2017

Impact Of Hydration On Collegiate Athletic Performance, Fatigue, And Recovery

Lauren Woodard
University of Mississippi

IMPACT OF HYDRATION ON COLLEGIATE ATHLETIC PERFORMANCE, FATIGUE, AND RECOVERY

A Thesis
presented in partial fulfillment of requirements
for the degree of Master of Science
in the Department of Nutrition and Hospitality Management
The University of Mississippi

Lauren Woodard Parrish

May 2017

ABSTRACT

The impact of dehydration on several key physiological functions critical for athletic performance is well studied. Hydration monitoring and restoration of fluids has been known to significantly impact impaired physical functions and maximize performance during training and competition. Impaired physical functions have been suggested as a limitation on explosive strength, musculoskeletal output, cardiovascular output, and proper technique in contact sports. The purpose of this study was to investigate the relationship between hydration levels and physiological profiles that can be used as a proactive approach in monitoring a collegiate athlete's athletic performance, fatigue, and recovery status. The hypothesis was that insufficient hydration levels would intensify physiological profiles of athletes, thus increasing an athlete's susceptibility to fatigue and decreased athletic performance. Urine specific gravity and body weight was used to determine the hydration level of collegiate football athletes. Real-time physiological data was recorded and analyzed through Zephyr's Performance Systems Monitor "BioHarness 3" during preseason football training camp at the University of Mississippi. Pearson correlation coefficient was used to (1) determine the relationship between urine specific gravity change and Zephyr Performance Systems physiological data, and (2) determine the relationship between percent change in body weight and Zephyr Performance Systems physiological data with statistical significance set at 0.05. An increased change in urine specific gravity resulted in a negative influence on the rate of force development (r = 0.768, p = 0.074), mechanical intensity (r = -0.885, p = 0.019), physiological intensity (r = 0.363, p = 0.479), and

average heart rate ($r = 0.396$, $p = 0.437$). An increased change in percent body weight resulted in a negative influence on the rate of force development ($r = -0.466$, $p = 0.352$), mechanical intensity ($r = -0.043$, $p = 0.936$), physiological intensity ($r = 0.628$, $p = 0.182$), and average heart rate ($r = 0.505$, $p = 0.307$). These results suggest that as an athlete becomes more dehydrated their physiological profile is negatively impacted, thus increasing the athlete's susceptibility to fatigue and decreased athletic performance. When comparing the two hydration assessment techniques, urine specific gravity change had a stronger correlation with rate of force development and mechanical intensity, while body weight change had a stronger correlation with physiological intensity and average heart rate. The process of selecting a single assessment technique based on results can be difficult, therefore it is recommended to utilize more than one approach to enhance diagnostic confidence. Urine specific gravity and body weight are both safe, accurate, and inexpensive, therefore they are appropriate techniques to assess hydration status in collegiate athletes.

LIST OF ABBREVIATIONS AND SYMBOLS

USG	Urine Specific Gravity
BW	Body Weight
NCAA	National Collegiate Athletic Association

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

TABLE PAGE

CHAPTER I

INTRODUCTION

The impact of dehydration on several key physiological functions that are critical for athletic performance has been extensively documented. Impaired physical performance has been suggested as a limitation on cardiovascular output, central nervous system function, musculoskeletal output, and altered metabolic function. However, over 50% of collegiate athletes continue to start practices and games in a dehydrated state (Godek, Godek, & Bartolozzi, 2005; Osterberg, Horswill, & Baker, 2009; Volpe, Poule, & Bland, 2009). Nichols, Jonnalagadda, Rosenbloom, & Trinkaus (2005) revealed National Collegiate Athletic Association (NCAA) Division I collegiate athletes do not have sufficient knowledge regarding proper hydration and fluid replacement practices, and suggest that this may be a cause of pre-practice dehydration. While agreeing with Nichols et al., (2005), Judge et al. (2016) more specifically determined that American collegiate football athletes were not aware of proper hydration techniques and often identified common misconceptions such as “thirst is the best indicator of dehydration”. Furthermore, when football student athletes’ level of hydration understanding was correlated to position played, linemen had the lowest hydration knowledge score. Also, linemen were more vulnerable to elevated maximal core temperatures and diminished heat dissipation due to larger body mass and low body surface area to mass ratio according to Godek, Bartolozzi, Burkholder, & Sugarman (2006). Lack of hydration awareness and education intensifies the probability an athlete will experience impaired mental and psychomotor ability, increased reaction time, diminished accuracy, elevated problem solving time, increased fatigue, and decreased alertness throughout athletic performance. Due to the lack of nutrition knowledge and positive behavior change in collegiate student athletes, Nichols et al. (2005) recommended regularly monitoring athletes' fluid consumption, hydration status, inappropriate hydration behaviors, and consequences of such behaviors. Ultimately, promoting student athlete hydration awareness will allow players to recognize and report hydration related concerns, encouraging behavior change while reducing the risk of injury (Kreider et al., 2010).

Nybo & Nielsen (2001) and Sawka & Coyle (1999) documented the effect of hypohydration on endurance aerobic exercise, however the influence of hypohydration on high intensity anaerobic performance is not as concrete according to Cheuvront, Carter, Haymes, & Sawka (2006) and Evetovich et al. (2002). Detailed assessments of high intensity athletic performance remain challenging to obtain as athletic success relies on factors such as cognitive function, postural stability, force development and complex skill technique. Maximum strength and power are well known physical factors that impact athletic performance, and they have been shown to be particularly significant physical performance components of American football (Secora, Latin, Berg, & Noble, 2004). American football consists of prolonged periods of exercise with repeated intermittent high intensity bouts of athletic performance resulting in a "start/stop" nature, increasing documentation difficulty.

Therefore, the purpose of this study is to investigate the relationship between hydration levels and physiological profiles that can be used as a proactive approach in monitoring a collegiate athlete's athletic performance, fatigue, and recovery status. The hypothesis of this study is that insufficient hydration levels will intensify physiological profiles of athletes, thus increasing an athlete's susceptibility to fatigue and decreased athletic performance

CHAPTER II

REVIEW OF LITERATURE

Hydration Assessment Techniques

The development of sweat and its evaporation to promote cooling of the body is essential during vigorous physical activity. However, sweat production of elite athletes can easily result in a dangerous body water deficit. Hypernatremia is a prominent issue in dehydrated athletes and results in higher than normal concentration of dissolved substances such as sodium when water volume is reduced (Cheuvront & Sawka, 2005). Conversely, if electrolytes are not replenished in a timely manner during periods of strenuous training, dangerously low levels of sodium can lead to hyponatremia, increasing the risk of serious health consequences such as impaired brain function, heat stroke, and cerebral edema. Observed and self-reported signs and symptoms of dehydration are often too generalized to make vital decisions. Therefore, the increased availability of more precise hydration assessment techniques may protect active individuals from hazardous dehydration conditions. In a detailed hydration assessment technique review, Armstrong, (2007) stated that there is no single gold standard for hydration assessment is not present. After reporting similar findings to Armstrong (2007), Cheuvront, Ely, Kenefick, & Sawka (2010) then proposed that information from two or more hydration assessment techniques should be used to determine hydration status in the field due to a lack of a gold standard. Using multiple hydration markers provides benefits for sports medicine facilities by enhancing diagnostic confidence. In order to monitor elite athletes on the field, hydration measurement methods must also be easy to use, safe, portable, and inexpensive.

The most reliable methods for monitoring the hydration of physically active individuals on the field are found to be body mass change, urine specific gravity, urine color, and thirst (Armstrong, 2007; Cheuvront et al., 2010). Cheuvront et al. (2010) emphasized the accommodations that must be made for renal function and urine composition when there is a lack of body fluid. These accommodations during dehydration result in an increase in urine biomarkers and a reduction in urine volume. Disproportioned biomarkers in urine produce high urine specific gravity, increased urine osmolality, and dark urine color. Urine specific gravity measures the relative density of urine to water and is often measured through refractometry, reagent strips, or hygrometry. To maximize hydration measurement reliability and minimize evaluation complications, (Cheuvront & Sawka, 2005) suggested using a sample from the first urination following an overnight fast. Urinalysis techniques have been previously known to be timing critical, and result in individualized frequency and color. However, these hydration screening methods are extremely easy and time efficient, which is imperative for athletic populations.

Body mass change is one of the most basic methods of hydration monitoring and can be defined as the difference between pre and post exercise body mass (Cheuvront & Sawka, 2005). An individual's dehydration severity index increases as a larger percentage of body mass is lost. Previously, body composition changes have increased assessment difficulty, however, body mass change is a simple and concise screening tool for hydration monitoring (Cheuvront & Sawka, 2005).

Athlete Hydration Levels

Volpe et al. (2009) define euhydration as adequate body water content and hypohydration as a body water deficit. Hypohydration has been associated with elevated core body temperatures, increased cardiovascular stress, reduced stroke volume, and decreased venous return. These associations can be extremely hazardous for elite athletes due to their increased exercise frequency, performance intensity and elevated risk for hypohydration. According to Osterberg et al. (2009) and Volpe et al. (2009), hypohydration, otherwise known as dehydration, is indicated by a body mass loss of 2% or more. Osterberg et al. (2009) further investigated high performance athletes during competition and revealed the average body weight change following a game was 1.4%. Godek et al. (2005) found similar findings by concluding collegiate football players lose an average of 1.5 to 2% of body weight during practices. Collegiate football players have been routinely known to lose 3.5 to 5 kilograms of body mass during a single practice and are not able to regain the lost fluid before the subsequent practice.

Elevated pre-practice and pre-competition urine specific gravity levels have been shown to indicate athlete hypohydration and influence the development of further dehydration during practice and competition (Godek et al., 2005; Osterberg et al., 2009; Volpe et al., 2005). The urine specific gravity reference range describes the ratio of urine density compared with water density. In a sample of 174 collegiate athletes, Volpe et al. (2009) found 66% to be hypohydrated (1.020 – 1.029) and 13% to be significantly hypohydrated (≥1.030) during pregame urine specific gravity screenings. While analyzing pre-game urine specific gravity samples of professional athletes, Osterberg et al. (2009) discovered 52% of the athletes were hypohydrated going into competition. Godek et al. (2005) revealed that 67% of collegiate football players were hypohydrated and 29% were significantly hypohydrated going into practice. The prominence of pre-practice and pre-game hypohydration levels indicate that athletes need additional education regarding proper hydration techniques to prevent physiological barriers and maximize performance. The sweat rate for collegiate football players averages at 2 liters per hour making it extremely difficult to maintain pre-practice hydration levels alone (Godek et al., 2005). Since such a large number of athletes are beginning sport and strength and conditioning sessions in a dehydrated state, maintaining adequate fluid levels is unfeasible. Combining pronounced hypohydration levels with additional body fluid deficits during physical activity can lead to extreme body fluid inadequacy, fatigue, increased recovery time, and even life threatening complications.

Strength, Power, and Muscular Endurance Exercise

Muscular strength is the power generated when a muscle engages in a maximum concentric action (Secora et al., 2004). It has been suggested that hypohydrated individuals will likely experience reduced strength in concentric, single-repetition athletic performance skills. Shirreffs (2005) summarized muscle contraction strength as the ability of the nervous system to recruit motor units in sequence with the number of muscle contractile units in cross-section. When the nervous system is maximally stimulated under hypohydrated conditions the muscular system may be negatively altered. Overall muscular strength and force generation capability may be negatively impacted due to detriments in neuromuscular function. After reviewing the evidence, Judelson et al. (2007) concluded athletes that lose approximately 3-4% of body weight due to hypohydration are susceptible to decreases in muscular strength by 2%. Minshull & James (2013) expanded on the findings of Judelson et al. (2007) and concluded neuromuscular performance of the knee extensor was associated with a 7.8% decrease in strength in hypohydrated athletes. Strength performance impairments to the knee extensor, a highly vulnerable joint, may lead to dynamic force stabilization deficits and increased susceptibility of injury. Ftaiti, Grélot, Coudreuse, & Nicol (2001) similarly reported decreases up to 17% in knee flexor and 25% in knee extensor isokinetic strength when individuals lost 2% or more of their body weight due to hypohydration. Hayes & Morse (2010) findings resemble Judelson et al. (2007) and Minshull & James (2013) and determined maximal isometric force was reduced in all dehydration conditions and isokinetic peak torque was reduced in dehydration conditions that had an equal to or greater than 2.6% loss in body weight.

Muscular power can be defined as the maximal force a muscle or muscle group can generate at a velocity (Secora et al., 2004). Judelson et al. (2007) concluded athletes that lose approximately 3-4% of body weight due to hypohydration are susceptible to decreases in muscular power by 3%. Supporting the findings of Judelson et al. (2007), Yoshida, Takanishi, Nakai, Yorimoto, & Morimoto (2002) observed a significant decrease in muscular power when collegiate athletes reached a dehydration level of 3.9%.

High-intensity muscular endurance involves repeated high-intensity activities that are sustained for 30-120 seconds such as bench press or knee extensions (Secora et al., 2004). Athletes that lose approximately 3-4% of body weight due to hypohydration are susceptible to decreases in high-intensity muscular endurance by 10% according to Judelson et al. (2007). Bigard et al. (2001) reinforced the findings of Judelson et al. (2007) and revealed a significant decrease in muscular endurance knee extension time to exhaustion following dehydration deficits of 3% in collage aged males.

Rate of Force Development

Regardless of the level and position played, the ability for an athlete to express strength, power, speed, and agility are essential characteristics when training for optimal American football performance. According to Hori et al. (2008) power output is dependent on an athlete's overall strength, while advancements in muscular power, speed, and change of direction are related to maximum muscular strength. Explosive exercise, a method of specialized strength training, has the ability to increase the rate coding of motor units and contribute to increased rates of force development, ultimately leading to higher power production (Kawamori & Haff, 2004). The rate of force development can be defined as the speed in which the contractile elements of a muscle group can develop force. Kraska et al. (2009) further explained the importance of improving an athlete's contractile rate of force development by validating the limited time for force application in essential athletic performance skills such as maximum strength and power. As a result of improved rate of force development, higher levels of neural drive and muscle force are reached in the early phase of muscle contraction (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002).

Cognitive Function

Dehydration has been known to decrease cognitive functions such as alertness, short-term memory, reasoning, and hand eye coordination. According to Lieberman (2012) and Smith, Newell, & Baker (2012) cognition begins to be adversely affected when approximately 1.5% of body weight is lost through water. Tomporowski, Beasman, Ganio, & Cureton (2007) observed that exercise induced dehydration in particular, had a negative affect on participants' cognitive function. Mental tasks that require increased cognitive effort are more negatively impacted compared to tasks that are repetitive and require less concentration. The results are particularly applicable to athletes that are required to make prompt decisions while competing in challenging conditions.

It is well proven that cognitive functions become increasingly difficult for individuals as fluid restriction progresses (Banddelow et al., 2010; Cian et al., 2008; Shirreffs, Merson, Fraser, & Archer, 2004). A dehydration analysis conducted by Cian et al. (2000) discovered cognitive performance decreased proportionally to hydration levels. Exercise induced dehydration showed the largest decrement in tracking performance, psychomotor skills, and short-term memory. Reaction time was significantly slower for the perceptual task during a dehydrated state, which can be detrimental to athletic performance. Banddelow et al. (2010) described body water mass lost through dehydration had a significant correlation with diminished Sternberg Working Memory and finger tapping assessments. Additional subjects recorded by Shirreffs et al. (2004) reported a lack of concentration and alertness during fluid restriction trials compared to euhydrated trials.

Postural Stability

During standard conditions, Riemann & Guskiewicz (2000) claim an individual is able to control balance by integrating sensory information from the visual, vestibular, and somatosensory systems. Postural stability evaluations have become more widely used by sports medicine professionals for the management of injuries and rehabilitation. Common symptoms of postural stability impediments included dizziness, hindered balance, and blurred vision. Lion et al. (2010) observed that balance stability after exercise was correlated with dehydration levels. The Neurocom standard situation assessment following dehydration trials showed a reduction in postural stability. The evaluation requires eyes to be open, visual surroundings to be stable, and the platform to be secure. Balance was also altered when only the vestibular cue relied on the Neurocom. During this assessment eyes were closed and the referenced platform shifted. The postural stability outcomes suggest that sensory structures, especially the vestibular system, are distressed during times of dehydration. Lion et al. (2010) endorsed the vestibular system is the only segment that hydration directly intervenes within the sensory transduction mechanism. Aligene & Lin (2012) confirm the central function of the vestibular system is to secure the eyes on a stationary target when head and body movement is present. Athletes that suffer from an inhibited vestibular system must increase dependability on visual inputs for balance since they are not able to fully use vestibular orienting information.

Dehydration Symptoms Impair Performance Technique

Gabbett (2008) established that dehydration symptoms relating to fatigue, may contribute to tackle related injuries in rugby league due to the high incidence of injuries that occur in the second half of matches. After monitoring physiological capacities and fatigue status, Gabbett noted many significant correlations to tackling technique. These significant decrements include diminished acceleration into the contact zone, decreased ability to contact the center of gravity target, failure to wrap arms around the opposing player, decreased body alignment, reduced agility and decreased leg drive. In addition to substantial tackling technique impairments, low muscular power had a strong trend towards increased fatigue decrements. The top nonfatigued tackling athletes had the largest decline in technique under fatigued conditions, demonstrating that skill level does not transfer over once an athlete is in a fatigued state.

CHAPTER III

METHODOLOGY

All researchers completed the Collaborative Institutional Training Initiative Program to conduct human subject research. All techniques were trained in their area of contribution. The Institutional Review Board approved the study protocol #17x224 as exempt since the data analyzed were collected as routine for athletic sport participation.

Population

A total of six male football players ages 18 to 23 from the University of Mississippi participated in the current study. Player recruitment was determined following discussion with the strength and conditioning staff, athletic trainers, and sports dietitians. Participants were selected based on their minutes played, number of repetitions per practice, history of dehydration or dehydration symptoms. The NCAA Division I collegiate athletes were evaluated over three days during preseason training camp.

Physiological Experimental Design

Participants wore Zephyr Performance Systems Monitor “BioHarness 3” during training to collect real time physiological data. The unobtrusive chest strap device contains a high impact triaxial linear accelerometer. The accelerometer allows the monitor to examine six degrees of freedom for linear acceleration. The real-time measurements to the nearest millisecond were summarized for each player: rate of force development, acceleration, mechanical intensity, mechanical load, physiological intensity, physiological load, and average heart rate.

Approximately 30 minutes before each practice the primary researcher assisted the subjects in operation and placement of the Zephyr Performance Systems Monitors. The monitors were worn around the chest via an elasticated strap resting on the skin. The monitors were removed immediately following practice. Zephyr Performance Systems data was processed to remove any accidental impacts prior to athlete placement or after removal of the monitor. Zephyr Performance Systems utilizes OmniSense Software to transport, analyze, store, and deliver physiological assessment data. The sport specific strength and conditioning staff were the only individuals aware of the correlating Zephyr Performance Systems Monitor to the athlete providing the data.

Figure 1. Physiological Assessment

Physiological Assessment Technique	Equipment Required	Real-Time Measurements
Professional heart rate and physiological monitor	• Zephyr Performance Systems BioHarness 3 Model BH3	• Duration • Total Yards • Yardage % • Total Miles • Rate of Force Development • Acceleration • Mechanical Intensity • Mechanical Load • Physiological Intensity • Physiological Load • Average Heart Rate

Rate of Force Development (N/s): measure of explosive strength, speed in which the contractile elements of the muscle can develop force

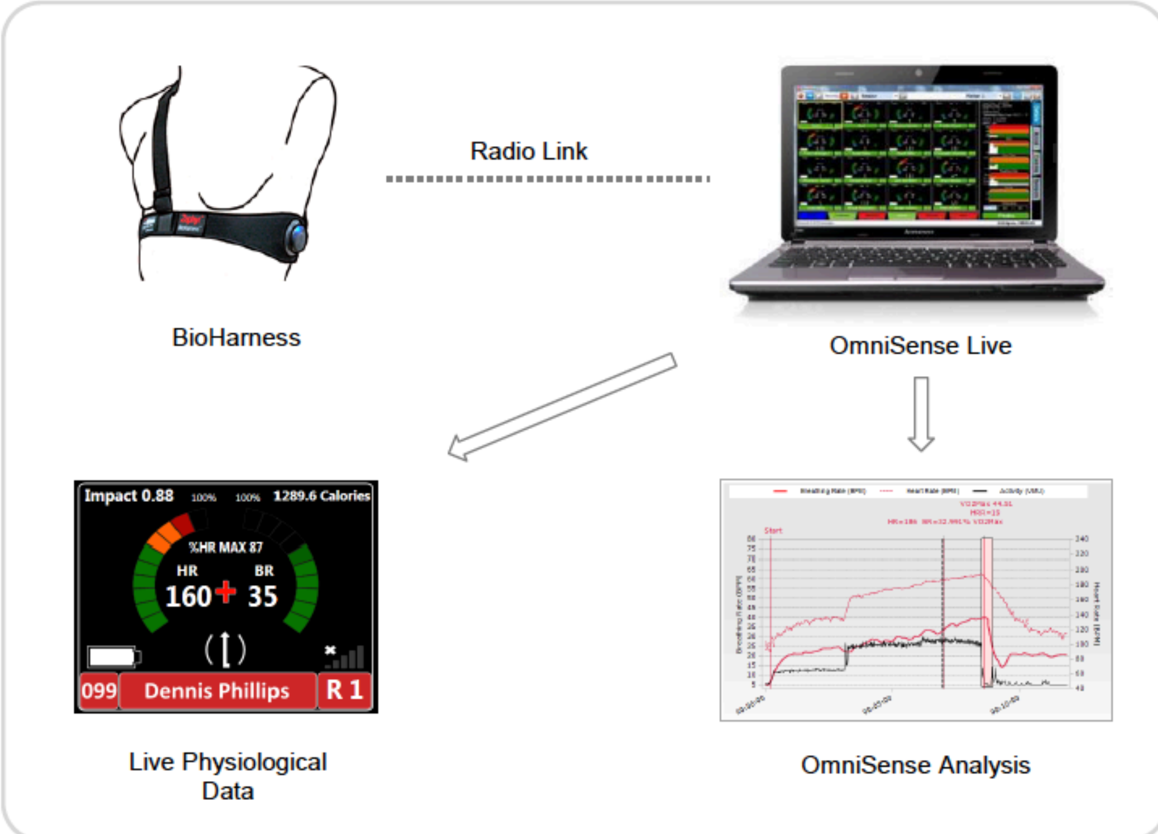
Mechanical Intensity (scale 1-10): index of musculoskeletal output, related to subject g force activity level, measured in 1/60 minute epochs

Mechanical Load: accumulation of mechanical intensities, total sum of mechanical intensities divided by 60

Physiological Intensity (scale 1-10): index of cardiovascular output, related to subject maximum heart rate, measured in 1/60 minute epochs

Physiological Load: accumulation of physiological intensities, total sum of physiological intensities divided by 60

Figure 2. Zephyr Physiological Monitoring



Zephyr utilizes OmniSense Software to transport, analyze, store, and deliver physiological assessment data. The Software gives immediate feedback on the health and condition of an athlete under stressful situations to promote training optimization.

Hydration Experimental Design

A handheld refractometer (Atago Digital Hand-Held Pen Refractometer) was used to determine the urine specific gravity of football participants. Approximately one hour before each practice the participants provided one spontaneously voided urine sample in a urine specimen cup. Before each analysis, the refractometer was calibrated using distilled water. Urine samples were analyzed for specific gravity within one hour of sample collection. The corresponding urine specific gravity was read and recorded by one researcher. All urine samples were discarded immediately after assessment. According to the National Athletic Trainers' Association and the American College of Sports Medicine three urine specific gravity hydration groups are identified (Casa, 2000; Sawka et al., 2007). Athletes that provided a urine specific gravity sample less than 1.020 were considered euhydrated. Hypohydrated athletes had a urine specific gravity between 1.020 and 1.029. Urine specific gravity samples that were equal to or are more than 1.030 were categorized as significantly hypohydrated.

Body weight was recorded to the nearest 0.1 pound on a professional quality scale (Health O Meter Professional Digital Scale) approximately one hour before practice and immediately following practice. Student athletes were required to towel off excess sweat and wear minimal dry clothing for each weigh-in. Athletes that experience a 2% or more body mass loss during practice were considered hypohydrated.

Figure 3. Hydration Assessment

Hydration Assessment Technique	Equipment Required	Body Fluids Involved	Outcome Variables	Euhydration values	Hypohydration values
Body Weight (BW) Change	• Health O Meter Professional Digital Scale	All	Body water loss or gain	<2% body weight loss	>2% body weight loss
Urine Specific Gravity (USG)	• Atago Digital Hand-Held Pen Refractometer • Urine specimen container	Excreted Urine	Relative density of urine vs. water	1.002-1.019	≥ 1.020

Euhydration: normal total body water content

Hypohydration: total body water below the basal value

Urine specific gravity: the concentration of solutes in urine, displays the ratio of urine density to water density

Statistical Analysis

Data analysis was conducted using SPSS (version 22.0; SPSS Inc. Chicago, IL). Descriptive statistics were calculated for age, weight, and height for demographic purposes. A Pearson correlation coefficient was used to measure the degree and direction of the linear relationship between (1) pre and post practice urine specific gravity change and Zephyr Performance Systems physiological data, (2) pre and post practice percent change in body weight and Zephyr Performance Systems physiological data. The data consisted of numerical scores from an interval scale of measurement. A probability level of 0.05 was used as the criterion for statistical significance.

CHAPTER IV

RESULTS

A total of 33% of (n = 2) collegiate athletes provided prepractice urine samples in which the mean urine specific gravity was greater than or equal to 1.020, indicating prepractice hypohydration. A total of 67% (n = 4) of football athletes were hypohydrated according to mean urine specific gravity samples following practice. Percent change in body weight was calculated for each athlete post practice and 0% of athletes had a mean loss greater than 2%, indicating adequate hydration status following practice. On average the athletes lost between 0.28% and 1.91% of their body weight during preseason practice.

Table 1. Demographic Characteristics of Collegiate Football Athletes (*n* = 6)

	Mean	Std. Deviation
Age	19.50	± 1.2247
Weight (kg)	103.76	± 24.3367
Height (cm)	188.81	± 7.8151

Table 2. Hydration Status of Collegiate Football Athletes, USG (Mean ± SD)

Participant	Pre-Practice	Post Practice	Change
1	1.0164 ± 1.0164	1.0231 ± 0.0064	+0.0067
2	1.0253 ± 1.0253	1.0235 ± 0.0021	-0.0018
3	1.0093 ± 1.0093	1.0181 ± 0.0019	+0.0088
4	1.0162 ± 1.0162	1.0221 ± 0.0089	+0.0058
5	1.0050 ± 1.0096	1.0156 ± 0.0025	+0.0106
6	1.0210 ± 1.0210	1.0214 ± 0.0047	+0.0033
USG ≥ 1.020	33.3%	66.7%	

Hypohydration is indicated by a urine specific gravity greater than or equal to 1.020, demonstrated by the ratio of urine density to water density.

Table 3. Hydration Status of Collegiate Football Athletes, Percent Change in BW (Mean ± SD)

Participant	Baseline (kg)	Change Post Practice (kg)	Percent Change
1	136.5	-0.7877 ± 0.75719	-0.58
2	88.6	-1.6968 ± 0.50332	-1.91
3	99.5	-1.0605 ± 0.70238	-1.07
4	89.5	-0.9090 ± 0.87178	-1.02
5	77.5	-1.3032 ± 0.50332	-1.68
6	131	-0.3636 ± 0.20000	-0.28
> 2% change			0

Hypohydration is indicated by a body weight loss greater than 2%.

Pearson correlation coefficient was calculated to determine the relationship between collegiate football athletes' pre and post practice change in urine specific gravity and pre and post practice percent change in body weight. A weak positive correlation was found ($r = 0.035$, $p = 0.947$) indicating the relationship was not significant between the two hydration status variables.

To examine the relationship between change in urine specific gravity and Zephyr Performance Systems physiological data, a Pearson correlation was calculated. A strong negative correlation, that was not significant, was found with rate of force development ($r = 0.768$, $p = 0.074$). A strong negative correlation with mechanical intensity ($r = -0.885$, $p = 0.019$) demonstrated significance at the two tailed 0.05 level. A moderate positive correlation was found for physiological intensity ($r = 0.363$, $p = 0.479$) and average heart rate ($r = 0.396$, $p = 0.437$). An increased change in urine specific gravity resulted in a negative influence on the rate of force development, mechanical intensity, physiological intensity, and average heart rate.

Table 4. Pearson Correlation Coefficients Between USG Change and Zephyr Performance Systems

Assessment Measurement	*r*	*p*
Percent Change in Body Weight	0.035	0.947
Rate of Force Development	-0.768	0.074
Mechanical Intensity	-0.885*	0.019
Physiological Intensity	0.363	0.479
Average Heart Rate	0.396	0.437

**Correlation is significant at the 0.05 level (2-tailed)*

Pearson correlation was used to examine the relationship between percent change in body weight and Zephyr Performance Systems physiological data. A moderate negative correlation was found with rate of force development (*r* = -0.466, *p* = 0.352). A weak negative correlation with mechanical intensity (*r* = -0.043, *p*= 0.936) was determined. A moderate positive linear correlation was found for physiological intensity (*r* = 0.628, *p* = 0.182) and average heart rate (*r* = 0.505, *p* = 0.307). All correlations between percent change in body weight and Zephyr Performance Systems physiological data were not significant. However, an increased change in percent body weight resulted in a negative influence on the rate of force development, mechanical intensity, physiological intensity, and average heart rate.

Table 5. Pearson Correlation Coefficients Between Percent BW Change and Zephyr Performance Systems

Assessment Measurement	*r*	*p*
Change in Urine Specific Gravity	0.035	0.947
Rate of Force Development	-0.466	0.352
Mechanical Intensity	-0.043	0.936
Physiological Intensity	0.628	0.182
Average Heart Rate	0.505	0.307

CHAPTER V

DISCUSSION

Determining the most accurate field-ready hydration assessment technique for high performance athletes can be difficult. The results of this study did not find a significant correlation between change in urine specific gravity and percent change in body weight, indicating multiple methods of hydration monitoring should be implemented for best results. Previous studies have concluded similar findings in active individuals, therefore a lack of a gold standard remains (Armstrong, 2007; Cheuvront & Sawka, 2005; Oppliger & Bartok, 2002). Urine specific gravity and percent change in body weight are both safe, accurate, and inexpensive, therefore they are appropriate techniques to assess hydration status in collegiate athletes.

The collegiate athletes in this study lost between 0.28% and 1.91% of their body weight during preseason practice on average, which is less than previously documented collegiate football players participating in preseason training. Godek et al. (2005) reported football players lost between 1.5% and 2.0% of their body weight during practice. Osterberg et al. (2009) revealed the average body weight change following competition of high performance athletes was 1.4%, while athletes in the current study lost an average of 1.09%.

Following collection of prepractice urine specific gravity, it was determined 33% of athletes started practice in a hypohydrated state. In order for an athlete to be considered hypohydrated their urine specific gravity must be between 1.020 and 1.029. The results are considerably lower compared to previous findings. Godek et al. (2005) found 67% of collegiate football athletes started preseason practice hypohydrated. Volpe et al. (2009) determined 66% of collegiate athletes and Osterberg et al. (2009) concluded 52% of professional athletes started competition in a hypohydrated state. Although our study had a particularly lower prominence of athlete prepractice dehydration compared to previous research, additional body fluid deficits during training continue to be a great concern. Following practice 66% of student athletes were considered hypohydrated in the current study. These results demonstrate maintaining adequate hydration status is unfeasible when initial dehydrated levels are combined with high intensity training. Inadequate fluid levels before, during, and after training increases the risk of detriments to neuromuscular performance, cognitive function, stability, and performance technique. These detriments could lead to overall earlier onset of fatigue, decreased rate of recovery, and declined athletic performance.

Previous research has suspected disparities in the critical level of water deficit at which a decrease in aerobic and anaerobic performance occurs. Particularly, it is suggested that aerobic athletic performance is more adversely influenced by hypohydration than anaerobic strength, power, and muscular endurance (Shirreffs, 2005; Yoshida et al., 2002). However, the topic remains controversial, as studies conclude anaerobic exercise is negatively impacted by hypohyration when as little as % 2 of body weight is lost (Ftaiti et al., 2001; Hayes & Morse, 2010; Yoshida et al., 2002).

The prevalence of test variables has made research difficult to generalize the impact of dehydration on anaerobic performance. Currently, there is not a criterion standard for measurement of anaerobic work capacity leading to tremendous exercise mode variations. When researching the impact hypohydration has on anaerobic performance previous physical tests have included vertical jump (Hayes & Morse, 2010; Judelson et al., 2007), 10 to 15 second maximal cycle sprints (Cheuvront et al., 2010; Yoshida et al., 2002), isokinetic force production (Hayes & Morse, 2010), and force production tests to exhaustion (Ftaiti et al., 2001). All of the previously listed exercise test modes utilize anaerobic pathways, however intrinsic differences exist. Interpreting the study results of aerobic and anaerobic performance for sports such as football that include intermittent high intensity bouts of exercise is further complicated due to the sport not being exclusively aerobic or anaerobic.

There is a substantial lack of evidence identifying the impact of hydration on the rate of force development. The rate of force development is an essential real time measurement collected by the Zephyr Performance Systems BioHarness and measures the speed in which the contractile elements of the muscle can develop force. Rate of force development is often used by strength and conditioning professionals as a fatigue or state of recovery factor when assessing athletes as it is a major determinant of maximal force and velocity that can be achieved through high intensity performance (Thorlund, Aagaard, & Madsen, 2009). Impaired rates of force development are often detected as an athlete becomes fatigued, has a decreased rate of recovery due to increased muscle damage, or experiences overtraining (Peñailillo, Blazevich, Numazawa, & Nosaka, 2015). The results of the current study reveal a strong negative correlation with hydration status and rate of force development. Even though the results are not significant, the established relationship indicates that as a high-performance athlete becomes more dehydrated their rate of force development is negatively impacted. Mechanical intensity measured by the Zephyr Performance Systems physiological monitor can be described as an index of musculoskeletal output specifically related to g force acceleration activity level. A significant negative correlation of hydration status and mechanical intensity was concluded from the current study. The results show that as an athlete become more dehydrated they have a negatively impacted instantaneous index of effort based on acceleration.

The adverse influence hypohydration has on rate of force development and mechanical intensity in the current study can be closely related to previous research on dehydration and the impact on athletic performance. Previous research has established the negative impacts induced by hypohydration on muscular strength and force generation may be caused by detriments in neuromuscular function. Supporting the current findings, when a muscle engages in a maximum concentric action under hypohydrated conditions muscular strength and overall force is impaired (Ftaiti et al., 2001; Hayes & Morse, 2010; Judelson et al., 2007; Minshull & James, 2013). The hypohydrated physiological findings of rate of force development and mechanical intensity were similar to (Judelson et al., 2007; Secora et al., 2004; Yoshida et al., 2002) as they concluded the maximal force a muscle group can generate at a velocity is negatively impacted when dehydration levels were reached in athletes.

There were several factors the limited the interpretation of the results in the present study. The failure for parameters to reach statistical significance may be related to the small sample size of 6 participants. As a sample size gets smaller, the magnitude of the correlation needed for significance gets larger. The collegiate athletes in the study experienced very modest levels of dehydration, often losing less than 2.0% of their body weight during practice, which is considered minimal dehydration. The first morning void has been well established as the recommended time to assess urine specific gravity (Armstrong, 2007). However, in the present study, voided urine samples collected for urine specific gravity were assess before and after practice. Urine specific gravity assessments were completed at this time to provide sports medicine staff members with a general idea of current athlete hydration status and it was the most convenient time for athletes, coaches, and sports medicine staff. As athletes provided hydration data, they quickly became more proactive towards their hydration status. Their increased awareness regarding percent body weight loss post practice and daily urine color may have potentially decreased the severity of dehydration levels. The lack of exercise criterion standards for sports such a football that include intermittent high intensity bouts of exercise can lead to further performance variations due to the sport not being exclusively aerobic or anaerobic.

In conclusion, the findings of the current study identify that as an athlete becomes more dehydrated their physiological profile is negatively impacted, thus increasing an athlete's susceptibility to fatigue, decreased athletic performance, and increased time to recovery. When determining collegiate athlete hydration status, a significant correlation did not occur between change in urine specific gravity and percent change in body weight, indicating multiple methods of hydration monitoring should be implemented. Prevalence in both pre and post practice hypohydration demonstrate maintaining adequate hydration status in collegiate athletes is unfeasible when initial dehydrated levels are combined with high intensity athletic performance. Future studies should be conducted on a greater sample size of collegiate athletes with more detrimental levels of hypohydration. Specific intervention studies should be conducted to investigate the effectiveness of various training regimes to compare muscle strength and rapid force characteristics outcomes.

REFERENCES

REFERENCES

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P., & Dyhre-Poulsen, P. (2002). Increased rate of force development and neural drive of human skeletal muscle following resistance training. *Journal of Applied Physiology*, *93*(4), 1318–1326.

Armstrong, L. E. (2007). Assessing hydration status: the elusive gold standard. *Journal of the American College of Nutrition*, *26*(5), 575S–584S.

Bigard, A. X., Sanchez, H., Claveyrolas, G., Martin, S., Thimonier, B., & Arnaud, M. J. (2001). Effects of dehydration and rehydration on EMG changes during fatiguing contractions. *Medicine and Science in Sports and Exercise*, *33*(10), 1694–1700.

Cheuvront, S. N., Carter, 3rd, Robert, Haymes, E. M., & Sawka, M. N. (2006). No effect of moderate hypohydration or hyperthermia on anaerobic exercise performance. *Medicine and Science in Sports and Exercise*, *38*(6), 1093–1097.

Cheuvront, S. N., Ely, B. R., Kenefick, R. W., & Sawka, M. N. (2010). Biological variation and diagnostic accuracy of dehydration assessment markers. *American Journal of Clinical Nutrition*, *92*(3), 565–573.

Cheuvront, & Sawka. (2005). Hydration assessment of athletes. *Sports Science Exchange*, (18(2)), 1–12.

Evetovich, T. K., Boyd, J. C., Drake, S. M., Eschbach, L. C., Magal, M., Soukup, J. T., … Weir, J. P. (2002). Effect of moderate dehydration on torque, electromyography, and mechanomyography. *Muscle & Nerve*, *26*(2), 225.

Ftaiti, F., Grélot, L., Coudreuse, J. M., & Nicol, C. (2001). Combined effect of heat stress, dehydration and exercise on neuromuscular function in humans. *European Journal of*

Applied Physiology, *84*(1), 87–94.

Godek, S. F., Bartolozzi, A. R., Burkholder, R., & Sugarman, E. (2006). Core temperature and percentage of dehydration in professional football linemen and backs during preseason practices. *Journal of Athletic Training*, *41*(1), 8.

Godek, S. F., Godek, J. J., & Bartolozzi, A. R. (2005). Hydration status in college football players during consecutive days of twice-a-day preseason practices. *The American Journal of Sports Medicine*, *33*(6), 843–851.

Hayes, L. D., & Morse, C. I. (2010). The effects of progressive dehydration on strength and power: is there a dose response? *European Journal of Applied Physiology*, *108*(4), 701–707.

Hori, N., Newton, R. U., Andrews, W. A., Kawamori, N., McGuigan, M. R., & Nosaka, K. (2008). Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction? *Journal of Strength and Conditioning Research*, *22*(2), 412–418.

Judelson, D. A., Maresh, C. M., Anderson, J. M., Armstrong, L. E., Casa, D. J., Kraemer, W. J., & Volek, J. S. (2007). Hydration and muscular performance: does fluid balance affect strength, power and high-intensity endurance? *Sports Medicine*, *37*(10), 907–921.

Judge, L. W., Kumley, R. F., Bellar, D. M., Pike, K. L., Pierson, E. E., Weidner, T., … Friesen, C. A. (2016). Hydration and fluid replacement knowledge, attitudes, barriers, and behaviors of NCAA Division 1 american football players. *Journal of Strength and Conditioning Research*, *30*(11), 2972–2978.

Kawamori, N., & Haff, G. G. (2004). The optimal training load for the development of muscular power. *Journal of Strength and Conditioning Research*, *18*(3), 675–684.

Kraska, J. M., Ramsey, M. W., Haff, G. G., Fethke, N., Sands, W. A., Stone, M. E., & Stone, M. H. (2009). Relationship between strength characteristics and unweighted and weighted vertical jump height. *International Journal of Sports Physiology and Performance*, *4*(4), 461.

Kreider, R. B., Wilborn, C. D., Taylor, L., Campbell, B., Almada, A. L., Collins, R., … Antonio, J. (2010). ISSN exercise & sport nutrition review: research & recommendations. *Journal of the International Society of Sports Nutrition*, *7*, 7–7.

Minshull, C., & James, L. (2013). The effects of hypohydration and fatigue on neuromuscular activation performance. *Applied Physiology, Nutrition and Metabolism*, *38*(1), 21–26.

Nichols, P. E., Jonnalagadda, S. S., Rosenbloom, C. A., & Trinkaus, M. (2005). Knowledge, attitudes, and behaviors regarding hydration and fluid replacement of collegiate athletes. *International Journal of Sport Nutrition & Exercise Metabolism*, *15*(5), 515.

Nybo, L., & Nielsen, B. (2001). Hyperthermia and central fatigue during prolonged exercise in humans. *Journal of Applied Physiology*, *91*(3), 1055–1060.

Oppliger, & Bartok. (2002). Hydration Testing of Athletes. *Sports Medicine*, *32*(15), 959–971.

Osterberg, K. L., Horswill, C. A., & Baker, L. B. (2009). Pregame urine specific gravity and fluid intake by national basketball association players during competition. *Journal of Athletic Training*, *44*(1), 53–57.

Peñailillo, L., Blazevich, A., Numazawa, H., & Nosaka, K. (2015). Rate of force development as a measure of muscle damage. *Scandinavian Journal of Medicine & Science in Sports*, *25*(3), 417–427.

Sabo, D., Veliz, P., & Women's Sports Foundation. (2008). *Go out and play: youth sports in america*. Women's Sports Foundation.

Sawka, M. N., & Coyle, E. F. (1999). Influence of body water and blood volume on thermoregulation and exercise performance in the heat. *Exercise and Sport Sciences Reviews*, *27*(Journal Article), 167–218.

Secora, C. A., Latin, R. W., Berg, K. E., & Noble, J. M. (2004). Comparison of physical and performance characteristics of NCAA division I football players: 1987 and 2000. *Journal of Strength and Conditioning Research*, *18*(2), 286–291.

Shirreffs, S. M. (2005). The Importance of Good Hydration for Work and Exercise Performance. *Nutrition Reviews*, *63*(6 Pt 2), S14–S21.

Thorlund, J., Aagaard, P., & Madsen, K. (2009). Rapid Muscle Force Capacity Changes after Soccer Match Play. *Int J Sports Med*, *30*(4), 273–278.

Volpe, S. L., Poule, K. A., & Bland, E. G. (2009). Estimation of prepractice hydration status of National Collegiate Athletic Association Division I athletes. *Journal of Athletic Training*, *44*(6), 624–629.

Yoshida, T., Takanishi, T., Nakai, S., Yorimoto, A., & Morimoto, T. (2002). The critical level of water deficit causing a decrease in human exercise performance: a practical field study. *European Journal of Applied Physiology*, *87*(6), 529–534.

VITA

Education

Master of Science in Food and Nutrition Services **May 2017**
Coordinated Program in Dietetics
Emphasis: Sport Nutrition
Thesis: Impact of Hydration on Collegiate Athletic Performance, Fatigue, and Recovery (subject pool: Ole Miss Athletics Football)
University of Mississippi University, MS

Bachelor of Science in Exercise Science **May 2015**
Minor: Business Administration
University of Mississippi University, MS

Professional Experience

Ole Miss Athletics Sports Nutrition Intern/Professional Practicum Student/Volunteer
University of Mississippi University, MS August 2014-Present

- Preseason fall camp (2014-2016)
- Supervise training tables, catered meals, and fueling stations
- Oversee inventory and restock five on-campus fueling stations
- Provide nutrition education opportunities including grocery store tours and cooking demos
- Perform body composition analysis via Bod Pod
- Provide hydration assessment, management, and counseling for student athletes
- Determine travel meal options and pack individualized travel snack bags
- Prepare informative and promotional social media material
- Prepare and present nutrition lectures for Oxford Middle School and Oxford High School students

Dietetic Intern
University of Mississippi University, MS May 2016-Present

- Comprised of sports nutrition, general clinical, renal nutrition, food service administration, child nutrition and community nutrition
- ACEND accredited Coordinated Program in Dietetics
- Approximately 1325 recorded hours of supervised practice

Race Across America (RAAM) Assistant Nutrition Coordinator – Toone Cycling
Toone Cycling, Birmingham, AL April 2017 – Present

- Properly fuel cyclist, Brian Toone, in preparation for and during multiple day ultra-endurance bicycle race across the United States
- Develop a set dietary plan to optimize fueling and hydration strategies throughout training and race
- Develop menu and meal plan to meet specific performance needs
- Manage food intolerance, GI distress, food allergies, and dietary modifications for travel

NFL Combine Training Program Dietetic Intern
St. Vincent Sports Performance Carmel, IN January 2017-February 2017

- Design, implement, and modify meal plans to prepare athletes for NFL Combine and Pro Day
- Educate athletes on nutrition for maximum performance
- Supervise training tables, hydration, and supplementation of athletes
- Monitor athlete's nutritional behavior before, during, and after training
- Observe individual client consultations

Department of Nutrition and Hospitality Management Graduate Assistant
University of Mississippi University, MS August 2015-May 2016

- Create, proofread, and format administrative documents
- Manage and update department website
- Operate and promote social media accounts
- Assist in instruction of undergraduate students

Heads in the Game Concussion Research Program Research Assistant
University of Mississippi University, MS May 2015-July 2016

- Design and implement an introductory level nutrition and sports performance course for high school junior and senior scholars
- Provide safe, effective, evidence based nutrition for overall health, fitness, and athletic performance as the sole nutrition research assistant
- Engage in literature searches and assist in grant writing

Ole Miss Athletics Student Athletic Trainer
University of Mississippi University, MS August 2013-January 2015

- Preseason fall camp (2013-2014)
- Assist with injury rehabilitation programs of student athletes
- Manage athletic training equipment set up/breakdown for training, practices, games and travel
- Maintain cleanliness and inventory of athletic training facility

Certifications

NSCA Certified Strength and Conditioning Specialist (CSCS) (2016-Present)
CITI Human Subjects Research Educational Program (2015-Present)
National Restaurant Association Servsafe (2014-Present)
American Heart Association First Aid CPR AED (2009-Present)

Publications

Parrish, L., Valliant, M., Morrison, M. 2017. Impact of hydration on mild traumatic brain injury susceptibility. Accepted to Journal of Concussion.

Morrison, M., Valliant, M., Waddell, D., Robinson, J., **Woodard, L.**, Humphrey, G. 2016. Heads in the Game: A STEM High School Concussion Outreach and Research Program. IEEE.

Morrison, M., Rogers, R., Harper, B., Sanchez, F., Singh, K., Williams, O., Williams, T., Humphrey, G., Valliant, M., **Parrish, L.**, Arnold, J., Haggard, G., Sims, E., Smith, H., Ralston, J. 2016. Research gaps and opportunities in sensor-based medical exploration capabilities in extravehicular astronaut suits. Accepted to NASA Technical Reports Database.

Presented Posters

Parrish, L., Valliant, M., Bass, M., Knight K. Impact of Hydration on Collegiate Athletic Performance, Fatigue, and Recovery. University of Mississippi Graduate Student Council Research Conference, 2017, Oxford, MS.

Parrish, L., Valliant, M., Bass, M., Knight K. Impact of Hydration on Collegiate Athletic Performance, Fatigue, and Recovery. Emory University STEM Research and Career Symposium, 2016, Atlanta, GA.

Woodard, L., Valliant, M., Morrison, M. The Impact of Hydration on Mild Traumatic Brain Injury
Susceptibility and Recovery. Sigma Xi Student Research Conference, 2015, Kansas City, MO.

Honors and Leadership Positions

CPSDA Research Committee (2016-Present)
IEEE Integrated STEM Education Conference H. Robert Schroeder Best Paper Award (2016)
University of Mississippi Chancellor's Honor Roll (2013-2016)
University of Mississippi School of Applied Sciences Presidents' Council (2014-2015)
Ole Miss Exercise Science Club President (2014-2015)
University of Mississippi Dean's Honor Roll (2015)
Ole Miss Exercise Science Club Treasurer (2013-2014)
University of Mississippi Chancellor's Leadership Class (2011)

Professional Organization Involvement

Collegiate and Professional Sports Dietitians Association (CPSDA) Student Member
Academy of Nutrition and Dietetics Student Member (AND)
National Strength and Conditioning Association (NSCA) Student Member
American College of Sports Medicine (ACSM) Student Member
Emory STEM Research and Career Symposium (2016)
7th Annual CPSDA Conference and Symposium (2015)
ACSM Southeast Regional Chapter Meeting (2015)
ACSM Southeast College Bowl (2015)
Sigma Xi Student Research Conference (2015)