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Making The Cut: Nutrition, Hydration, & Performance In Combat Sports

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MAKING THE CUT:

NUTRITION, HYDRATION, & PERFORMANCE IN COMBAT SPORTS

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ABSTRACT

This study investigated nutrition, hydration, supplementation, and body composition in relation to performance among mixed martial arts athletes practicing rapid weight loss. Mixed martial arts athletes practice intentional dehydration and nutritional fasting to achieve rapid weight loss, a practice that can damage health and performance. Male mixed martial arts athletes practicing rapid weight loss participated in the study during a week of competition which was not the same for all athletes. Food/activity journals were collected to assess nutrition, fasting, and supplementation. Urine specific gravity was assessed at baseline, weigh-ins, and endpoint. Body composition and punch velocity were assessed at baseline and endpoint. Competition result and self-rated performance data were also recorded. Descriptive statistics, Pearson correlations, ANOVA, and *t*-tests were utilized to determine the significance of relationships between variables. Of the participants who completed the study, eight (88.9%) were dehydrated at the official weigh-ins to qualify for competition, with one (11.1%) failing to achieve euhydration prior to competition. Among the sample of nine mixed martial arts athletes, significant weight loss was observed (M=14.54 lb, SD=4.21 lb). Changes in punching velocity were negatively correlated with fasting duration ($r=-0.763$, $p<.05$). Self-rated performance was positively correlated with changes in punching velocity ($r=0.676$, $p<.05$) and negatively correlated with endpoint USG ($r=-0.678$, $p<.05$). These findings suggest shorter fasting periods may be

beneficial to combat sports athletes practicing rapid weight loss. However, a study of these factors across a larger sample is warranted before drawing definitive conclusions.

DEDICATION

I dedicate this dissertation to my daughter Scarlett, may you be strong, brave, and unique. I cannot wait to meet you.

To my husband, Mykel, for his unwavering support, positivity, and wonderful skills at brewing coffee and mixing cocktails, I dedicate this dissertation to you.

I also dedicate this research to the combat sports fighters of the past, present, and future. This research honors the sacrifices you make in your pursuit for greatness.

LIST OF ABBREVIATIONS AND SYMBOLS

ABC	Association of Boxing Commissions and Combative Sports
AF	Activity factor
ALEA	Acute Low Energy Availability
AMPK	AMP-activated protein kinase
BF%	Body fat percentage
BMR	Basal metabolic rate
BW	Body weight
CLA	Conjugated linoleic acid
CSAC	California State Athletic Commission
DHA	Docosahexaenoic acid
EEE	Exercise energy expenditure
EPA	Eicosapentaenoic acid
FFA	Free fatty acids
FFM	Fat-free mass
IOC	International Olympic Committee
ISAK	International Society for the Advancement of Kinanthropometry
LEA	Low Energy Availability
MMA	Mixed Martial Arts

NCAA	National Collegiate Athletic Association
NDSR	Nutritional Data System for Research
RED-S	Relative energy deficiency in sport
RWL	Rapid weight loss
TEA	Total energy availability
TEE	Total energy expenditure
TEF	Thermic effect of food
TKD	Taekwondo
URTI	Upper respiratory tract infection
USG	Urine specific gravity

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CHAPTER 1

INTRODUCTION

Combat sports competitions, which include boxing, kickboxing, wrestling, judo, jujitsu, karate, taekwondo (TKD), and mixed martial arts (MMA), are often separated into weight divisions to promote fairness in competition. However, this encourages fighters to attempt to gain a competitive edge through rapid weight loss (RWL) and refeeding, a practice that involves voluntary dehydration, fasting, and other behavioral strategies aimed at achieving significant weight loss prior to qualifying for weight-class competition (Brito et al., 2012; Coswig, Fukuda, & Vecchio, 2015; Fleming & Costarelli, 2007; Langan-Evans, Close, & Morton, 2011; Matthews & Nicholas, 2016; Pallares et al., 2016; Pettersson, Eckstrom, & Berg, 2012; Pettersson, Ekstrom, & Berg, 2013; Reljic et al., 2015; Timpmann, Oopik, Paasuke, Medijainen, & Ereline, 2008). RWL is common among combat sports athletes of all age groups (Brito et al., 2012). Though, the safety of RWL among this population is unclear and yet to be placed under scientific scrutiny, the practice has been linked to hospitalization (Carroll, 2018; MMANewPL, 2017) and death (Cruz, 2013; Rondina, 2017; Zidan, 2014).

Fighters modify their nutrition, hydration, and behavior during training to "make weight," the process of achieving enough weight loss to compete in a lighter weight class. Despite its seeming importance, there appears to be no consensus opinion on which nutritional strategies produce the best results for health and performance. Hydration is central to the RWL and refeeding process, and athletes practice several different strategies to lose water weight, including but not limited to the use of diuretics and saunas, as well as exercising in sauna suits (Brito et al., 2012; Franchini et al., 2012; Matthews & Nicholas, 2016), to remove large amounts of body water through perspiration and urine in order to make weight. These practices, as well as the general practice of RWL, present risks and rewards for combat sports athletes seeking a competitive edge. This analysis aims to identify the nutritional and behavioral practices utilized by combat sports athletes in order to “make the cut,” achieving a weigh-in weight that does not exceed the maximum allowable weight in their weight class. It is also important to identify the consequences of this practice on the physical and cognitive ability of combat sports athletes.

Research Objectives and Specific Questions

The purpose of this study is to analyze how hydration, nutrition, dietary supplementation, and body composition are associated with athletic performance among MMA athletes practicing RWL. This research aims to answer these specific questions:

1. What is the status of MMA fighters pertaining to dehydration, acute energy availability, dietary supplementation, and body composition at different stages of combat preparation?
2. What associations exist between hydration, nutrition, dietary supplementation, and acute changes to weight and body composition among MMA fighters?
3. Are changes in performance after refeeding correlated with acute body composition changes, nutrition, and hydration status among MMA fighters?
4. How are hydration, acute energy availability, dietary supplementation, and acute changes in weight and body composition related to objective and perceived performance among MMA fighters?

CHAPTER 2

REVIEW OF LITERATURE

Although RWL and refeeding to quickly regain weight are familiar practices among combat sports athletes of all age groups (Brito et al., 2012), the practice has been linked to hospitalization (Carroll, 2018; MMANewPL, 2017) and death (Cruz, 2013; Rondina, 2017; Zidan, 2014), results that are increasing as combat sports, particularly MMA, have become more popular. This review highlights existing literature regarding hydration, nutrition, and dietary supplementation among combat sports athletes, identifying topics which may deserve more attention from empirical studies.

Hydration

Intentional water restriction is a very common practice among combat sports athletes practicing RWL (Hoffman & Maresh, 2011). Additionally, several studies have found that many combat sports athletes, at various levels of competition, are inadequately hydrated (Fleming & Costarelli, 2007; Matthews & Nicholas, 2016; Pallares et al., 2016; Pettersson & Berg, 2014). Researchers have observed dehydration's association with impaired physical (Cheuvront, Carter, Montain, & Sawka, 2004; Nielsen et al., 1981) and cognitive (Edwards et al., 2007; Wilson & Morley, 2003) functions. Physical traits such as heart rate and body temperature significantly increase among dehydrated athletes competing in high-intensity activities (Maughan, 2003). Dehydration prior to exercise has an observed association with higher self-reported fatigue as well as the incidence and severity of concussions and associated symptoms (Patel, Mihalik, Notebaert, Guskiewicz, & Prentice, 2007). Dehydration may also have a confounding influence on the clinical measures of baseline concussion tests (Weber et al., 2013). Intentional dehydration appears to warrant additional attention from athletes, coaches, policymakers, and other stakeholders who may influence guidelines and reduce exposure to the risks of intentional dehydration.

In 2017, the National Collegiate Athletic Association (NCAA) set several standards and regulations pertaining to the weight of collegiate wrestlers and the practice of RWL (National Collegiate Athletic Association, 2017). According to these NCAA guidelines, urine specific gravity (USG) should be utilized as a screening for qualification to weigh-in prior to wrestling competition. Currently, collegiate wrestlers are required to determine hydrated weight through a measurement of weight and urine specific gravity. In doing so, collegiate wrestlers are required to be present for weight measurements and to provide urine samples to be analyzed using a digital refractometer, providing an assessment of hydration status based on USG. A measurement of body mass taken with an accompanying urine specific gravity of less than or equal to 1.020 is considered a valid hydrated weight. Once hydration weight has been determined, body fat percentage is calculated using skin-fold measurements, hydrostatic weighing, or plethysmography analysis using a Bod PodTM (COSMED, Rome, Italy). From this, the wrestler's weight at 5% body fat is calculated. After body fat has been determined, the final determination of minimum wrestling weight is determined by comparing the outcomes of two methods. The first method estimates the wrestlers weight at 5% body fat, holding other factors constant. The second method allows for a reduction of 1.5% body weight (BW) each week prior to competition; this is estimated with the equation: BW – (0.015/7 × number of days until competition × BW) = minimum BW. Once the two estimations of lowest allowable weight are calculated, the athlete's minimum wrestling weight is always the higher of the two values.

In 2017, the California State Athletic Commission (CSAC) passed the most stringent restrictions, to-date, on RWL among MMA athletes in the United States (Raimondi, 2017). Although several components of the CSAC's 10-point plan dealt with the financial aspect of the sport, two key points were aimed at addressing the risks of RWL among MMA athletes competing under the CSAC's jurisdiction. First, additional weight divisions for MMA competitions sanctioned by the CSAC were created at the 165, 175, 195, and 225-pound levels. Previously, weight divisions existed at the 115, 125, 135, 145, 155, 170, 185, 205, and 265-pound levels, leaving 15+ lb gaps between some weight divisions. Despite fitting closely between the newly created weight-divisions, the CSAC did not vote to eliminate the 170-pound weight division after considering its significance in the history of MMA in the United States. The 170-pound "welterweight" division has featured popular mixed martial artists such as Pat Miletich, Matt Hughes, B.J. Penn, Georges St-Pierre, Robbie Lawler, Johnny Hendricks, and Tyron Woodley, giving it a prominent place in the history of the sport for its role in the growth in the sport's popularity in the United States. Additionally, the new regulations allow for MMA athletes competing in CSAC-sanctioned competitions to regain no more than 10% of his or her body weight between weigh-in and fight-day weight checks. In reaction to the passing of these CSAC regulations, the Association of Boxing Commissions and Combative Sports (ABC) adopted 165, 175, 195, and 225 weight divisions under the unified rules for MMA (Marrocco, 2017). The ABC did not adopt the 10% limit on regained weight that was within the CSAC regulations.

Previous research has identified mild dehydration at a decrease of 1-2% body weight (Parrish, Valliant, Knight, & Bass, 2018), a threshold associated with impaired athletic ability (Cheuvront et al., 2004; Nielsen et al., 1981) and cognitive function (Edwards et al., 2007; Wilson & Morley, 2003). Therefore, the restrictions placed on MMA athletes under the 10-point CSAC plan may not be effective in eliminating all the detrimental effects of intentional dehydration during RWL. Studies among this population have observed sample weight-cuts as low as 2.3% body mass (Reale et al., 2016) and as high as 10.0% (Coswig, Fukuda, & Vecchio, 2015), among both male and female athletes (Fleming & Costarelli, 2007; Matthews & Nicholas, 2016; Timpmann et al., 2008). It is important to note that the Coswig, Fukuda, & Vecchio (2015) and the Matthews & Nicholas (2016) studies were the only two found through this review which assessed the RWL practice of MMA athletes. These samples also displayed the greatest observed values for percentage of body mass reduction through RWL (Coswig et al., 2015; Matthews & Nicholas, 2016), suggesting that MMA athletes may undergo extreme RWL compared to other combat sports athletes. The place of RWL in combat sports culture, particularly its nearly-universal practice among MMA fighters (Hillier et al., 2019), combined with potentially inadequate regulations, may put combat sports athletes at serious risk for health and performance issues as a result of intentional dehydration during RWL.

The metabolic implications of dehydration have been thoroughly documented as several animal studies have found an association between hydration and muscle glycogen uptake (Low, Rennie, & Taylor, 1996; Neufer et al., 1991; Waller, Heigenhauser, Geor, Spriet, & Lindinger, 2009). While Fernández-Elías, Ortega, Nelson, & Mora-Rodriguez (2015) did not find a relationship between muscle hydration and glycogen in male cyclists, their findings did not oppose such a relationship either. Muscle glycogen is depleted through exercise, but 40% of the expenditure can be restored after four hours with adequate carbohydrate intake (Ivy, Katz, Cutler, Sherman, & Coyle, 1988; Ivy, Lee, Brozinick, & Reed, 1988). Muscle glycogen is stored with water at a ratio of 1:3 (Fernández-Elías et al., 2015), highlighting the importance of adequate hydration in order for optimization of energy availability during athletic performance. However, despite the findings of muscular water-to-glycogen ratios as high as 17:1 by Fernández-Elías et al. (2015), recent research has found that this excess water is not released during exercise and utilized to rehydrate the body (King, Jones, & O'Hara, 2018). This suggests that although dehydration could be detrimental to performance, intentional hyperhydration, compared to euhydration, likely yields no additional benefits to glycogen storage within muscle tissue. Due to the practice of dehydration during RWL, combat sports athletes could be training and potentially competing with less than optimal glycogen stores within their muscle tissues.

In a study of hydration and protein metabolism, McCue, Sandoval, Beltran, & Gerson (2017) observed increased rates of muscle catabolism in mice during times of low food intake and dehydration. While this effect was not statistically significant and not as dramatic as similar observations among birds (Gerson & Guglielmo, 2011), it does show that mammals increase protein catabolism while dehydrated and fasting. The mechanism behind this metabolic shift is likely due to the amount of water that is released as a result of protein catabolism, five times the amount of water released during fat oxidation (Gerson & Guglielmo, 2011; Jenni & Jenni-Eirmann, 1998). These processes may not be present in humans, and more research is needed to explore the association between dehydration and increased protein catabolism. If this effect is present among human subjects, then intentional dehydration during RWL cycles would directly conflict with the aims of reducing fat mass while retaining lean mass prior to competition.

Hydration and energy metabolism have been studied extensively for the past 20 years, primarily with a focus on reducing the prevalence of obesity and other chronic illnesses. Evidence of the role of hydration in nutrient metabolism among healthy men is fairly limited, but findings suggest that dehydration, acute or chronic, could have undesirable effects on the metabolism of combat sports athletes. Multiple studies have found individuals in a state of hyper-hydration to experience protein-sparing effects compared to those in a dehydrated or euhydrated state (Berneis, Ninnis, Haussinger, & Keller, 1999; Keller, Szinnai, Bilz, & Berneis, 2003). Additionally, lipolysis appears to be upregulated by higher intercellular hydration levels (Achten & Jeukendrup, 2004; Berneis et al., 1999; Keller et al., 2003), independent of lipolysis-regulating hormones (Bilz, Ninnis, & Keller, 1999). These findings suggest that the intentional dehydration practices that combat sports fighters undergo may not be conducive to the retention of lean mass and catabolism of fat mass during the fight week. Important considerations of hydration, metabolism, lean-mass retention, and weight-loss goals should be made by fighters and coaches during the fight-week weight cut; however, these associations are complex and are not well-observed among this population.

The intentional dehydration practice of combat sports athletes is among the life-threatening aspects of sport today. The risks of intentional dehydration in this family of sports is apparent through its association with recent hospitalizations (Carroll, 2018; MMANewsPL, 2017) and deaths (Cruz, 2013; Rondina, 2017; Zidan, 2014). Specifically, these hospitalizations and deaths have all been the result of acute changes in cardiac performance, which can cause stroke, heart attack, cardiopulmonary failure, and sudden death. Scientific investigation of the acute cardiac changes associated with RWL among combat sports athletes is scarce. Electrolyte balance is a potential causal factor in this phenomenon as the Sodium-Potassium ATPase proton pump (NA+ - K+ ATPase) sparks glycolysis and ATP production, particularly in neural tissue (Armengaud et al., 2009; James et al., 1996; Raffin, Sick, & Rosenthal, 1988; Raffin, Rosenthal, Busto, & Sick, 1992; Roberts, 1993). Because of Na+-K+ ATPase's role in maintaining a stable heartbeat (Karaki, Urakawa, & Kutsky, 1984; Pohl, Wheeler, Murray, 2013), excessive dehydration could theoretically neutralize the electrical gradient across cellular membranes, resulting in significant alterations to cardiac rhythm. We have yet to critically investigate how hydration, nutrition, and dietary supplementation during the RWL cycles of combat sports athletes affect cardiac function. Electrolytes have important implications for protein synthesis (Canady, Ali-Osman, & Rubel, 1990; Cannon, Frazier, & Hughes, 1952; Cunningham & Bridgers, 1970), bone health (Barzel, 1995; Green & Kleeman, 1991; Krieger, Frick, & Bushinsky, 2004; Lemann, Litzow, & Lennon, 1966; Lemann, Bushinsky, & Hamm, 2003), and metabolism (Armengaud et al., 2009; James et al., 1996; Raffin et al., 1988; Raffin et al., 1992; Roberts, 1993). Yet, we know little of the how electrolyte levels fluctuate during the fight-week RWL cycle commonly practiced in combat sports. Further research into the safety of RWL, particularly intentional dehydration, may be instrumental in preventing death, hospitalization, injury, and impaired performance among this population. Additionally, research efforts in this subfield of nutrition could yield important information for combat sports athletes, coaches, and administrators associated with combat sports that could shape the future of the sport to optimize safety, health, and performance.

Nutrition

Due to the influence of carbohydrates, fats, proteins, vitamins, minerals, and water on energy availability and health, it is essential that fighters consume of these nutrients to ensure optimal performance during training and after the RWL-refeeding process. As mentioned previously, water is especially important due to its involvement in transporting nutrients, temperature regulation, and most other physiological processes of the human body. In addition to intentional dehydration being the primary nutritional approach to RWL, research has identified the widespread practice of limiting nutritional intake among judo (Artioli et al., 2010), boxing (Hall & Lane, 2001; Morton, Robertson, Sutton, & MacLaren, 2010), taekwondo (Fleming & Costarelli, 2007; Fleming & Costarelli, 2009), and wrestling competitors (Alderman, Landers, Carlson, & Scott, 2004; Kiningham & Gorenflo, 2001; Oppliger, Steen, & Scott, 2003). Other studies have observed MMA fighters reducing nutritional intake significantly during RWL cycles (Coswig et al., 2015; Matthews & Nicholas, 2016). Presently, the parameters which combat sports athletes follow in regards to their nutrition during RWL are unclear.

Carbohydrates are the driving force behind anaerobic activity, the primary facilitator of the intermittent skeletal movements in combat sports. Despite the importance of carbohydrates in fueling relevant muscle contractions and the limited amount of carbohydrate storage available, many fighters choose to reduce carbohydrates during RWL (Fleming & Costarelli, 2007; Pettersson & Berg, 2014; Reljic et al., 2015). By reducing glycogen stores, the capacity for anaerobic respiration during training is impaired. Though, fighters accept that risk with the aim of reloading glycogen stores with carbohydrate consumption between weigh-in and competition, often by consuming carbohydrate-rich drinks (Pettersson & Berg, 2014). By utilizing this practice of carbohydrate loading prior to competition, fighters limit their ability to oxidize lipids during activity (Langan-Evans et al., 2011). This limitation is the result of insulin secretions in response to carbohydrate-rich foods and beverages, a detriment to lipolysis (Horowitz, Mora-Rodriguez, Byerley, & Coyle, 1997). Additionally, this slowing of lipolysis may last for up to four hours after a meal (Montain, Hopper, Coggan, & Coyle, 1991). Research has suggested that an effectively-timed meal that is high in carbohydrates, with a lower glycemic impact, will not attenuate lipolysis to the same degree as foods with higher glycemic impacts (Wee, Williams, Tsintzas, & Boobis, 2005). While providing adequate glycogen stores should be a priority for combat sports athletes who will require significant energy through glycolysis and the lactic acid cycle, it is important that fighters and coaches are well-educated on the importance of priming additional fuel systems such as the Kreb's Cycle by promoting lipolysis. The popularity of carbohydrate-rich drinks among combat sports athletes was observed by Petterson & Berg (2014) and suggests that fighters and coaches are not effective in fueling the multiple energy systems that will be relied on during the high-intensity, intermittent activities involved in martial arts competition. According to current research, both athletes and their coaches may lack the necessary nutritional understanding to ensure adequate fueling for training, and particularly competition after RWL.

Dietary protein provides the body's building blocks for muscle synthesis. Under ideal conditions, protein would never be a primary source for energy during activity. This presents one of the primary nutritional concern for combat sports athletes practicing RWL, the need for protein. Fighters may need as much as 3 or 4 times more dietary protein compared to the average person (Hoffman, 2002). Daily protein consumption at 0.8 – 1.0 g/kg body weight is needed for the maintenance of adequate nitrogen balance, facilitation of muscle synthesis, and improvement of muscular strength under stress (Hoffman et al., 2009; Lemon, Tornopolsky, Macdougal, & Atkinson, 1992). The Academy of Nutrition and Dietetics suggests that athletes consume between 1.2 – 2.0 g/kg body weight of protein each day, consistent with the demands of their training sessions (Academy of Nutrition and Dietetics, American College of Sports Medicine, and Dietitians of Canada, 2016; Campbell et al., 2007). For additional strength benefits, it has been suggested that power athletes consume more than 2.0 g/kg protein each day (Hoffman, Ratamess, Kang, Falvo, & Faigenbaum, 2006). This high requirement for protein presents a complicated situation for combat sports athletes practicing RWL as they seek to maintain lean mass while reducing their body mass, sometimes by more than 15% during the week of competition.

Increased protein consumption makes it difficult to restrict caloric intake; however, it is necessary to prevent the degradation of lean mass. Moreover, RWL often requires extreme caloric restriction, such that competitors cannot meet protein requirements. Despite adaptations to preserve body proteins during prolonged fasting (Cahill, 1970; Saudek & Felig, 1976), previous studies have observed that long fasting periods result in muscle loss (Fryburg, Barrett, Louard, & Gelfand, 1990; Nair, Woolf, Welle, & Matthews, 1987; Pozefsky, Tancredi, Moxley, Dupre, & Tobin, 1976) as proteins are catabolized and mobilized to fuel gluconeogenesis in the liver. This adaptation to low energy availability is signaled by reduced insulin and the increased presence of glucocorticoids (Kettelhut, Pepato, Migliorini, Medina, & Goldberg, 1994). Starvation conditions result in the signaling of atrogenes which rapidly mobilize proteins for breakdown (Lecker et al., 2004); though the atrogene responses to starvation can vary by muscle fiber type (Moriscot et al., 2010). Research has observed that protein breakdown to fuel gluconeogenesis during fasting is more pronounced in the fast-twitch muscle fibers that athletes rely on for explosive movements (Li & Goldberg, 2006). While athletes regularly practice fasting to an extent that mobilizes large amounts of protein tissue for gluconeogenesis, scientific evidence suggests that training can attenuate protein metabolism and promote lipolysis to fuel gluconeogenesis and the Kreb’s Cycle (Gudiksen et al., 2018). Though, this may aid athletes in lean-mass retention during RWL, there is no cessation of protein metabolism during the extended fasting state that many combat athletes experience during RWL. Though combat sports athletes typically experience fasting periods much shorter than the 60+ hour fasting periods associated with observed muscle loss, little is known of its role in predicting health and performance outcomes among this population.

The literature indicates that dietary fat may be the prioritized source of energy for the fighter utilizing a low-carbohydrate, protein-rich diet. Fatty acids can be metabolized for energy at light and moderate intensities of activity (Hoffman & Maresh, 2011). As glycogen stores are depleted, fat takes over as the primary source for energy throughout the remainder of an activity session (Hoffman, 2002). Assuming the intensity of training does not exceed the fueling ability of fat, the primary difficulty with dietary approaches that prioritize fat and protein over carbohydrate, for fighters, is that they must "prime" their bodies for fat oxidation throughout the day (Langan-Evans et al., 2011) in order to reduce the impact of the insulin response on lipolysis. This can be accomplished by spreading out the training sessions across the day to balance the utilization of macronutrients (Langan-Evans et al., 2011). The case-study by Morton *et al.* (2010) found that a professional boxer could have success with a carbohydrate-restricting diet while having a morning running session, a pre-lunch technical session, and a final session focused on strength and conditioning in the early evening. This practice has scientific merit as a means to prime the body for fat oxidation by avoiding the lipolysis-slowing effects of carbohydrate intake and the subsequent insulin response that lasts for hours (Montain et al., 1991). However, researchers should seek a deeper understanding of the high-fat, low-carbohydrate dietary approach and its effects on performance in training and competition among this population.

Regarding the metabolic importance of macronutrients, carbohydrate consumption is necessary to produce and store glycogen needed for energy metabolism, particularly during physical activity. Both insulin and endurance training stimulate the uptake of glucose by skeletal muscle (Jensen, Rustad, Kolnes, & Lai, 2011). It is in the skeletal muscles where glucose is primarily disposed, with 90% of the muscles' glucose being stored as glycogen (Jue et al., 1989). The importance of glycogen stores cannot be exaggerated in regards to athletic performance, as glycolysis is the primary energy pathway for the movement of Type II, or slow twitch, muscle fibers. By breaking down glycogen, these muscles are provided ATP needed for exercise; however, these stores run out quickly which then places the burden of energy metabolism on free glucose and free fatty acids (FFA) (Holloszy, Kohr, & Hansen, 1998). Additionally, the onset of activity stimulates the process of glycolysis through the activation of several enzymatic pathways (Greenberg, Jurczak, Danos, & Brady, 2005). As muscle contractions continue, glycogen stores become depleted, resulting in the slowing of glycogen phosphorylase activity (Chasiotis, Sahlin, & Hultman, 1983). While research does not agree on the importance of glucose uptake for all populations, the review by Greenberg, Jurczak, Danos, & Brady (2005) indicates that, at high intensities, an increased uptake of glucose is necessary for continued muscle contraction once glycogen stores run out and lipolysis slows. The literature suggests that, through careful, well-executed dietary glucose uptake, combat sports athletes could prime their bodies for metabolizing FFAs by repeatedly depleting and limiting glycogen stores during training sessions (Pilegaard et al., 2002). AMP-activated protein kinase (AMPK) is the enzyme that acts as the primary force behind this shift from glycogenolysis to lipolysis during physical activity (Winder, & Hardie, 1999). AMPK increases energy production while inhibiting the storage of muscular glycogen. The regulation of energy metabolism by AMPK is activated as ATP is utilized and the ratio of AMPK to ATP increases (Hardie, 2004). In addition to this, AMPK has been shown to bind glycogen and is not affected by further addition of glycogen (Polekhina et al., 2003). This allows the body to utilize extracellular glucose and FFA to produce energy through the activation of translocation of the enzyme GLUT4, and the restriction of the limiting-enzyme, acetyl-CoA carboxylase (Greenberg et al., 2005). These metabolic processes during high-intensity activity highlight the importance of adequate energy availability at the time of competition in combative sports.

In a consensus statement, the International Olympic Committee (IOC) listed male combat sports athletes as a population at risk for relative energy deficiency in sport (RED-S) (Burke et al., 2018; Mountjoy et al., 2018). Central to the IOC's model of RED-S is chronic low energy availability (LEA). LEA has significant biological impacts across many organ systems in both sexes. However, the differences and similarities between the biological responses to chronic LEA among male and female athletes is unknown (Loucks, 2007). While the intentional dehydration practiced by combat sports athletes presents serious health concerns, chronic LEA associated with RED-S presents a multitude of concerns for various body systems, specifically in regards to the hormone testosterone (Hackney, Moore, & Brownlee, 2005; Hooper et al., 2017; Tenforde, Barrack, Nattiv, & Fredericson, 2016). With targeted weight loss >10%, almost all fighters would be classified as having acute LEA according to parameters suggested by previous research (De Souza, et al., 2014). In the IOC's Consensus Statement, a strong case is made for the advancement of the scientific understanding of RED-S in various athlete populations due to the metabolic, hematological, hormonal, cardiovascular, immunological, gastrointestinal, and psychological constructs and consequences associated with the condition (Mountjoy et al., 2018). Very little research has been conducted to include LEA, acute or chronic, and RED-S as they relate to the various groups of combat sports athletes. Understanding the weight-management practices and potential health and performance implications of combat sports athletes is crucial to building our scientific body of knowledge on the subject.

The nutritional needs of the athlete in combat sports vary depending on the sport. For instance, training needs will be very different for wrestlers as opposed to boxers. In theory, a low-carbohydrate, high-protein diet with well-timed, calorically-balanced meals could be very beneficial in priming these power athletes' bodies for performance. The evidence, however, indicates that combat sports athletes regularly consume diets that would not align with these principles (Alderman et al., 2004; Artioli et al., 2010; Fleming & Costarelli, 2007; Fleming & Costarelli, 2009; Coswig et al., 2015; Hall & Lane, 2001; Kininghamn & Gorenflo, 2001; Matthews & Nicholas, 2016; Morton et al., 2010; Oppliger et al., 2003). Combat sports athletes going through RWL are aiming to reduce body mass as much as possible, while also priming the body for a high-intensity bout of activity. Herein lies the key nutritional dilemma faced by this population, but they have coping strategies. There is a large body of evidence citing the use of supplements among combat sports athletes. As indicated in the review by Langan-Evans *et al.* (2011), the common supplements taken by athletes during RWL could be defined as either a weight-loss supplement or an immune-boosting supplement. There is a large variance in the amount of research and the validity of data regarding these supplements, as they relate to combat sports athletes.

The most common weight-loss supplement used by combat sports athletes is caffeine (Langan-Evans et al., 2011). Supplementation of caffeine has been associated with improved metabolism during exercises of at least moderate intensity (Graham, 2001; Graham, Baltram, Dela, El-Sohemy, & Thong, 2008; Ivy, J.L., Costill, Fink, & Lower, 1979; Maki et al., 2009;

Rains, Agarwal, & Maki, 2011; Venebles, Hulston, Cox, & Jeukendrup, 2008; Wetserterp-Platenga, 2010). In addition to metabolic function, caffeine enhances weight loss through thermogenic effects (Hursel & Wetserterp-Plantenga, 2010). Caffeine has an observed positive effect on performance and energy availability (Davis & Green, 2009). A study by Santos *et al.* (2014) found that caffeine supplementation of 5 mg/kg of body mass reduced reaction time in combat sports athletes who were not fatigued. Additionally, caffeine supplementation of 3-5 mg/kg of body mass has improved intensity early in fights while also helping to maintain intensity through successive bouts of competition among combat sports athletes (Diaz-Lara et al., 2016; Santos et al., 2014). Risks associated with caffeine consumption include central nervous system responses resulting in anxiety, dependency, and withdrawal (Burke, 2008; Jenkinson & Harbert, 2008; Tunnicliffe, Erdman, Reimer, & Shearer, 2008).

Another supplement that is popular among combat sports athletes is a naturally-occurring fatty acid, conjugated linoleic acid (CLA). Combat sports athletes consume CLA supplements because of its claimed ability to reduce fat mass, improve insulin sensitivity, and decrease plasma glucose. While most of the research on the effects of CLA have been conducted on animals (Langan-Evans et al., 2011), there have been some studies conducted using human subjects that show promise. A randomized, double-blind study of 60 overweight or obese individuals found that supplementation of 3.4 – 6.8 g/d of CLA was associated with a significant reduction in body fat, compared to a placebo group receiving 9 g/d of olive oil (Blankson et al., 2000). This study did not find that 6.8 g/d of CLA was more effective than 3.4 g/d of CLA. Another research, with a similar design, observed this association among 53 healthy individuals. This double-blind trial resulted in a 3.8% reduction in body-fat percentage in the CLA group, which was significantly different from the olive oil placebo group (Smedman & Vessby, 2001).

A study of CLA supplementation among subjects with experience in resistance training found promising but no statistically significant effects on body mass and fat mass (Kreider, Ferreira, Greenwood, Wilson, Almada, 2002). The merits of CLA supplementation among combat sports athletes are questionable after considering the findings of Kreider *et al.* (2002).

The review by Langan-Evans *et al.* (2011) identified carnitine supplementation as a common practice among combat sports athletes. Normally consumed as part of a regular diet, carnitine is stored in the muscles and plays a role in the transportation of fatty acids for oxidation. The primary issue with supplementation of L-carnitine is that it is not put to use in the muscle, rather it passes through the body as free carnitine, unable to be utilized (Barnett et al., 1994). Research by Stephens *et al.* (1985) suggested that insulin may be a factor in muscular carnitine retention. More recent efforts have found that carnitine levels increase in the muscle when supplementation is taken at a time where carbohydrates are readily available (Stephens, Constantin-Teodosiu, Laithwaite, Simpson, & Greenhaff, 2006). In regards to combat sports athletes, the literature suggests the potential benefits of L-carnitine supplementation may not be worth the carbohydrates needed to retain the carnitine in the muscle tissue.

Multivitamins are a popular immune-boosting option for combat sports athletes practicing RWL (Langan-Evans et al., 2011). There is a plethora of information regarding the role of micronutrients found in multivitamins and their role in immune functions. The stress of training has been investigated for its role in suppressing the immune system (Bishop, Blannin, Walsh, Robson, & Gleeson, 1999). Additionally, the risk for nutritional deficiencies could potentially exacerbate the adverse effects of training on the immune system of combat sports athletes. Particularly during a weight cut, combat sports athletes reduce carbohydrate intake to the point of micronutrient deficiency (Langan-Evans et al., 2011). While research has identified that healthy adults practicing diets focused on macronutrient intake can consume adequate levels of micronutrients (Gardner et al., 2010), it remains to be determined if combat sports athletes regularly consume micronutrients at levels that would or would not warrant the use of multivitamins.

In order to increase eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) intake, many combat sports athletes supplement their diets with fish oils during a weight cut. These fatty acids are claimed to reduce inflammation and boost immune function (Buckley & Howe, 2009; Ramel, Martinez, Bandarra, & Thorsdottir, 2010). Simopoulos (2007) suggested that many athletes should aim to consume EPA and DHA at a ratio 2:1, respectively, with consumption of 1 to 2 g/d of the fatty acids. This is much different from the standard ratio of today's Western diets which contain EPA and DHA at ratios between 10:1 and 20:1, which may limit the body's ability to reduce inflammation during and after high-intensity activity (Simopoulos, 2007). A recent study observed that EPA and DHA were effective in decreasing indicators of inflammation; however, these effects were not significant after 60 minutes of moderate exercise (Bloomer, Larson, Fisher-Wellman, Galpin, & Schilling, 2009). Bloomer *et al.* (2009) found that exercise-trained men experienced minimal inflammation and oxidative stress responses to hour-long bouts of exercise, regardless of EPA/DHA supplementation.

Another supplement that is often used by combat sports athletes is the flavonoid quercetin. It is claimed to provide antiviral immune support, attractive to athletes looking to avoid upper respiratory tract infections (URTIs) (Langan-Evans et al., 2011). The effectiveness of quercetin in reducing URTI incidence has been observed in a double-blind randomized trial involving 40 trained cyclists (Nielman et al., 2007). There is additional evidence suggesting that quercetin supplementation may be effective in reducing the stress of exercise on the immune system, reducing the risk for URTI (Davis, Murphy, McClellan, Carmichael, & Gangemi, 2008). While the body of knowledge regarding quercetin supplementation is still growing, immune benefits appear to be present when supplementation is 1 gram daily.

Other supplements offer potential benefits to combat sports athletes looking to make a weight cut; however, there is a large variation in the quality and validity of current evidence regarding each supplement. The most promising of these supplements is bovine colostrum, the first milk from a cow. Bovine colostrum has been associated with improved biomarkers of immune health and lower incidence of URTI (Crooks, Wall, Cross, & Rutherfurd-Markwich, 2006; Davison & Diment, 2010). There are conflicting reports regarding the benefits of Echinacea supplementation. The herbal supplement has some scientific merit; however, more recent studies do not corroborate with those findings (Hall, Fahlman, & Engels, 2007; Senchina, Hallam, Dias, & Perera, 2009; Szolomicki, Samochoweic, Wojcicki, & Drozdzik, 2000). Supplementation of the amino acid glutamine has no observed benefits or risks in human trials; however, it is commonly consumed by combat sports athletes under the assumption that supplementation will aid in muscle recovery (Gleeson, 2008; Langan-Evans, 2011). Manuka honey possesses a high level of antibacterial activity, but research has yet to identify if it has any role in reducing the incidence of URTI (Badet & Quero, 2011). Athletes are likely testing other supplements in the search of a competitive edge, particularly during the weight cutting process.

Gaps in Knowledge

The evidence suggests that athletes in combat sports commonly practice intentional dehydration, limit nutritional intake, and practice questionable supplement usage (Brito et al., 2012; Fleming & Costarelli, 2007; Hoffman & Maresh, 2011; Langan-Evans et al., 2011; Matthews & Nicholas, 2016; Pallares et al., 2016; Franchini et al., 2012; Pettersson & Berg, 2014; Pettersson & Berg, 2014; Reljic et al., 2015; Timpmann et al., 2008). These practices, aimed at achieving RWL, are likely detrimental to performance in competition within physical (Cheuvront et al., 2004; Nielsen et al., 1981) and cognitive domains (Edwards et al., 2007; Wilson & Morley, 2003). The practice of intentional dehydration is particularly risky due to its association with recent hospitalizations and deaths (Carroll, 2018; MMANewPL, 2017) and deaths (Cruz, 2013; Rondina, 2017; Zidan, 2014). Further understanding of the practices of MMA fighters is needed due to the lack of breadth of knowledge regarding their RWL practices. Additionally, this subpopulation of combat sports athletes also possesses the most extreme observed losses in body mass (Coswig et al., 2015; Matthews & Nicholas, 2016). These findings suggest that MMA fighters may be placing themselves at the greatest risk for hospitalization or death. With the risks well-known and publicized, creating changes within the culture of combat sports may be necessary to catalyze revolutionary changes in the practices and administration of combat sports athletes and promotions. Due to its place in the sport, a reasonable approach for researchers is to seek opportunities to clarify which weight-management practices are most strongly associated with health and optimal performance. Despite the popularity of weight-cutting through intentional dehydration and dietary fasting, there is little evidence of how hydration, nutrition, and dietary supplementation impact MMA fighters' physical performance. The sport of MMA combines aspects of most combat sports and may place a unique combination of exercise-induced stresses on the sport's athletes. Due to the gaps in our knowledge regarding MMA athletes, the risks involved in RWL, and the implications of weight-management practices in combat sports, further research is warranted into assessing the role of hydration, nutritional intake, and dietary supplementation in predicting the athletic performance of MMA athletes.

CHAPTER 3

METHODS

Study Design

This research is a cross-sectional study. Nutrition, hydration, body composition, and performance were measured among a sample of MMA fighters at various stages of the week prior to competition. The research methods included participant screening, measurements of height, weight, bone girths, skinfold measurements, punch force, and energy expenditure. Additionally, participants provided food journals, personal supplement usage, RWL strategies utilized, and their perceptions of the RWL process and their performance.

Recruitment and Data Collection Procedures

All participants were amateur or professional MMA fighters recruited from competitions within fight promotion organizations in the southeastern United States. Recruitment and measurement protocols were approved by the University of Mississippi Institutional Review Board. Recruitment occurred via written email invitation [Appendix A] which may have been followed by additional methods of recruitment such as phone calls and emails to accompany the written invitation. Participants were provided informed consent and contact information of the primary investigator prior to participation in the study [Appendix B]. Information gathered through this study such as participants' identities was coded at the conclusion of data collection to provide confidentially. Screening was conducted to ensure participants are 18 years or older. Individuals who did not meet the screening criteria were thanked for their time and invited to participate once they are eligible, if possible. Participants were invited to perform multiple cycles of RWL, if possible. Data collection required a baseline measurement 7-10 days prior to weigh-ins, before the RWL cycle. Endpoint data were collected approximately 24 hours after weigh-ins.

Through recruitment and retention efforts, nine male MMA fighters completed participation and provided their complete, reliable data. Recruitment was affected by several factors including injuries, fight cancellations, failure to submit completed materials at the fault of the participant, rejection of participation, and event cancellation in response to the COVID-19 pandemic. Without any direct incentives, multiple points of contact were skeptical of the benefit they and/or their fighters would receive through participation.

Variables and Measurement

Nutrition

Nutritional data were assessed through the collection of self-reported 7-day food journals. The food journals provided information regarding caloric intake (kcal), carbohydrate intake (g), protein intake (g), fat intake (g), and water intake (fl oz). Diet records were analyzed using the Nutritional Data System for Research (NDSR) (Schakel, 2001; Schakel, Buzzard, & Gebhardt, 1997; Schakel, Sievert, & Buzzard, 1988) which utilizes a validated database suitable for nutrition analysis in research. Dietary intake estimations were corrected for BW. Participants provided lists of dietary supplements used during the study. Prior to analysis, dichotomous variables were created for each supplement reported by participants with responses being coded as “0” for no supplement usage or “1” for supplement usage, respective to each supplement observed across the sample.

A 7-day physical activity log was provided alongside food journals. This information was used to determine physical exertion and caloric needs of training during fight-week. Dietary and activity information was necessary to determine total energy availability (TEA) which was crucial in determining the acute effectiveness of the participants' training diet in meeting fueling needs. Total energy expenditure (TEE) was calculated as the sum of basal metabolic rate (BMR), exercise energy expenditure (EEE), and thermic effect of food (TEF). The Cunningham equation, as seen in (1), was used to assess BMR due to its accuracy and the availability of information regarding lean body mass (Thompson & Manore, 1996; Fink, Burgoon, & Milesky, 2006). The TEF of participants was calculated using the generalized approach of estimating TEF as 10% of caloric intake (Reed & Hill, 1996). Additionally, EEE was assessed using metabolic equivalent (MET) estimations for caloric expenditure during activity, as seen in (2). Mynarski, Krolikowka, Rozpara, Nawrocka, & Puciato (2013) estimated MET values for various martial arts-related activities including aikido, capoeira, jujutsu, karate, kickboxing, and MMA. For each activity, EEE was calculated and added to reflect a daily total for EEE which was used to accurately estimate TEE.

Total energy availability was defined during three distinct timeframes: Pre-RWL, RWL, and Refeeding. The length of each timeframe varied between subjects. The "RWL" dietary timeframe was defined as the time between the last full meal during the Pre-RWL timeframe and the time of weigh-ins. From the "RWL" timeframe, the dichotomous variable *Short Fast* was created and scored as a "1" for fasting periods of less than 24 hours and scored as "0" otherwise. Therefore, "Pre-RWL" referred to the timeframe of measured dietary intake prior to dietary restriction, and "Refeeding" referred to the timeframe of measured dietary intake after weigh-ins and up to the time of competition. From TEA, calculated as the difference in caloric intake and TEE (the sum of BMR, EEE, and TEF) during three distinct timeframes, the dichotomous variable *Acute Low Energy Availability* (ALEA) was created. For positive values of TEA, ALEA was coded as “0”, and for negative values of TEA, ALEA was coded as “1”. ALEA, being only an acute assessment of energy availability, is not a valid assessment of risk for RED-S among this population. Therefore, conclusions of the prevalence and/or the relative risk for RED-S were not drawn during this study. Comparisons were conducted analyzing the difference in the consumption of carbohydrates, protein, and fat, each represented as grams per kilogram of body mass.

$$BMR=500+22\times FFM(kg) \tag{1}$$

$$EEE/min=0.0175\times MET\times BW(kg) \tag{2}$$

Hydration Status

Hydration status was determined using urine specific gravity. There are several methods for measuring urine specific gravity. Refractometry has been shown to be more consistent and reliable than alternative methods of measuring urine specific gravity (Minton, O’Neal, & Torres-McGehee, 2015; Stuempfle & Drury, 2003). Minton *et al.* (2015) showed that either manual or digital refractometry is appropriate for measuring urine specific gravity; hence, this study utilized a digital refractometer to obtain accurate data in a timely manner. Hydration status was defined as euhydration or dehydration. The dichotomous variable *Dehydration* was scored as “1” if the subject’s USG is greater than 1.020 and scored as “0” otherwise. This definition of dehydration using urine specific gravity was made in accordance with NCAA standards for determining hydration status among collegiate wrestlers (National Collegiate Athletic Association, 2017). Additional information regarding intentional dehydration strategies such as sauna-suit use, diuretics use, and sauna use were collected with dietary data in the 7-day food journals. These data were used to score the dichotomous variable *Intentional Dehydration Strategies* as “1” if the participant indicated using any intentional dehydration strategy and “0” otherwise.

Kinanthropometrics

The participants’ height and weight were assessed at baseline. Bone girths and skinfold measurements were taken prior to RWL cycle. Skinfold measurements were taken again on the day of competition. All girth and skinfold measurements were taken by a Level-1 certified International Society for the Advancement of Kinanthropometry (ISAK) anthropometrist following ISAK protocol **[Appendix C]**. ISAK methods were utilized to provide essential consistency and validity to the measurement of skinfolds (Hume & Marfell-Jones, 2008). In addition to skinfold measurements, ISAK body composition analysis provided information on height, weight, as well as muscle and bone mass (MBM). Body fat (BF) was estimated using Civar’s equation, as seen in (3) (Civar, Ozer, Aktop, Tercan, & Ayceman, 2003), due to its validated consistency with dual-energy x-ray absorptiometry analyses of athletic populations (Lopez-Taylor et al., 2018). By comparing baseline and endpoint values for BW, BF%, and MBM%, new variables were calculated to reflect the changes in these values as a percentage. The body composition variables that will be relevant to statistical tests are ΔBW, ΔBF, and ΔMBM. Additionally, dichotomous variables *BF Increase* and *MBM Increase* were scored as “1” to reflect increases in body fat percentage and/or muscle and bone mass percentage, respectively, and scored as “0” otherwise.

$$BF\% = (0.432 \times \text{triceps}) + (0.193 \times \text{abdomen}) + (0.364 \times \text{biceps}) + (0.077 \times \text{BW}) - 0.891 \quad (3)$$

Performance

This study analyzed performance in terms of punching velocity. Punching velocity was measured using Everlast's PIQ Blue System, a wearable technology that utilizes two 3-axis accelerometers and a 3-axis gyroscope to assess the movement and performance of fighters during training. Data collected by the PIQ sensors was transmitted to an accompanying mobile app in real-time. PIQ sensors were worn by fighters, on their gloves, during training sessions. Punching velocity was assessed at baseline and endpoint. These figures were used to calculate the absolute change in peak velocity associated with RWL and refeeding. This data was reflected in the variable ΔVelocity. The dichotomous variable *Improved Punching Velocity* was scored as "1" for positive values of ΔVelocity and scored as "0" otherwise. Competition results were also analyzed as a measure of performance, being coded as "1" for a win and "0" otherwise. Responses to the question, "How would you rate your performance in the fight?" were used to score the variable *Self-Rated Performance*. This variable was utilized in analyses as a categorical dependent variable reflecting self-rated performance on a 5-point scale (1 = Very Poor to 5 = Very Good).

Demographics and Other Variables

Participants were asked to provide demographic and other general information. This data included: age; race/ethnicity; sex; level of competition; and primary fighting style.

Data Analysis

The IBM SPSS statistical software was used for all statistical analyses. All statistical tests utilized a two-tailed 95% confidence interval or a significance level of α=.05.

To answer the first research question, descriptive statistics such as frequencies, means, and standard deviations were calculated for the relevant variables and measurements TEA, ALEA, short fast, dehydration, intentional dehydration strategies, supplementation, and body composition. Baseline, weigh-in, and endpoint values were calculated for each measure, while body composition was only evaluated at baseline and endpoint.

To answer the second research question and determine the associations between hydration, acute energy availability, and dietary supplementation with changes in body mass and composition among MMA fighters, ANOVAs were conducted using the independent variables TEA, ALEA, short fast, dehydration, intentional dehydration strategies, and supplementation with the dependent variables ΔBW, ΔBF, BF increase, ΔMBM, MBM increase.

Pearson's correlation coefficients were calculated between all factors included in this study. To answer the third research question and determine the relationships between key variables, special attention was paid to Pearson's correlation results regarding the key variables TEA, ALEA, short fast, dehydration, intentional dehydration strategies, supplementation. ΔBW, ΔBF, ΔMBM, BF increase, MBM increase, ΔVelocity, and improved punching velocity.

To answer the fourth research question, t-tests were conducted to observe if differences in the dependent variables *Improved Punching Velocity* and *Self-Rated Performance* were observed across various conditions associated with the nominal independent variables ALEA, short fast, dehydration, intentional dehydration strategies, supplementation, BF increase, and MBM increase. ANOVA was used to determine the associations between the independent variables and the dependent variable ΔVelocity.

Table 1 summarizes definitions and measurements of the variables used in analyses. Table 2 outlines relevant information for analyses such as research questions, alternative hypotheses, and plans for analyses.

Table 1
Variable Definitions and Measurements

Variables	Definition	Coding
Dehydration	The respondent has a USG ≥ 1.020 and is dehydrated, in accordance with NCAA regulations on weight-management among collegiate wrestlers.	0 = Hydrated, USG < 1.020 1 = Dehydrated, USG ≥ 1.020
ALEA	Defined by a negative value for TEA, which is the difference between caloric intake and TEE.	0 = Adequate Energy, TEA ≥ 0 1 = ALEA, TEA < 0
Supplementation	Variables will be created for each supplement observed.	0 = No Supplementation 1 = [Supplement] Use
Short Fast Period	Defined by a fasting period of less than 24 hours.	0 = 24+ Hour Fasting Period 1 = Fasting Period < 24 Hours
ΔBW	Percentage change in body mass for participants between baseline and endpoint.	Percentage change in BW.
ΔBF	Percentage change in body fat for participants between baseline and endpoint.	Percentage change in BF%.
ΔMBM	Percentage change in muscle and bone mass for participants between baseline and endpoint.	Percentage change in MBM%.
ΔVelocity	Absolute change in peak punch velocity for participants between baseline and endpoint.	Change in punching velocity.
Self-Rated Performance	Single self-rated score to the question, "How would you rate your performance in the fight?" Responses range from very poor to very good.	Numerical value of ranging 1-5, with 5 being the highest rating.
Fight Result	Dichotomous coding for the result of MMA competition. Losses, draws, and no-contests will be coded the same.	0 = Loss, Draw, or No-Contest 1 = Win

Table 2

Hypotheses and Statistical Analysis

Research Question	Hypothesis	Analysis
What is the status of MMA fighters pertaining to dehydration, acute energy availability, dietary supplementation, and body composition at different stages of combat preparation?	N/A	Frequencies for dehydration, ALEA, and supplement use M and SD for BW, BF, MBM[a]
What effects do hydration, acute energy availability, dietary supplementation have on changes to weight and body composition during RWL?	Dehydration has a negative effect on changes in weight and body composition during RWL. Energy availability has a positive effect on changes in weight and body composition during RWL. Dietary supplementation has an effect on changes in weight and body composition during RWL.	ANOVAs IVs: dehydration, ALEA, and supplementation DVs: ΔBW, ΔBF, and ΔMBM
Are changes in performance after refeeding correlated with acute body composition changes and hydration status?	Changes in BW, BF%, and FFM% are positively correlated with changes in performance. Dehydration is negatively correlated with changes in performance.	Pearson correlation coefficients Factors: dehydration, ΔBW, ΔBF, ΔMBM, and ΔVelocity
How are hydration, acute energy availability, dietary supplementation, and changes in weight and body composition associated with objective and perceived performance among MMA fighters?	Dehydration is negatively associated with performance. Energy availability is positively associated with performance. Dietary supplementation is associated with performance. Changes in BW, BF%, and FFM% are positively associated with performance.	Independent-samples t-tests for Improved Punching Velocity and Self-Rated Performance ANOVA with DV: ΔVelocity IVs: ALEA, fasting, dehydration, intentional dehydration strategies, supplementation, ΔBW, ΔBF, and ΔMBM

Note. Italicized text used for dependent variables in Analysis column.

[a] BW, BF, & MBM will be presented as baseline and endpoint values. Other variables will have an additional weigh-in value.

CHAPTER 4

RESULTS

Sample Characteristics

The sample for analysis consisted of nine male participants who provided complete participation through a non-simulated trial of RWL and refeeding during a week of competition. Among the sample, six participants (66.7%) were professional athletes, and three (33.3%) were amateur athletes. Participant age ranged between 24 and 35 years (*M*=29.44, *SD*=3.71).

Key Parameters during Rapid Weight Loss and Refeeding

Table 3 presents information regarding the nutritional, hydration, anthropometric, and performance parameters assessed at the three stages of rapid weight loss that were observed in this study. Fasting periods between 19 and 72 hours were observed (*M*=34.80 h, *SD*=19.92). The sample displayed energy deficits during the Pre-RWL, RWL, and fight-week timelines (*M*=-4692.52, *SD*=5540.86). Additionally, a mean USG (*M*=1.024, *SD*=0.006) above the threshold for the diagnosis of dehydration was observed at weigh-ins.

Table 3
Sample Characteristics at Various Stages of Rapid Weight Loss (N=9)

	Mean (SD)		
	Pre-RWL	RWL	Refeeding
Duration of Stage (days)	5.22 (0.79)	1.45 (0.83)	1.13 (0.8)
Total Energy Availability	-3678.59 (4786.80)	-2473.70 (1235.28)	1459.76 (1080.58)
Carb (g)/kg	1.12 (1.03)	0 (0)	5.35 (2.41)
Protein (g)/kg	1.29 (0.66)	0 (0)	1.74 (0.59)
Fat (g)/kg	0.65 (0.37)	0 (0)	1.12 (0.60)
Urine Specific Gravity	1.006 (0.004)	1.024 (0.006)	1.008 (0.008)
Body Mass (lb)	178.81 (20.19)	164.27 (18.49)	175.43 (18.58)
Body Fat %	11.09 (1.85)	--	10.71 (1.81)
Muscle & Bone Mass %	52.81 (2.31)	--	53.21 (2.97)
Peak Punch Velocity (mph)	18.44 (5.99)	--	17.12 (5.29)

Table 4 presents information detailing the frequency of observations of key nutritional, hydration, anthropometric, and performance factors across the three stages of rapid weight loss that were observed in this study. Low energy availability and dehydration were prevalent at various stages of the RWL-refeeding cycle. Nearly every participant (*n*=8, 88.9%) had a negative value for total energy availability within the timeframe of the entire fight week. Despite the prevalence of dehydration among participants at weigh-ins (*n*=8, 88.9%), all but one participant was able to achieve euhydration prior to competition. Caffeine (*n*=4, 44.4%) and cannabidiol (CBD) oil (*n*=3, 33.3%) supplementation was observed. One participant utilized both green tea and apple cider vinegar in pursuit of weight and performance goals. Intentional dehydration practices were commonly utilized among the sample (*n*=5, 55.6%). These practices included sauna (*n*=1, 11.1%) and sauna suits (*n*=3, 33.3%), as well as one participant (11.1%) reportedly achieving significant perspiration through utilizing the heater of his vehicle during the 2-hour commute to the weigh-in location. Almost half of the participants (*n*=4, 44.4%) utilized a shorter fasting period of less than 24 hours. Most participants (*n*=7, 77.8%) successfully met their goal weight to fully qualify for competition.

Table 4
Frequencies for Rapid Weight Loss Parameter among MMA athletes (N=9)

	Frequency	Percentage
Acute Low Energy Availability		
Pre-RWL	8	88.9%
RWL	9	100%
Refeeding	1	11.1%
Fight Week	8	88.9%
Short Fast Period (<24 hours)	4	44.4%
Dehydration		
Baseline	0	0%
Weigh-in	8	88.9%
Endpoint	1	11.1%
Intentional Dehydration Strategy [a]	5	55.6%
Met Weight Goal	7	77.8%
Won Fight	2	22.2%
Improved Punching Velocity [b]	5	55.6%
Self-Rated Performance		
Very Poor	0	0%
Poor	2	22.2%
Average	2	22.2%
Good	3	33.3%
Very Good	2	22.2%

[a] Participants indicated various strategies including sauna and sauna suits, among others.
[b] Indicated by an endpoint peak punching velocity value that was greater than the baseline punching velocity measured.

Effects of Hydration, Nutrition, and Supplementation during RWL

ANOVAs were used in identifying the effects that variables related to nutrition, hydration, and supplementation have on acute changes to body weight, body composition, and punching velocity. These analyses, with the dependent variables ΔBW, ΔBF, and ΔMBM, addressed the second research question. Table 5 presents the results from these analyses, in addition to results from ANOVAs calculated with the dependent variable ΔVelocity. No statistically significant effect was observed. Several *F*-values reflected differences greater than 1% for the dependent variables ΔBW, ΔBF, and ΔMBM. There was no statistically significant effect of ALEA during refeeding on ΔBW, $F(1,7)=4.805$, $p=0.064$. ALEA during refeeding had no statistically significant effect on ΔMBM, $F(1,7)=1.024$, $p=0.345$. The effect of fasting duration (short vs long) on ΔBW was not statistically significant, $F(1,7)=1.896$, $p=0.211$. Dehydration at weigh-ins had an effect on ΔBF that was not statistically significant, $F(1,7)=4.554$, $p=0.070$. Intentional dehydration behaviors had no statistically significant effect on ΔBW, $F(1,7)=1.055$, $p=0.338$, and ΔBF, $F(1,7)=2.391$, $p=0.166$. Caffeine supplementation had no significant effect on ΔBF, $F(1,7)=3.083$, $p=0.123$, or ΔMBM, $F(1,7) = 1.328$, $p = 0.287$. While many of the independent variables expressed near-zero effects on ΔVelocity, *F*-values greater than one were observed for the independent variables Short Fast, $F(1,7)=1.503$, $p=0.260$, and Caffeine Supplementation, $F(1,7)=1.655$, $p=0.239$.

Table 5

One-Way ANOVA for Changes in Body Composition during RWL (N=9)

	df [a]	*F*	*p-value*
ΔBW x Pre-RWL ALEA	1,7	0.218	0.655
ΔBF x Pre-RWL ALEA	1,7	0.013	0.914
ΔMBM x Pre-RWL ALEA	1,7	0.318	0.591
ΔVelocity xPre-RWL ALEA	1,7	0.043	0.842
ΔBW x Refeeding ALEA	1,7	4.805	0.064
ΔBF x Refeeding ALEA	1,7	0.219	0.654
ΔMBM x Refeeding ALEA	1,7	1.024	0.345
ΔVelocity x Refeeding ALEA	1,7	0.000	0.987
ΔBW x Short Fast	1,7	1.896	0.211
ΔBF x Short Fast	1,7	0.043	0.841
ΔMBM x Short Fast	1,7	0.900	0.374
ΔVelocity x Short Fast	1,7	1.503	0.260
ΔBW x Weigh-in Dehydration	1,7	0.541	0.486
ΔBF x Weigh-in Dehydration	1,7	4.554	0.070
ΔMBM x Weigh-in Dehydration	1,7	0.598	0.464
ΔVelocity x Weigh-in Dehydration	1,7	0.003	0.961
ΔBW x Endpoint Dehydration	1,7	0.398	0.548
ΔBF x Endpoint Dehydration	1,7	0.082	0.782
ΔMBM x Endpoint Dehydration	1,7	0.032	0.864
ΔVelocity x Endpoint Dehydration	1,7	0.000	0.987
ΔBW x Intentional Dehydration Strategies	1,7	1.055	0.338
ΔBF x Intentional Dehydration Strategies	1,7	2.391	0.166
ΔMBM x Intentional Dehydration Strategies	1,7	0.381	0.556
ΔVelocity x Intentional Dehydration Strategies	1,7	0.632	0.453
ΔBW x Caffeine	1,7	0.323	0.588
ΔBF x Caffeine	1,7	3.083	0.123
ΔMBM x Caffeine	1,7	1.328	0.287
ΔVelocity x Caffeine	1,7	1.655	0.239

Note: Some variables excluded due to violations to the assumption of homogeneity of variance.
[a] Degrees of freedom represented as “between-groups,within-groups”

Pearson Correlation Coefficients: Nutrition, Hydration, Body Composition, and Performance Parameters

To answer the third research question, Pearson's correlation coefficients were estimated for the parameters related to changes in body composition, hydration, and changes in peak punching velocity. Table 6 presents these results for key parameters as well as additional Pearson's correlation coefficients for other factors included in the study. With no statistically significant effect sizes observed in ANOVA analyses, this approach was taken to provide a more-comprehensive analysis of the observations made among this sample of MMA fighters. The dependent variables in the scope of these Pearson's correlation analyses were ΔVelocity, Improved Punching Velocity, Self-Rated Performance, and Fight Result.

Acute low energy availability, for each stage of the study, did not express statistically significant Pearson's correlation coefficients for any of the dependent variables. Total energy availability during the RWL stage of the study had a statistically significant positive correlation coefficient with ΔVelocity (r=0.688, p<.05). The duration of fasting, in hours, had a statistically significant negative correlation with ΔVelocity (r=-0.763, p<.05) and improved punching velocity

(r=-0.680, p<.05). Fasting periods of less than 24 hours were positively correlated with improved punching velocity (r=0.800, p<.01). Improved punching velocity was positively correlated with protein consumption during the Refeeding stage (r=0.669, p<.05). Endpoint USG was negatively correlated with self-rated performance (r=-0.678, p<.05). Dehydration status and intentional dehydration strategies had no statistically significant correlations with the performance parameters in this study. ΔMBM had a statistically significant positive correlation with ΔVelocity (r=0.698, p<.05). Increased body fat percentage had a significant negative correlation with ΔVelocity (r=-0.951, p<.001). Fight result was negatively correlated with fat consumption during the refeeding timeframe (r=-0.689, p<.05).

Age was negatively correlated with weigh-in USG (r=-0.691, p<.05) and positively correlated with endpoint USG (r=0.677, p<.05). Changes in body fat percentage, from baseline to endpoint, were negatively correlated with changes in muscle-and-bone mass across the same time-frame (r=-0.709, p<.05). There was a significant positive correlation between self-rated performance and improved punching velocity (r=0.676, p<.05).

Table 6

***Pearson's r: Nutrition, Hydration, Body Composition, Supplementation, & Performance* (*N*=9)**

	Pearson's *r*			
	ΔVelocity	Improved Velocity	Self-Rated Performance	Fight Result
Acute Low Energy Availability [a]				
Pre-RWL	-0.078	-0.316	0.184	0.189
Refeeding	0.006	-0.395	0.147	0.661
Total Energy Availability				
Pre-RWL	-0.074	0.174	-0.286	-0.469
RWL	0.688*	0.652	0.361	-0.292
Refeeding	0.165	0.414	-0.303	-0.487
Fasting				
Duration in hours	-0.763*	-0.680*	-0.378	0.263
Fasting < 24 hours	0.420	0.800**	0.583	0.060
Carbohydrates g/kg of Body Mass				
Pre-RWL	0.393	0.456	0.107	0.097
Refeeding	0.262	0.543	0.010	-0.070
Fat g/kg of Body Mass				
Pre-RWL	0.503	0.636	0.203	-0.378
Refeeding	0.202	0.160	-0.452	-0.689*
Protein g/kg of Body Mass				
Pre-RWL	0.251	0.446	-0.150	-0.161
Refeeding	0.467	0.669*	0.199	-0.605
Supplement Use				
Caffeine	-0.437	-0.100	-0.676*	-0.478
CBD Oil	-0.595	-0.316	-0.590	-0.378

Urine Specific Gravity				
Baseline	-0.069	-0.034	0.159	0.180
Weigh-in	-0.196	0.243	0.230	0.130
Endpoint	0.032	-0.352	-0.678*	-0.409
Dehydration [a]				
Weigh-in	0.019	0.395	0.184	0.189
Endpoint	0.006	-0.395	-0.516	-0.409
Intentional Dehydration Strategies	-0.288	0.100	-0.163	-0.060
Body Composition				
ΔBW	-0.235	0.463	0.193	-0.454
ΔBF	-0.623	-0.047	-0.380	-0.023
ΔMBM	0.698*	0.144	0.455	0.546
BW Increase	-0.434	0.158	0.074	-0.378
BF Increase	-0.951***	-0.395	-0.516	-0.189
MBM Increase	0.497	0.060	0.279	0.289
BW% Reduced Making Weight	0.178	-0.029	0.030	0.438

[a] Pearson's *r*-values could not be computed due to constant values in at least one variable.
*Significant at the 0.05 level (2-tailed)
**Significant at the 0.01 level (2-tailed)
***Significant at the 0.001 level (2-tailed)

Independent-Samples T-Tests of Performance

Independent-samples t-tests were conducted to compare performance outcome parameters to conditions related to acute energy availability, fasting, hydration status, intentional dehydration strategies, supplementation, and acute changes in body composition.

Table 7 presents findings from independent-samples t-tests with the independent variables reflecting the conditions ALEA, short fast, dehydration, supplementation, BF increase, and MBM increase. The dependent variable in these analyses was the dichotomous variable improved punching velocity. There was a significant difference in improvements to punching velocity for short fasting (M=1.000, SD=0.000) and long fasting (M=0.200, SD=0.447) conditions $t(7)$=-3.528, p=0.010. There were no other statistically significant findings to report from these analyses.

Table 7
Independent-Samples T-tests for Improved Punching Velocity (N=9)

	M	*SD*	*df*	*t-statistic*	*p-value*
Pre-RWL ALEA			7	0.882	0.407
No	1.000	0.000			
Yes	0.500	0.535			
Post-RWL ALEA			7	1.139	0.292
No	0.625	0.518			
Yes	0.000	0.000			
Short Fast			7	-3.528	0.010*
Long Fast	0.200	0.447			
Short Fast	1.000	0.000			
Caffeine Use			7	0.266	0.798
No	0.600	0.548			
Yes	0.500	0.577			
CBD Oil Use			7	0.882	0.407
No	0.667	0.516			
Yes	0.333	0.577			
Weigh-in Hydration			7	-1.139	0.292
Dehydration	0.625	0.518			
Euhydration	0.000	0.000			
Endpoint Hydration			7	1.139	0.292
Dehydration	0.000	0.000			
Euhydration	0.625	0.518			
Dehydration Strategies			7	-0.266	0.798
Did not use	0.500	0.577			
Used	0.600	0.548			
BF Increase			7	1.139	0.292
No	0.625	0.518			
Yes	0.000	0.000			
MBM Increase			7	-0.158	0.879
No	0.500	0.707			
Yes	0.571	0.535			

Note: Some IVs were not included because of constant values.
*Significant at the 0.05 level (2-tailed)

Table 8 presents findings from the independent-samples t-tests with the dependent variable self-rated performance There was a significant difference in self-rated performance for caffeine abstention (M=4.200, SD=0.837) and caffeine supplementation (M=2.750, SD=0.957) conditions $t(7)$=2.428, p=0.046. There were no other statistically significant findings to report from these analyses.

Table 8
Independent-Samples T-tests for Self-Rated Performance (N=9)

	M	*SD*	*df*	*t-statistic*	*p-value*
Pre-RWL ALEA			7	-0.496	0.635
No	3.000	0.000			
Yes	3.630	1.188			
Post-RWL ALEA			7	-0.394	0.705
No	3.500	1.195			
Yes	4.000	0.000			
Fasting			7	-1.898	0.100
24+ hours	3.000	1.000			
< 24 hours	4.250	0.957			
Caffeine Use			7	2.428	0.046*
No	4.200	0.837			
Yes	2.750	0.957			
CBD Oil Use			7	1.932	0.095
No	4.000	1.095			
Yes	2.670	0.577			
Weigh-in Hydration			7	-0.496	0.635
Dehydration	3.630	1.188			
Euhydration	3.000	0.000			
Endpoint Hydration			7	1.594	0.155
Dehydration	2.000	0.000			
Euhydration	3.750	1.035			
Dehydration Strategies			7	0.438	0.675
Did not use	3.750	0.500			
Used	3.400	1.517			
BF Increase			7	1.594	0.155
No	3.750	1.035			
Yes	2.000	0.000			
MBM Increase			7	-0.768	0.468
No	3.000	1.414			
Yes	3.71	1.113			

Note: Some IVs were not included because of constant values.
*Significant at the 0.05 level (2-tailed)

CHAPTER 5

DISCUSSION

Discussion of Findings

The present study utilized a multi-faceted approach to explore how hydration, nutrition, dietary supplementation, and body composition are associated with athletic performance among MMA athletes practicing rapid weight loss. The data and analyses provided insights into the nutritional strategies, hydration status, acute body composition changes, punching velocity changes, and self-perceived quality of performance of MMA fighters practicing a non-simulated period of rapid weight loss and refeeding during a week of competition. The participants in this study were generally successful at achieving their desired weight loss through RWL (*n*=7, 77.8%).

The observed nutritional, hydration, and supplementation strategies associated with RWL among this sample were consistent with previous findings among various subgroups of combat sports athletes (Brito et al., 2012; Fleming &

Costarelli, 2007; Hoffman & Maresh, 2011; Langan-Evans et al., 2011; Matthews & Nicholas, 2016; Pallares et al., 2016; Franchini et al., 2012; Pettersson & Berg, 2014; Pettersson & Berg, 2014; Reljic et al., 2015; Timpmann et al., 2008). Although intentional dehydration had been associated with hospitalizations (Carroll, 2018; MMANewPL, 2017) and deaths (Cruz, 2013; Rondina, 2017; Zidan, 2014), the athletes in this study universally dehydrated intentionally, to some extent. The prevalence of dehydration at weigh-ins was 88.9%. However, most (n=8) participants were able to achieve euhydration prior to competition.

Potentially compounding the risks associated with dehydration, all but one participant (n=8, 88.9%) failed to meet their dietary energy needs for the week of competition. This was primarily correlated with caloric deficiency during the Pre-RWL timeframe (r=0.938, p<.001), suggesting that the nutritional practices of MMA athletes prior to fasting present the most significant risk for acute low energy availability during the week of competition. Nutritional fasting was practiced by all participants.

This study utilized a novel approach, relating the RWL-refeeding practice to a quantitative marker of performance, punching velocity, specifically looking for the determinants of performance improvement prior to competition. However, acute low energy availability, for each stage of the study, did not express statistically significant Pearson's correlation coefficients or *t*-statistics for any of the dependent variables. Total energy availability during the RWL stage of the study had a statistically significant positive correlation coefficient with ΔVelocity (r=0.688, p<.05). There was a significant difference in improvements to punching velocity for short fasting (M=1.000, SD=0.000) and long fasting (M=0.200, SD=0.447) conditions $t(7)$=-3.528, p=0.010. Additionally, a statistically significant positive Pearson's correlation coefficient was observed between short fasting periods and improved punching velocity (r=.800, p<.01). Among the sample, only one participant experienced improved punching velocity after an extended fast of 26 hours.

One of the main components of the RWL-refeeding process is rehydration during the time between weigh-ins and competition. Most participants in the sample (n=8, 88.9%) were successful in achieving euhydration during this timeframe. However, there was a significant correlation between endpoint urine specific gravity and self-rated performance, suggesting that subclinical dehydration may affect performance in discrete ways beyond the scope of this study. Interestingly, the age of fighters was negatively correlated with weigh-in

USG (r=-0.691, p<.05) and positively correlated with endpoint USG (r=0.677, p<.05). This suggests that athletes' ability to dehydrate and rehydrate may be influenced by age, resulting in increased difficulty to achieve optimal hydration among older athletes. These findings suggest that fighters of advanced age and coaches working with older fighters may benefit from pursuing competition in weight-classes that are closer to the baseline weight of fighters, relying less on intentional dehydration to meet RWL goals. This observation contradicts observed behaviors among mixed martial arts athletes who attempt to lose more weight with each performance (Park, 2019).

Changes in muscle-and-bone mass during the RWL-refeeding cycle were positively correlated with absolute changes in punching velocity (r=0.698, p<.05). This is a novel observation among combat sports athletes. The observed changes in muscle-and-bone mass were negatively correlated with changes in body fat percentage (r=-0.709, p<.05), suggesting that substrate-level metabolic changes during RWL may significantly impact body composition, resulting in a preference for protein catabolism over lipolysis to fuel gluconeogenesis. Due to an observed correlation between changes in muscle-and-bone mass and changes in punching velocity, prioritizing the preservation of lean mass during RWL should be a priority for fighters and coaches in combat sports.

Relationships between fasting, body composition, and punching velocity were observed in this study. There was a positive correlation between changes in muscle-and-bone lean mass and changes in punching velocity. In addition to this, the current study is the first known research to observe a relationship between fasting periods and changes in punching velocity among combat sports athletes. Specifically, fasting periods of less than 24 hours correlated with improved punching velocity after rapid weight loss and refeeding. This represents a significant finding for athletes and coaches participating in combat sports. More research is required, however, to identify the specific mechanisms involved in performance improvements achieved through RWL. Training load, recovery, technical skill-level, and fasting-adaptation were not parameters included in this study, but they may play a significant role in changes during the RWL-refeeding cycle.

Technical skills and physiological abilities and adaptations may not be the only predictive parameters for success in mixed-martial arts. Participants provided a self-rated evaluation of the quality of their performance. Only caffeine consumption had a statistically significant Pearson's correlation coefficient with self-rated performance (r=-0.676, p<.05). This is a novel observation relating consumption of caffeine, popular among combat sports athletes (Langan-Evans et al., 2011; Santos et al., 2014), to self-ratings of performance in MMA competitions. The negative direction of this correlation may coincide with caffeine-withdrawal symptoms such as anxiety, dependency and withdrawal that have been observed by other studies (Burke, 2008; Jenkinson & Harbert, 2008; Tunnicliffe et al., 2008). Self-rated performance was positively correlated with improved punching velocity (r=0.676, p<.05). However, self-rated performance did not have a statistically significant correlation with fight result, suggesting that the athletes in the sample utilized a complex self-evaluation process that was beyond the scope of this study. Connecting objective physical outcomes to a subjective self-evaluation is difficult to explain given the scope of the present study. Previous research regarding the psychology of the sport may help build a bridge into understanding this finding. Slimani, Miarka, Briki, & Cheour (2015) observed a strong association between mental toughness and performance in power tests among elite kickboxers. A component of mental toughness is confidence, a focus of psychological research in the area of MMA research

(Harpold, 2008; Milton, 2004; Slimani et al., 2015). Jensen, Roman, Shaft, & Wrisberg (2013) identified major themes related to the experience of competing in a mixed martial arts competition. Their research found a sense of community, an emphasis on fighting skills, and a purposeful commitment to the competition despite anxieties and fear of failure. Additionally, participants in this study ubiquitously described a “cage reality” that revealed the mental ups and downs of being in a mixed martial arts competition. One component of the cage reality discussed by each participant was the physical aspects of not only the fight, but of the demanding RWL-refeeding process. With observed correlations between power output and mental toughness in this population (Slimani et al., 2015), the psychological theme “cage reality” (Jensen et al., 2013) may explain how the sample of MMA fighters in the present study self-rated their performance in conjunction with their punching velocity following a RWL-refeeding cycle, regardless of the result of the competition. An expanded study investigating this physio-psychological complex among a large sample of MMA fighters would provide an opportunity for a more-robust understanding of the determinants of athletic performance and success among this population.

One participant, Subject 9, required hospitalization following competition. Subject 9 suffered a defeat during competition due to a fracture of the right femur and the subsequent ruling of a technical knockout in favor of his opponent. A 27-year old male, professional MMA fighter, Subject 9 reduced his body mass by a relatively mild amount (13.5 lb, 6.79%). Subject 9 successfully achieved euhydration prior to competition. However, he experienced negative changes in body composition with an increase in body fat percentage (+0.67%) and a decrease in muscle-and-bone mass (-2.26%). These figures represented the most extreme observations among the sample of MMA fighters who participated in the study. These negative body composition outcomes were concurrent with a reduction in peak punching velocity (-19.9 mph) following a 72-hour fasting period and refeeding. These were consequences of the RWL-refeeding cycle, despite failing to meet the proposed 10% weight-loss criteria for LEA (De Souza et al., 2014).

Subject 2, a 24-year old male, amateur MMA fighter directly contradicted the experiences of Subject 9. Subject 2 was the only other participant who fasted for 60+ hours, with a total of 67 fasted hours. This participant reduced his body mass 22.90 lb (11.87%), resulting in relatively modest changes to body-fat percentage (-0.63%) and bone-and-muscle lean mass (+1.58%). Subject 2 experienced reduced peak punching velocity (-1.2 mph) after successfully achieving euhydration prior to competition, winning his fight by knocking out his opponent in the first round of his fight. The observations of Subjects 2 and 9 in this study highlight challenges for future research. Despite a comparatively, very-long fasting period, Subject 2 experienced an increase in muscle-and-bone mass, contradicting previous observations among adult males (Fryburg et al., 1990; Nair et al., 1987; Pozefsky et al., 1976). With consideration of Subject 9, the findings of this study suggest our understanding of low energy availability and performance predictors is undeveloped. Low energy availability and relative energy deficiency in sport are deserving of extensive attention from future research.

Interestingly, this study observed a statistically significant positive correlation between fighter age and endpoint USG, suggesting that older fighters may experience some difficulty rehydrating after intentional dehydration for RWL. A negative correlation between changes in body fat percentage and muscle-and-bone mass percentage was indicative of substrate-level metabolic changes related to the scarcity of fuel involved in RWL, with some fighters experiencing a loss of muscle mass as a result.

After weigh-ins and refeeding, the researchers assessed peak punching velocity to obtain a comparative measure. Other performance parameters included fight result and self-rated performance. Of the predictor variables, only endpoint USG was correlated with self-rated performance. This study found no relationships between variables and fight result, suggesting that predicting the results of MMA competition may be complex and beyond the scope of this study protocol.

Limitations

Recognizing the limitations of the present study is important when highlighting its implications for practice and future research. Analyzing the independent role of each predictor variable for the dependent variables punching velocity, fight result, and self-rated performance was difficult due to the small sample size. Utilizing Chi-square analyses was not most appropriate, given the distribution of subjects within the cross-tabulations. However, by providing *LRT* and Cramer's *V* calculations, the present study utilized an alternative test that was appropriate for describing the effects and answering the research questions while also describing the statistical strength and significance of the correlations observed. A larger sample have would allowed for the use of regression analyses to measure the independent associations between predictors and outcomes related to rapid weight loss in combat sports. The present study did not include parameters related to training load and subsequent recovery, technical skill-level, fasting-adaptions, or specific dietary approaches that may yield benefits to fighters practicing RWL. A larger sample with more-comprehensive parameters would have provided more valid estimations of the effects diet, hydration, training, and body composition have on performance markers among combat sports athletes. However, the present study provides novel insights into relationships between nutrition, fasting, hydration, body composition, and athletic performance among a sample of MMA fighters going through a natural, non-simulated, cycle of rapid weight loss and refeeding prior to competition.

Conclusion

This study observed a sample of MMA fighters reducing body mass by 5-12% during a six-day time period in order to meet the weight requirements for competition. Only one participant did not display a USG in the abnormal range at the time of weigh-ins, suggesting that MMA fighters deny their bodies fluids to a point of clinical dehydration. Each participant in this study utilized fasting to reduce body mass. While almost all participants fasted for periods between 19 and 27 hours, two MMA fighters in the sample utilized very long fasting periods of greater than 60 hours. There may be between-group differences in the impact of fasting on performance due to metabolic adaptations to longer adaptations. Chi-square analysis revealed a statistically significant relationship between fasting periods of less than 24 hours and improved punching velocity. These findings have significant implications for combat sports athletes and coaches seeking competitive advantages through the utilization of RWL. However, larger studies would be required to describe the association between dietary behaviors, hydration, and fasting as they relate to athletic performance. After qualifying for competition in their respective weight-class, combat sports athletes “refeed” in an attempt to refill glycogen stores and achieve euhydration prior to competition, a timeframe of 26-30 hours for the participants in this study. Most participants in the sample achieved euhydration after refeeding. While larger future studies with more robust measuring protocols are required to identify definitive predictors of performance, beyond punching velocity, this study utilized a novel approach and observed significant relationships with practical implications for athletes and coaches in combat sports. Specifically, these findings suggest athletes and coaches in combat sports may be able to utilize RWL-refeeding cycles to improve athletic performance after significant RWL of 5-12% body mass.

Future studies should aim to recruit larger samples of fighters from various disciplines of combat sports to address the wide array of factors associated with athletic performance. Despite the findings of the present study suggesting improvements to athletic performance can be achieved after RWL-refeeding cycles, research has yet to place scrutiny on the implications of RWL-refeeding cycles on athlete health, particularly acute cardiac changes. Further evaluation of the safety of this practice is required, but the findings from this study suggest that shorter fasting periods, less than 24 hours, may yield substrate-level metabolic benefits as well as improvements to athletic performance markers when compared to fighters who utilize fasting periods greater than 24 hours.

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LIST OF APPENDICES

APPENDIX A: INVITATION TO PARTICIPATE

Dear [Gym/Owner Name]

I'm hopeful that your fight promotion can contribute to my dissertation research at the University of Mississippi. I am Katie Halfacre-Cunningham, and I am a PhD student in the Department of Nutrition and Hospitality Management. I'm a lifelong fan of martial arts and have developed an exciting study design to observe the impact of nutrition and hydration on the performance of fighters as they go through the fight-week weight cut. It is a non-invasive study, and I'd be happy to share more information regarding the study design if you are interested.

Primarily, I need access to fighters to conduct my research. I was hoping that, with your assistance, I could reach out to fighters competing in your promotion to request their participation in this study. Your assistance in getting in touch with fighters would be greatly appreciated. You can reach me via email at this address (klhalfac@go.olemiss.edu) and phone (662-705-1292). If you try to give me a call, I may be in class or giving a lecture, but I will get back to you ASAP. I look forward to hearing from you soon.

APPENDIX B: INFORMED CONSENT

Consent to Participate in Research

Making the Cut: Nutrition and Hydration Practices among MMA Fighters

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Key Information for You to Consider
• **Purpose**. The purpose of this research is to determine how changes in hydration, dietary intake, supplement usage, and body composition are associated with athletic performance after rapid weight loss and refeeding among MMA fighters. • **Duration.** It is expected that your participation will last a week. You will participate in two one-hour sessions, the first being 7-10 days prior to competition and the second being on the day of competition. You will need to provide a urine sample prior to weigh-ins. Your total participation will require about 2 hours and 5 minutes over the course of the fight week. • **Activities.** You will be asked to do the following: have your body composition analyzed twice; provide three (3) urine samples; use wearable technology to perform punches and jumps on two (2) occasions; and provide a food/supplement journal during or after your week of preparation for competition. • **Why you might not want to participate.** Some of the foreseeable risks or discomforts of your participation include the assessment of body composition which requires pinching of the skinfolds which is mildly painful.

- **Why you might want to participate.** Some of the benefits that may be expected include knowledge of your body composition and athletic performance. You may gain insight into your nutrition, hydration, and weight-loss practices during a weight cut. You will be contributing to the scientific knowledge regarding weight-cutting in MMA fighters.

You are being asked to volunteer for a research study. It is up to you whether you choose to participate or not. There will be no penalty or loss of benefits to which you are otherwise entitled if you choose not to participate or discontinue participation.

Combat sports competitions such as mixed martial arts (MMA) are often separated into weight divisions. These weight-classes motivate fighters to gain a competitive edge through rapid weight loss (RWL). This practice has been linked to hospitalizations and deaths. Research into the health and performance implications is warranted. The goal of this study is to determine how changes in hydration, dietary intake, supplement usage, and body composition are associated with athletic performance after RWL and refeeding among elite MMA fighters.

☐ By checking this box I certify that I am 18 years of age or older.

What you will do for this study

This study is a non-invasive measurement of various functions of your body, with the intention of gaining a better scientific understanding of the fight-week weight cut among MMA fighters. You will have your height, weight, skinfolds, and bone girths measured by a certified anthropometrist. This will be done 7-10 days prior to competition and on the day of competition. You will provide urine samples 7-10 days prior to competition, on weigh-in day, and after refeeding (on the day of competition). You will be asked to briefly wear a devise to assess your punch force 7-10 days prior to competition and on the day of competition. You will be asked to perform a counter-movement vertical jump to assess the force generated by your lower body. During the week after competition, you will be asked to provide a food journal and respond to a 10-question survey. The survey will assess your feelings about the fight-week weight cut you underwent, your performance, and other attitudes regarding the weight-cut process. In the food journal, in addition to providing information regarding your dietary intake, you will be asked to describe the weight-cutting strategies (sauna, sauna suit, diuretics) and supplements that you used during the fight-week weight cut.

Time required for this study

Day 1 will take about 1 hour. Weigh-in day will only require about 5 minutes. Participation after refeeding will take about 1 hour. Total time required should be 2 hours and 5 minutes.

Possible risks from your participation

No significant risks but the pinching of skinfolds is mildly painful.

Benefits from your participation

You should not expect any direct benefits from participating. However, you will be contributing to scientific knowledge about weight cutting in your sport. You may also gain insight into your athletic performance (punch force and lower body force) and attitudes regarding weight cuts.

Confidentiality

Research team members will have access to your records. Your confidentiality will be protected by coding and separating the information that identifies you from your responses. Members of the Institutional Review Board (IRB) – the committee responsible for reviewing the ethics of, approving, and monitoring all research with humans – have authority to access all records. However, the IRB will request identifiers only when necessary. We will not release identifiable results of the study to anyone else without your written consent unless required by law.

Right to Withdraw

You do not have to volunteer for this study, and there is no penalty if you refuse. If you start the study and decide you do not want to finish, or you would like to opt out of one part of the study, then just tell the experimenter. Your decision to participate or abstain from participation will not affect your current or future relationship with the Department of Nutrition and Hospitality Management, or with the University of Mississippi, and it will not cause you to lose any benefits to which you are entitled.

Collection of Identifiable Private Information or Identifiable Biospecimens

Identifiers might be removed from your identifiable private information and your identifiable biospecimens (urine samples) such that your information and biospecimens collected as a part of this research will not be used or distributed for future research studies.

IRB Approval

This study has been reviewed by The University of Mississippi's Institutional Review Board (IRB). The IRB has determined that this study fulfills the human research subject protections obligations required by state and federal law and University policies. If you have any questions or concerns regarding your rights as a research participant, please contact the IRB at (662) 915-7482 or irb@olemiss.edu.

Please ask the researcher if there is anything that is not clear or if you need more information. When all your questions have been answered, then decide if you want to be in the study or not.

Statement of Consent

I have read the above information. I have been given an unsigned copy of this form. I have had an opportunity to ask questions, and I have received answers. I consent to participate in the study.

Furthermore, I also affirm that the experimenter explained the study to me and told me about the study's risks as well as my right to refuse to participate and to withdraw.

Signature of Participant Date

Printed name of Participant

VITA

KATHARINE L. HALFACRE

EDUCATION

Bachelor of Science in Kinesiology with a concentration in Health Fitness Studies, Mississippi State University, December 2014, *magna cum laude*

Master of Science in Food & Nutrition Services, University of Mississippi, Oxford, MS, May 2017, Master's Thesis: Diet Quality and Food Insecurity among University Students: The Role of Food Preparation Ability

EMPLOYMENT

Institute of Child Nutrition

Aug. 2015 to May 2016 Graduate Administrative Assistant

Department of Athletics, Sports Nutrition

July 2019 to Jan. 2020 Graduate Research Assistant

Department of Nutrition and Hospitality Management

Jan. 2017 to Present Graduate Instructor

Aug. 2016 to Present Graduate Teaching Assistant

HONORS AND AWARDS

2017 Featured (top-4) poster presentation at the Wellness and Public Health educational session of the Academy of Nutrition and Dietetics Food and Nutrition Conference & Expo

2017 Outstanding Abstract at Academy of Nutrition and Dietetics Food and Nutrition Conference & Expo

2014 Graduated with honors, *magna cum laude*, Mississippi State University