on cognitive and physical tasks is assessed with the
sideline evaluations such as the SAC, SCAT, and SCAT2, athletes are also given more of
an opportunity to edit their performance in order to conceal the fact that they have
sustained a concussion. In addition, women tend to report more symptoms, a greater
range of symptoms, and an increased severity symptoms than men, (Lovell, et al., 2006;
Frommer, et al., 2011) younger athletes (high school), and older athletes (collegiate and
professional) (Lovell et al., 2006) report. Research has shown that reliance on the self-
reported symptoms of patients may actually result in under-diagnosis of concussion and
premature return to play decisions. In fact, research has concluded that neurocognitive
testing increases diagnostic accuracy when used in conjunction with self-reported
symptoms (Van Kampen, Lovell, Pardini, Collins, & Fu, 2006). In addition, the SCAT,
SCAT2, and SAC do not account for previous concussions and possible concussion
symptoms as a result of prior concussion incidents nor do they measure cognitive
functionality on an individual basis.

The issue of individualized and personalized data collection was addressed when
doctors Mark Lovell and Joseph Maroon created the computer based concussion
assessment tool. The Immediate Post-Concussion Assessment and Cognitive Testing
(ImPACT) was developed in the early 1990’s. This computer based test takes
approximately 30 minutes to complete, and has fast become a standard tool that is used in
comprehensive clinical management of concussions for athletes. ImPACT focuses on the
idea that concussion management is essentially complex, therefore, it is crucial to
individualize the concussion management process as much as possible. This
individualization is incorporated into the virtual test through administration of a baseline
test and post injury neurocognitive testing when necessary. Baseline testing should be
administered every 1 to 2 years for the competitive athlete, and is considered the
foundational measurement of cognitive ability. When the athlete sustains a concussion,
post-injury neurocognitive testing is performed until the athlete’s cognitive abilities are
similar to baseline measures and athlete’s symptoms are minimal or completely absent.
The purpose of the ImPACT is to assist in objectively evaluating the concussed athlete’s
post-injury condition and track the athlete’s recovery to allow for a safe return to play
(Iverson, Gaetz, Lovell, & Collins, 2002a; Iverson, Gaetz, Lovell, Collins, & Maroon,
2002b). This system of proper concussion management and constant tracking of an
athlete’s recovery helps to prevent cumulative effects of concussion that could lead to
dangerous consequences in the future (Kerr et al., 2012).

The ImPACT test is currently the most widely used computer-based testing
program in the world. This concussion management program is successfully implemented
in high school, collegiate, and professional levels of sport participation. Implementation
of the ImPACT test is widespread due to its availability and simplicity as the ImPACT
test can be administered on any computer. The ImPACT test is comprised of a series of
six modules that assess the cognitive performance of the athlete. The test is designed to
evaluate multiple variables of cognitive function through various tests including attention
span, working memory, sustained and selective attention time, response variability, non-
verbal problem solving, and reaction time. Modules include word memory, design
memory, X’s and O’s reaction time and short term memory, color match, and three letter
memory. The ImPACT test not only assesses cognitive ability, but it also takes into consideration concussion history and symptom recognition and severity. Following test administration, the program provides a descriptive printout of the results, comparing the scores in each category to systematic norms. If the athlete were to sustain a concussion, the results of the test administered after a concussion would be compared to both their baseline and systematic norms. In addition, categories that display substantial differences in results are highlighted using a red flag indicator system so that drastic changes in areas of cognitive function and symptoms can be identified (Iverson, Gaetz, Lovell, & Collins, 2002a; Iverson et al., 2002b).

The validity, reliability, and specificity of the ImPACT test have been critically evaluated to ensure that the neurocognitive testing appropriately measures cognitive function and performance and that it is a trustworthy tool to utilize when making return to play decisions. In order to determine the validity of the ImPACT test, the prognostic ability of the computerized neurocognitive testing in combination with sub-acute symptoms had to be quantified. Research conducted by Lau, Collins, and Lovell (2011) showed that individually, ImPACT neurocognitive testing and symptom cluster scores show similar sensitivity and specificity and a positive predictive values of 73.8%. Additional research conducted by Schatz, Pardini, Lovell, Collins, and Podell, (2006) using both concussed and non-concussed athletes demonstrated that approximately 82% of subjects in the concussion group and 89% of subjects in the control (non-concussion) group were correctly classified through the use of the ImPACT test. Furthermore, results of this study showed that the sensitivity of the ImPACT test was 81.9% and the specificity was 89.4% (Lau, et al., 2011; Schatz et al., 2006).
Before the ImPACT test could be released to the sports medicine market, it had to be deemed valid. Research conducted by Iverson and company (2002) found the ImPACT test to have both convergent and divergent validity of computerized neuropsychological testing. The validity of the ImPACT test, specifically in areas of measuring attention span and processing speed, was examined in research conducted by Iverson, Lovell, and Collins (2004). In order to validate these specific areas, the computerized testing system and traditional neuropsychological measures were compared using athletes that had sustained a concussion within the last 21 days. The study demonstrated that the processing speed composite and the reaction time composite from the ImPACT test and the symbol digit modalities test (SDMT), the traditional neuropsychological measurement, indeed measured the same underlying concept. This demonstration of similarity shows that the two specific portions of the ImPACT test examined are valid measurements.

The reliability of the ImPACT test also had to be challenged prior to its release. Research to determine the ImPACT test reliability was conducted by Lovell et al., (2006) and compared the symptomatic reporting reliability of the ImPACT test in comparison to the previously validated Post Concussion Scale (PCS). The ultimate goal of the PCS was to objectively document the extremely subjective symptoms reported by athletes that had sustained a concussion injury. The PCS consisted of 22 symptoms that correlate with concussion and in order to determine the severity of the symptoms, provided a numeric scale in which to rank each individual symptom. There is an identical format of symptom recognition and ranking included within the computerized ImPACT test which is based solely off of the PCS format. In order to establish reliability, the two formats were
compared to determine the degree of reliability in accurately assessing symptoms of athletes following a concussion. The research showed that the internal consistency reliability of the PCS and the PCS within the computerized ImPACT test ranged from .88 to .94 across samples within the study. This range proved that the reliability of the PCS within the ImFACT test was very high.

The research conducted by those concerned with the validity and reliability of the ImPACT test have helped to create and refine the evaluation tool used to assess both neurocognitive performance and symptoms. This computerized concussion assessment is considered the “cornerstone” of proper concussion evaluation and management by both national and international sports fields, and the use of the ImPACT test to manage concussions is steadily increasing. Since concussions have proven to be prevalent in the sport of wrestling, the ImPACT test may be the most appropriate method to assess the injury, evaluate neurocognitive ability and symptoms, pinpoint deficits, and ultimately manage the return to play for athletes that participate in such an intense combat sport.

DEHYDRATION AND THE EFFECT ON COGNITIVE PERFORMANCE

The concept of DEH and the negative effect it has on physical function and work capacity is well documented and fully accepted throughout the literature. Despite the familiarity of the relationship between DEH and its detrimental effects on physical performance, the concept of DEH and the effect on cognitive function and performance has only been accepted providing that the degree of DEH is severe, or greater than 5% loss of BW. In fact, severe DEH inevitably results in a marked decline in overall brain function, including the capacity to perform cognitive tasks, and can lead to delirium, coma, and even death (Maughan, Shirreffs, & Watson, 2007). Regardless of the severity
of DEH, an imbalance in the homeostatic function of the internal environment of the body occurs (Maughan et al., 2007; Wilson & Morley, 2003). This alone may constitute to adverse effects on cognitive capacity and may interfere with performance of work related activities that require the use of specific neurocognitive skills and functions.

Although the effects of severe DEH on cognitive function have been examined, moderate DEH and the effects it has on cognitive performance has yet to be fully understood or exhaustively researched. Moderate DEH has been associated with cognitive performance detriments during heat exposure. When DEH is induced by both heat and exercise, multiple domains of cognitive function and task performance may be affected, particularly after a BW loss of 2% or greater (Sharma, Sridharan, Pichan, & Panwar, 1986; Gopinathan, Pichan, & Sharma, 1988; Adan, 2012; & Ganio et al., 2011). Body mass losses of less than 2%, however, have not shown definitive results in regards to cognitive performance deficits (Ganio et al., 2011).

**Mild Dehydration and the Effect on Cognitive Performance**

In attempt to assess the effect of mild DEH between 1-2%, Ganio and colleagues (2011) conducted a study that specifically examined cognitive performance and mood in healthy young males. In order to induce this degree of DEH, a mild exercise protocol in a mild environment (27.7°C) was performed. Following the DEH procedure, behavioral tests used to assess simple to complex skills, included vigilance, reaction time, learning, working memory, logical reasoning, and mood states and symptoms. Results of the study showed that DEH at a mean level of 1.59% DEH caused an increase in errors on visual vigilance, while visual working memory response latency decreased. Mild DEH also increased tension, anxiety, and fatigue when examining mood and symptoms after the
DEH procedure. The results of this study indicated that mild DEH may have subtle effects on cognitive abilities that are limited but detectable.

**Moderate Dehydration and its Effect on Sustained and Selective Attention Time**

When looking at research that focuses on moderate DEH and the effect it has on cognitive function and performance, a specific area of cognitive performance that is frequently examined is vigilance. The cognitive skill of vigilance refers to the ability to maintain attention and alertness over long periods of time. Tests that explore an individual’s vigilance range from continuous performance tasks such as a computerized letter combination recognition task to an object identification task. Adan (2012) notes that although performance of simple attention tasks was not significantly impaired in states of DEH of 1-2%, after DEH exceeded 2%, the attention of young subjects on simple attention tasks was negatively affected.

A study conducted by D’Anci, Vibhakar, Kanter, Mahoney, and Taylor, (2009) found that after DEH of 1.5-2.0% induced by a standardized 60-75 minute crew or lacrosse practice, vigilance attention decreased. The test used to assess vigilance attention in this particular study was a computerized 15 minute continuous letter order and combination recognition task. After evaluation it was discovered that as the test progressed, vigilance attention decreased. When fluid deprivation was used as a method to induce DEH, a decline in subjectively assessed concentration and alertness was discovered after 13 hours and 1% loss of BW. This decline continued to increase after a 24-hour fluid restriction and 1.8% loss of BW and showed an even greater decrease after 37 hours of fluid restriction and 2.7% DEH (Petri, Dropolie, & Kardum, 2006; Shirreffs, Merson, Fraser, & Archer, 2004; Szinnai, Schachinger, Arnaud, Linder, & Keller, 2005;
Suhr, Hall, Patterson, & Niinisto, 2004). Regardless of the method used to induce DEH, research has shown that a degree of DEH of more than 2% resulted in recognizable decreases in alertness and concentration ability in addition to fatigue and tiredness in young subjects (D’Anzi et al., 2009; Covassin, Weiss, Powell, & Womak, 2007; Patel et al., 2007; Cian, Barraud, Melin, & Raphael, 2001; Cian, Koukianou, Barraud, & Raphael 2000).

**Moderate Dehydration and the Effect on Visual Motor Tracking**

In sports, hand-eye coordination and visual perception are critical skills that aid in athletic decision making and lead to athletic success. Previous research has examined young healthy individuals (Cian et al., 2000; Cian et al., 2001; & Petri et al., 2006) and elderly people (Suhr et al., 2004) and how the performance on psychomotor tasks decreased as DEH increased. It was determined that a loss of BW of 2% or more led to a decrease in the performance on tasks that require visual motor skills, specifically hand-eye coordination. This detriment in performance was seen regardless of the method of DEH used. Additionally, research conducted by Devlin, Fraser, Barras, and Hawley, (2001) found that after 2.8% DEH, cricketers’ hand-eye coordination skills significantly decreased.

Research that focuses on hand-eye coordination is often military based due to the fact that most military personnel must rely heavily on hand-eye coordination in order to perform basic tasks. One task that is primarily executed in military training that combines both visual perception and hand-eye coordination is target shooting. In a study conducted by the Israel Defense Forces Physiological Research Unit (Epstein, Keren, Moisseiev, Gasko, & Yachi, 1980), the concept of DEH and its effect on the basic military exercise
of target shooting was examined. The study assessed the combined effect of differential heat loads and varying mission intensities on psychomotor performance. A computerized game was used in this study to simulate a combat situation and the skill of rifle marksmanship. Although the results showed that heat load had little effect on the subjects' abilities to perform easy tasks, the number of target hits were reduced by 17.5% on complicated tasks in each of the heated conditions. The results led to the conclusion that the effect of exercise intensity and heat stress on decreasing performance are in cooperation; psychomotor performance declines even before physiological responses are compromised. In addition, even highly motivated subjects, in this case, military personnel, are influenced by heat stress, especially when assigned to complex tasks that require a high state of cooperation and coordination as well as vigilance.

Hand-eye coordination testing was also utilized following DEH procedures in a study conducted by Sharma et al., (1986). After subjects completed moderate exercise in heated conditions and underwent levels of DEH ranging from 1-3%, each subject was administered a hand-eye coordination test. The test was administered to subjects in a thermoneutral, hot-humid, and a hot-dry environment following the dehydration protocol. Results showed that significant decreases in hand-eye coordination occurred at all three levels of DEH.

In research conducted by Gopinathan et al., (1988), hand-eye coordination and visual tracking were examined using a computerized manual tracking task. After DEH of approximately 2.6%, there was not a significant decrease in manual tracking and hand eye-coordination, however, subtle decreases did occur. It was reasoned that the amount of DEH was possibly not significant enough to create significant alterations in hand-eye
coordination. Additionally, it was decided that perhaps the tracking period was not a long enough to see changes in hand-eye coordination.

Research has shown that regardless of the means of DEH, visual motor tracking, specifically hand-eye coordination and visual perception, are diminished. More importantly, these skills can be affected by DEH levels as low as 2.5%, which is a level of DEH that is standard for most athletes, especially at higher levels of competition. These cognitive motor skills are essential to athletes in order to perform specific maneuvers and make crucial decisions during competition.

**Moderate Dehydration and its Effect on Working Memory**

Previous research has revealed that the area of cognitive function that seems to be the most affected by DEH is short term memory (STM) and tasks that employ the use of STM and memory recall. Sharma et al. (1986) found that after exercise and thermal DEH of 1-3%, subjects had significant declines in cognitive performance related to STM. Research demonstrated that after DEH levels reached 2% or more, significant detriments in STM and verbal material tasks were evident, particularly in tasks such as remembering sequences of words or numbers (Covassin et al., 2007; Gopinathan et al., 1988).

Major discoveries in regards to STM were found in research conducted by Cian and colleagues (2000). Two methods of DEH were utilized in order to examine the effects on cognitive function, in addition to analyzing subjects that remained EUH throughout similar procedures. Subjects were DEH via 2 hours of passive heat or through exercise for 2 hours at 60% VO₂ Max on a treadmill. Psychological testing that consisted of tests including long term memory, serial reaction time, perceptive discrimination, STM, and unstable tracking was administered 30 minutes after a stabilization period.
Results of the study showed that although there was not a significant difference between DEH conditions utilized, DEH of 2.8% or more produced a general decline in STM performance. The decline in STM was demonstrated specifically through the decrease in numerical digit memorization and recall.

Additional research conducted by Cian et al. (2001) employed a similar DEH design. Subjects in this study were DEH via passive exposure to heat or by treadmill exercise. After weight loss of 2.8%, subjects underwent a 1 hour recovery period. Neurocognitive testing was conducted 30 minutes after the DEH period and again 2 hours following fluid ingestion. This study showed that both passive heat and exercise induced DEH produced the same degree of DEH in all subjects. Consistent with other studies, when examining the cognitive testing sessions, both forms of DEH had negative effects on STM tests, specifically numerical digit and design memorization and recall.

During a competitive season, wrestlers may repeatedly undergo RWL. Subsequently, as a result of RWL, DEH can lead to hypoglycemia. Neuroglycopenia, impairment in cognitive function, is secondary to the hypoglycemia that occurs as a result of RWL and DEH. Based on the neuroglycopenia that occurs in DEH subjects, Choma, Sforzo, and Keller (1998) examined the concept of DEH on a sport specific level. This study looked at long term RWL in collegiate wrestlers during a standard competitive season and the effect that DEH had on cognitive performance. A minimum of 5% BW loss was required of subjects. Baseline data were collected approximately 1 week prior to the wrestling season, while RWL data were collected immediately after an official weigh-in and 18-24 hours before a competition. Rehydration data were collected approximately 72 hours after weigh-in. Cognitive testing consisted of five tests that assessed visual
attention, visual-motor skills, STM, and visual acuity. Results of the study found that after weight loss of 6.2%, STM declined significantly. Measures 72 hours after RWL demonstrated that decreases in STM were reversible with rehydration in conjunction with BW, plasma volume, and blood glucose returning to baseline values.

Research demonstrates that weight loss, both long term weight loss and single bouts through exercise or passive heat, undoubtedly lead to DEH. Whether the extent of DEH is moderate or severe, the outcome of dehydration proves to have a similar negative effect on STM. It has been proposed that the neurological mechanisms associated with long term memory may be very different than the mechanisms involved in STM processes (Bacdeley, 1986; & Polster, Nadel, & Schacter, 1991). Despite the differences in neurological processes, Squires, Knowlton, and Musen (1993) have suggested that new information, such as the information obtained in STM processes, must first be entered through the STM neurological mechanism before being stored in the long term memory bank. Based on the conclusions obtained through research, additional research involving DEH and its effect on short and long term memory is undeniably necessary.

Moderate Dehydration and the Effect on Decision Time

The area of mental functioning that proves to be especially important in both execution of a task and success in competition is ability to make effective and operative decisions. During competition of any kind, it is essential for the athlete to anticipate situations, read plays, and ultimately use competitive cues and game awareness abilities to execute the correct competitive decisions that will lead to success. Research has shown, however, that DEH may lead to the deterioration of decision making abilities by increasing the length of time it takes for a DEH individual to make crucial decisions.
Research conducted by Serwah and Marino (2006) examined the effect that exercise and heat induced DEH had on choice reaction time. A choice reaction time task was completed by subjects at rest, after 20 minutes of cycling exercise, after 40 minutes of exercise, and at the conclusion of exercise. Subjects were tested on choice reaction time and instructed to react to the stimuli presented as quickly and as accurately as possible. Results of the study showed that mean accuracy was not significantly altered by hydration level or by the stage of exercise in which the choice reaction task was performed. However, the data revealed a significant main effect for the number of choices, as the 4-choice task was performed less accurately than the 1- and 2-choice tasks as DEH and exercise time increased. Results showed that although choice reaction time actually decreased as exercise duration and DEH levels increased, the time to make a choice decision within the task increased as the number of choices increased as exercise duration and DEH levels increased.

Decision time was also a factor that was studied in research conducted by Cian and colleagues (2001). After 2.8% DEH, results showed that decision time was altered. In this study, decision time was measured by means of a test that examined perceptive discrimination through evaluation of the subjects' relative judgment of line length. Decision time was affected particularly when subjects were faced with a complex task that involved visual cues and perception. Results showed that the total number of correct choices was unchanged; however, the subjects needed more time in order to make the correct decision. Additional research conducted by Ganio et al. (2011) found that after 40 minute exercise DEH procedures, visual working memory response latency, essentially decision time, increased. The conclusions from the research insinuate that moderate DEH
ultimately increases the time it takes for an individual to make an accurate and correct
decision, especially when it deals with complex tasks.

**Moderate Dehydration and the Effect on Perception of Fatigue and Mood**

It is a well-known fact that dehydration is one of the main causes of physical
fatigue. However, although it may not appear as evident as physical fatigue, both mental
fatigue and mood are affected by DEH as well. Mood and mental fatigue alterations
could explain why other vital cognitive functions such as vigilance, STM, visual motor
tracking, and decision time show a decrease after moderate dehydration has occurred.

When looking at cognitive fatigue after DEH, the main methods of evaluation are
subjective questionnaires that assess the individual’s perception of fatigue. These
questionnaires additionally assess mood through questions designed to help subjects rate
their mood. Cian et al. (2000) issued a subjective questionnaire following DEH
procedures. The questionnaire revealed that perception of fatigue increased after DEH. In
research conducted by Ganio et al., (2011) a similar subjective questionnaire was given to
subjects following both exercise and passive DEH protocols. Results showed that after
>1% DEH had occurred, fatigue and tension/anxiety increased due to passive heat DEH
and fatigue increased as a result of exercise induced DEH. Additional research has shown
that a level of DEH of more than 2% resulted in discernible decreases in subjectively
assessed fatigue, tiredness, and drowsiness in young subjects (Weber et al., 2013; D’Anci
et al., 2009; Patel et al., 2007; Cian et al., 2001; and Sharma et al., 1986) regardless of the
method used to induce DEH.

One of the main effects of prolonged exercise is physical fatigue. Additionally,
prolonged exercise stress leads to DEH, leading to an increase in cardiovascular strain as
well as a progressive decline in neuromuscular function and thermoregulation. It has been suggested that as thermal homeostasis is disturbed, cognitive function and performance on cognitive tasks may be impaired due to central nervous system fatigue (Hancock, 1986). Grego et al., (2005) found that during the last hour of a 3-hour cycling DEH protocol, a significant alteration in perceptual response and the increase in errors were observed suggesting the nervous system fatigue phenomenon. Additional research performed by Choma et al., (1998) found that after extended durations of DEH induced by methods such as prolonged exercise, heat stress, fasting, and fluid restriction in wrestling athletes, subjects displayed a negative mood state. The negative moods that were increased following weight loss and DEH were increased tension-anxiety, depression-despair, anger-hostility, fatigue, and confusion-bewilderment, ultimately demonstrating a negative mood state. The negative mood states observed after prolonged DEH, however, proved to be reversible following rehydration.

**Dose-Response Relationship Between Dehydration and Cognitive Performance**

The topic of DEH has been extensively evaluated in regards to how it can physically affect the performance of an individual. Subsequently, different levels of DEH have a graded effect on the physical performance: the greater the degree of DEH, the greater the physical performance deterioration. The question has also been posed in relation to a dose-response effect of DEH on cognitive performance and whether a greater level of DEH produces a more significant decline in cognitive functions.

Gopinathan and associates (1988) were most recognized for their research with various degrees of DEH and the effect on cognitive performance. The subjects used in this research were fully acclimated to heat stress and were DEH to different degrees of
1%, 2%, 3%, and 4%. When the desired level of DEH had been reached, subjects were allowed a recovery period. Tests to evaluate arithmetic ability, STM, and visual motor tracking were administered before and after the DEH procedure. The results the study showed that STM and visual motor tracking were affected after DEH levels of 2% or greater. Additionally, as the degree of DEH increased, the cognitive performance in both STM and visual motor tracking subsequently decreased, suggesting a dose-response relationship between the degree of DEH and cognitive performance. Research has concluded that in young subjects, there is a decrease in speed and efficiency that occurred after 2% loss of BW. This deterioration in speed and efficiency increased when the level of DEH was 3% (Sharma et al., 1986) and additionally increased when DEH was 4% (Gopinathan et al., 1988). Although additional research is needed in order to solidify the dose-response relationship between DEH and cognitive performance, previous research provides a rationale that such a relationship exists.
REFERENCES


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