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The effects of acute dehydration of 5% body mass on performance and physiology of mixed martial arts athletes

Oliver Roland Barley
Edith Cowan University

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MASTERS OF SCIENCE (SPORTS SCIENCE)

**THE EFFECTS OF ACUTE DEHYDRATION OF 5% BODY MASS ON
PERFORMANCE AND PHYSIOLOGY OF MIXED MARTIAL ARTS ATHLETES**

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Co-principal Supervisor: Mrs Fiona Iredale (Edith Cowan University)

Associate Supervisor: Dr Dale Chapman (Australian Institute of Sport)

2016

The declaration page
is not included in this version of the thesis

USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

ACKNOWLEDGMENTS

My Journey

Now that I look back at my Masters experience I can honestly say the conclusion is bittersweet. When I began I had a question I was desperate to know the answer to, myself and people around me had cut weight for competitions many times and I needed to know how it was affecting our competitive experiences. I put in two years of the hardest work I have done in my life, I grew as a person and gained more knowledge and experience than I could have ever anticipated. Now having come out the other end of this experience I think if I had told myself two years ago the outcome of my Masters I would have been disappointed. I don't have clear answers to the questions I had (though I am definitely closer) and I have far more questions than I began with. That is what makes it bittersweet, the more I learn the more I realise I don't know. The process of research seems to be a never ending uphill battle, every question answered results in ten more questions emerging as a result of the answer. Despite its nature the concept of research gives me purpose. I am not sure what changed over two years but now the prospect of never ending questions motivate me. I am motivated to learn as much as I possibly can during my research journey. Early in my Masters it became clear to me that I want to pursue academia for the rest of my working life. I have to know more, as now I know that I don't know enough. In the uphill battle that is research I am ready to march on until I have my answers (and the inevitable fallout of more questions).

Supervisory Panel

A/Prof Chris Abbiss: I remember describing to a friend how calm you seemed during situations I perceived as stressful and it came out as: *So Chris is sitting in a burning building and he just says "this is fine, we can work this out" and five minutes later he is standing outside the building*

holding a coffee and the fire is somehow out. I look back and realise this story outlines one of the many traits you have that make you a great mentor. Your support has been invaluable, working with someone like you has been a humbling experience and I look forward to working together in the future.

Mrs Fiona Iredale: You have always provided a down to Earth perspective on my research experience. There have been many times I have walked into your office with an issue I thought would be huge and left realising it wasn't. I have appreciated all the support you have provided me, without you this masters wouldn't have gone as smoothly as it did.

Dr Dale Chapman: You have high standards and as a result of this you have motivated me to want to provide a higher quality of work to try to exceed those standards. You are the kind of supervisor that makes me really think about how to make my work better. I thank you for all your help as you were an essential part of this piece of work and my Masters experience overall.

Technical Staff

I feel sometimes the technical staff get overlooked as without the help of Nadija Vrdoljak, Elisabeth Depetro and Helen Alexander my research wouldn't have been possible. I apologise for the amount of sweat my research brought to the lab, the heat chamber probably won't ever smell the same again.

Final Thoughts

As much as there are many other people I could thank I don't want this section to be too long, I have read other peoples manuscripts and the acknowledgments section seems to stretch on forever. Thank you to everybody at the university who was a part of my Masters experience in any way. Special thanks to everyone who agreed to be a subject in my study, I know it wasn't a pleasant experience.

Thanks to my family and friends who have been supporting me throughout this entire process and provided me with a network I can truly rely on. Though I feel the need to single out my mother, her support and interest in my education has been not only present in my Masters but my whole life. She has always been proud of me no matter what I was doing, I aim to keep making her proud.

I will delve into a cliché here and thank my partner Taryn Smith, your love and support helps get me out of bed every day with a positive attitude and a drive to improve myself. There are times when I must have been unbearable during this experience (more so than normal anyway) and you have not faltered even once in your support. You will always have my love and support in return. I hope you are ready for my PhD experience, I imagine it will be like my Masters experience on steroids.

Finally I would like to thank you the reader. You are about to see the result of two years of hard work and passion. I hope it will be enjoyable and informative to read. We are all part of this journey that is learning and I just hope each time we cross paths we can leave knowing a little more.

Sic Parvis Magna: "Thus great things from small things come." - Sir Francis Drake

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ABSTRACT

Mixed Martial Arts (MMA) athletes are weighed 24 h prior to competition. In order to compete in a lower weight class MMA athletes will often rapidly lose weight via dehydration. Despite the prevalence, there is currently no known published data examining the effects of acute dehydration on physiology and performance in mixed martial arts athletes. The present study aimed to examine: i) the effects of 5% acute dehydration on performance (vertical jump, medicine ball throw, grip strength and repeated sled push) and physiology (body weight, haematocrit, urine specific gravity, serum osmolality and urine osmolality) of MMA athletes. A total of 14 MMA athletes between the ages of 18 and 40 y with at least 2 y of competitive experience were recruited. Participants performed a familiarisation session, followed by two experimental sessions including a control protocol (CONT) or a dehydration protocol (DHY) in a randomised order. During the DHY athletes cycled for 3 h in a heated chamber (40°C and 30% relative humidity) wearing a sweat suit in order to lose 5% of their bodyweight (BW). Athletes then underwent a 3 h recovery period, during which they consumed fluids/food *ad libitum*. Athletes then performed a series of performance tests, including vertical jump, medicine ball throw, wrist grip and repeated sled push. A further 21 h recovery period was allowed before athletes performed the same tests. Prior to weight loss, immediately post weight loss, pre performance testing (3 h post weight loss) and 24 h post weight loss, urine and blood samples were collected and body weight was measured. A lower average speed during the repeat sled push ($5.65 \pm 1.3 \text{ km} \cdot \text{h}^{-1}$) was observed 3 h post DHY compared with 3 h post CONT ($6.99 \pm 0.85 \text{ km} \cdot \text{h}^{-1}$; $P < 0.05$). Average sprint speed during the sled push was lower at 24 h post DHY ($6.36 \pm 1.44 \text{ km} \cdot \text{h}^{-1}$) when compared with 24 h post CONT ($7.12 \pm 0.95 \text{ km} \cdot \text{h}^{-1}$; $P < 0.05$). Peak sprint speeds of $8.69 \pm 1.17 \text{ km} \cdot \text{h}^{-1}$ and $9.14 \pm 1.1 \text{ km} \cdot \text{h}^{-1}$ were observed 3 h post DHY/CONT and $8.82 \pm 1.41 \text{ km} \cdot \text{h}^{-1}$ and $9.35 \pm 1.06 \text{ km} \cdot \text{h}^{-1}$ 24 h post DHY/CONT. A decreased time to fatigue and increased perceived exertion was also observed. The decrements in performance were

observed at both 3 h and 24 h post DHY with the decrements still being present but not as large 24 h. When comparing measures of hydration in the DHY with CONT, significantly lower measures of hydration were observed 30 min post DHY and 3 h post DHY. None of the measured markers of hydration indicated athletes were dehydrated 24 h post DHY. The observations of this present study indicate that current weight loss practices in MMA and other combat sports may not be conducive to the best physical performance possible. Current practices should be reconsidered since performance was compromised even following 24 h of recovery. Future research should investigate possible physiological mechanisms behind the observed decrement in performance.

CHAPTER 1

INTRODUCTION

1.1 Overview

This Masters thesis contains a literature review (Chapter 2) and an original scientific study (Chapters 3-5) investigating the effects of acute dehydration of 5% body mass on physiology and performance in mixed martial arts (MMA) athletes with recovery periods of 3 h and 24 h.

1.2 Background

Mixed Martial Arts (MMA) is a combat sport built from multiple disciplines including Muay Thai, kickboxing, boxing, wrestling and jiu jitsu (La Bounty, Campbell, Galvan, Cooke, & Antonio, 2011; Lenetsky & Harris, 2012). MMA has grown in popularity over the past two decades with multiple organisations emerging to coordinate professional competitions (Buse, 2006; Dooley, Re, & Stamford, 2013; La Bounty et al., 2011). MMA is a physically demanding sport typically involving between three and five rounds, each of which lasts 5-min. Rounds involve fast, powerful and explosive high-intensity movements typically lasting 6 to 14 s, interspersed with periods of longer (i.e 15 to 36 s) low intensity work or pauses (Del Vecchio, Hirata, & Franchini, 2011). Motion analysis of MMA competitions have found that the typical ratio between high and low intensity activity (including pauses) is between 1:2 and 1:4 (Del Vecchio et al., 2011). More recent studies conducting time motion analysis in professional MMA have found high intensity to low intensity ratios ranging from 1:2 and 1:5 (Miarka, Coswig, Vecchio, Brito, & Amtmann, 2015; Miarka, Vecchio, Camey, & Amtmann, 2015). As a result of

these physical demands, to be successful MMA athletes are required to have high strength, be extremely powerful and have well-developed anaerobic and aerobic physiological characteristics (La Bounty et al., 2011).

As with other combat sports, MMA competitions are divided into multiple weight classes varying from flyweights (upper limit of 56.7kg) to heavyweights (upper limit of 120.2 kg). At professional MMA events participants are weighed at least 24 h before the competition starts. In order to gain a weight advantage over opponents, athletes will often aim to lose significant weight over the days and weeks leading up to being weighed for the event which is colloquially termed 'cutting weight'. Following this, athletes will aim to rapidly regain weight and arrive at the competition heavier than their actual allocated weight class. The methods used to achieve the weight loss are largely based on tradition and are believed to be important in the preparation for competitions by many athletes (Durkalec-Michalski, Gościańska, Jeszka, & Podgórski, 2014; Jetton et al., 2013; Smith, Dyson, Hale, Harrison, & McManus, 2000). The reduction in body weight in order to make a specific weight class is also found in other combat sports such as boxing, wrestling, Judo and kickboxing (Artioli, Gualano, et al., 2010; Brito et al., 2012; Gann, Tinsley, & La Bounty, 2015; Garthe, Raastad, & Sundgot-Borgen, 2011; Kinningham & Gorenflo, 2001; Morton, Robertson, Sutton, & MacLaren, 2010). However, the time frames and methods used by athletes in order to reduce weight are likely to differ between sports due to differences in procedures regarding the available weight classes to athletes and the period of time between weigh in and competitions.

To date there is little scientific evidence examining the prevalence of and methods used for such rapid weight loss by MMA athletes. A study of high school wrestlers Kinningham and Gorenflo (2001) found that athletes adopt a number of strategies to reduce weight, including energy intake restriction (gradual dieting and fasting); total body fluid reduction (restricting fluid intake, increasing sweat response [heated wrestling, plastic suits, saunas and spitting] and;

pseudo extreme/abusive medical practice (laxatives, diet pills, diuretics, enemas, sporting bulimia [vomiting]). It was reported that 52% of wrestlers engaged in more than one method and 72% used at least one weight loss method. Despite not having 100% of participants report cutting weight the average weight loss of all the participants was 3% of their total body weight in the five days before the event. A study of rapid weight loss in MMA athletes found that 88% of athletes reported reducing weight for competition with 37.5% of athletes reporting restricting intake of fluids and/or using a sauna whilst 50% of athletes reported doing exercise in heated rooms (Andreato et al., 2014). Other studies have shown the prevalence of athletes using at least one of the weight loss methods ranging from 60% up to 89% in various combat sports such as Judo, wrestling, boxing and traditional martial arts (Artioli, Gualano, et al., 2010; Artioli, Scagliusi, et al., 2010; Brito et al., 2012; Franchini, Brito, & Artioli, 2012; Kinningham & Gorenflo, 2001; Steen & Brownell, 1990). A recent study of MMA athletes conducted by Crighton, Close, and Morton (2015) observed that athletes on average lost $9 \pm 2\%$ of body mass in the week before competition and a further $5 \pm 2\%$ in the 24 h before athletes were weighed for competition which is a larger amount compared to other combat sports (Brito et al., 2012; Kinningham & Gorenflo, 2001). Fluid loss, fluid restrictions and extreme dieting are typically the most commonly reported methods in most other combat sports (Brito et al., 2012; Franchini et al., 2012; Morton et al., 2010; Smith et al., 2000).

The effect of hypohydration (often referred to as dehydration) on anaerobic performance is unclear with studies reporting no change or a significant reduction in performance with as little as 3.1% decrease in body weight (Hall & Lane, 2001; Jones, Cleary, Lopez, Zuri, & Lopez, 2008). Such decreases appear to have a considerable influence on aerobic performance (McArdle, Katch, & Katch, 2010). Indeed, a reduction in plasma volume associated with hypohydration results in a reduction in total blood volume and reduced venous return. As a result, heart rate is increased in order to maintain a given cardiac output (González-Alonso,

Mora-Rodriguez, Below, & Coyle, 1997; Nielsen et al., 1993). Despite an increase in heart rate, cardiac output is still compromised at higher intensities resulting in limitations to muscle blood flow and skeletal muscle metabolism (Cheuvront, Kenefick, Montain, & Sawka, 2010). The influence of dehydration/hypohydration on anaerobic performance is less clear yet decreases in muscle function and explosive power have been reported following 4% reductions in total body water (Jones et al., 2008; Kraft et al., 2011; Smith et al., 2000). It is possible that such reductions in anaerobic performance are the result of altered electrolyte concentrations and associated neuromuscular fatigue (Sawka et al., 2007; Sawka & Montain, 2000; Sjøgaard, 1985).

Dehydration of 5% of total body mass or greater over five days has been found to have effects on the composition of blood up to seven days after dehydration occurred (Reljic, Feist, Jost, Kieser, & Friedmann-Bette, 2015; Reljic, Hässler, Jost, & Friedmann-Bette, 2013). Studies have shown that progressive weight loss over five days led to a decrease in total body water, extracellular water, blood volume, total haemoglobin mass (tHB_{mass}) and plasma volume two days prior to the competition. Seven days post competition tHB_{mass} remained 3% below baseline measures, which is likely to have a significant effect on aerobic performance (Schmidt & Prommer, 2010). This is relevant to the field of combat sports and highlights the need for research examining the influence of hypohydration on blood composition and performance in the timeframes relevant to MMA.

There is evidence to suggest that following dehydration MMA athletes are not adequately rehydrating prior to their competition (Jetton et al., 2013). Urinary measures of hydration and measures of body mass taken at the weigh in 24 h prior to the competition and 2 h prior to the competition showed that athletes gained 4.4% of their body mass over the 22 h of recovery, yet 39% of athletes were still competing in a state of significant dehydration (Urine specific gravity of >1.021) (Jetton et al., 2013). This dehydration could result in a lower quality of performance

and negative health effects. Clearly further research examining the dehydration and rehydration practices of MMA athletes along with the effects on performance is warranted.

To the best of my knowledge no study has examined the effects of acute dehydration of 5% of total body weight on high intensity performance after a 3 and 24 h recovery period in MMA athletes.

1.3 Purpose and Significance

Participation in MMA is rapidly increasing among not only professionals but also members of the public who are watching and/or practicing the sport (Dooley et al., 2013). The common practices for making weight are largely based on tradition rather than evidence. There is currently insufficient evidence to provide effective guidelines on the influence of weight loss on performance, health and wellbeing of MMA athletes. Therefore, the aim of this study was to examine the effects acute dehydration of 5% body mass on performance (vertical jump, medicine ball throw, hand grip and repeated sled push) and physiology (body weight, haematocrit, urine specific gravity, serum osmolality and urine osmolality) of MMA athletes. This study will provide data that can aid in the development of guidelines or best practice strategies in the preparation of MMA athletes whilst considering athlete safety. This data will translate into other sports that involve weight cutting such as boxing, kickboxing, judo, taekwondo, wrestling, horse riding or weightlifting.

1.4 Research questions and Hypotheses

1. What effect does acute dehydration of 5% body mass have on 10 m repeated maximal sled push sprint ability (i.e. peak sprint time, average sprint time, total testing time and

fatigue index), vertical jump, hand grip and medicine ball throw in competitive MMA athletes following a short (i.e. 3 h) and long (i.e. 24 h) recovery period?

- Maximal sled push sprint ability, vertical jump, hand grip and medicine ball throw will be lower than control conditions at both 3 h and 24 h following acute dehydration.
2. What effect does acute dehydration of 5% body mass have on urine specific gravity (USG), serum osmolality, urine osmolality, body mass and haematocrit percentage after a short (3 h) and long (24 h) recovery period?
- Compared with control conditions USG, serum osmolality, urine osmolality body mass and haematocrit percentage will have changed to indicate lower levels of hydration when compared to control conditions at both 3 h and 24 h following acute dehydration.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Introduction

Mixed Martial Arts (MMA) is a sport involving physical combat between two competitors and allows submission holds and striking with hands, elbows and legs to standing or grounded opponents (Buse, 2006). Within the past decade MMA has grown from an underground spectacle to a sanctioned sport with multiple organisations emerging to coordinate competitions (Buse, 2006; La Bounty et al., 2011; Lenetsky & Harris, 2012). Professional MMA is now an internationally regulated high profile sport with millions of spectators which provides many athletes with full time sources of income (Franchini et al., 2012; Lenetsky & Harris, 2012).

MMA is a physically demanding sport typically involving between three and five rounds, each of which last 5-min. These rounds involve fast, powerful and explosive high-intensity movements typically lasting 6 to 14 s, interspersed with periods of longer (i.e 15 to 36 s) low intensity work or pauses (Del Vecchio et al., 2011). Motion analysis of MMA competitions have found that the typical ratio between high- and low- intensity activity (including pauses) is between 1:2 and 1:4 (Del Vecchio et al., 2011). As a result of these physical demands, MMA athletes are required to have high strength, be extremely powerful and have well-developed anaerobic and aerobic capacities (La Bounty et al., 2011).

MMA competitions are divided into weight classes to ensure similarly sized opponents compete against each other. In professional events athletes are typically weighed 24 h prior to competitions whereas at amateur events athletes are weighed 2 to 4 h prior to competitions (Franchini et al., 2012; Smith et al., 2000). In order to compete against lighter, smaller and weaker opponents athletes will often attempt to rapidly reduce body weight in the days and hours

leading up to being weighed and then regain that weight prior to the competition (Franchini et al., 2012). However, the influence of such practice on performance of MMA athletes is not well understood. Indeed, there is currently minimal research examining the effects of rapid weight loss in MMA athletes. The purpose of this review is to examine and discuss the literature describing: i) the prevalence and different methods of rapid weight loss in relation to MMA, ii) dehydration and the effects it has on physiology, and, iii) the effects of dehydration followed by subsequent rehydration on performance. Given the limited literature on MMA, this review will also examine weight loss in other combat sports.

2.2 MMA Weight Classes and Prevalence of Weight Cutting

MMA competitions are typically divided into weight classes to ensure combatants are similar sizes to their opponents. Athletes have been found to lose up to 10% of their body weight in the week leading up to the event and up to 5% of that within 3 h of being weighed for the event (Durkalec-Michalski et al., 2014; Gann et al., 2015). A study of rapid weight loss in MMA athletes found that 88% of athletes reported reducing weight for competition (Andreato et al., 2014). A recent study investigating MMA athletes observed that athletes on average lost $9\pm 2\%$ of body mass in the week before competition and a further $5\pm 2\%$ in the final 24 h before athletes were weighed for competition, such magnitudes of weight loss are reported as greater than other combat sports (Crighton et al., 2015). The aim of this weight loss is to gain a physical advantage over opponents by competing in a lower weight class than the athletes natural weight would allow them (Reljic et al., 2013). The methods used to achieve the weight loss are largely based on tradition and are believed to be important in the preparation for competitions by many athletes (Durkalec-Michalski et al., 2014; Jetton et al., 2013; Smith et al., 2000).

Athletes use a wide range of weight loss methods including gradual dieting, missing meals, fasting, restricting fluids, increased exercise, heated training rooms, sauna, use of plastic

suits, spitting, laxatives, diuretics, diet pills or vomiting (Artioli, Scagliusi, et al., 2010). Many of these weight loss mechanisms are potentially dangerous (i.e fasting, saunas, plastic suits and vomiting (Kinningham & Gorenflo, 2001)). It has been reported that between 60% and 89% of athletes may use at least one potentially dangerous weight loss method across a range of combat sports such as Judo, wrestling, boxing and traditional martial arts (Artioli, Gualano, et al., 2010; Artioli, Scagliusi, et al., 2010; Brito et al., 2012; Franchini et al., 2012; Kinningham & Gorenflo, 2001; Steen & Brownell, 1990). In a recent study of MMA athletes it was reported that all participants engaged in fasting or low carbohydrate diets within 5 days of being weighed and over 65% of athletes reported using fluid manipulation to make the weight required (Crighton et al., 2015). The study also found that 67% of athletes reported using a method of weight loss called 'water-loading' where athletes reduce sodium intake and over drink water (eg, 20-23 L over 3 days), with the aim being to trigger a 'flushing mode' to induce excessive urine production. It was also observed that 73% of athletes reported using nutritional supplements during weight loss periods but 61% of them were unsure if the supplements contained banned substances (Crighton et al., 2015). Furthermore, only 20% of the athletes consulted a qualified sports dietician/nutritionist (Crighton et al., 2015).

To the best of my knowledge there has been no study investigating the prevalence of the wide range of different weight loss methods used by MMA athletes. Previous studies have shown similar or greater amounts of weight loss in MMA compared to other combat sports (Crighton et al., 2015; Jetton et al., 2013). The similar amounts of weight loss makes it likely that the prevalence of different weight loss strategies will be similar in MMA to other combat sports but further investigation is required to confirm or reject this hypothesis (Gann et al., 2015).

Weight loss occurring on the same day as being weighed is mostly lost from total body water, as this weight can be lost quickly and replenished quickly. One important mechanism by which athletes attempt to reduce body water close to a competition is dehydration. This can be

achieved by exposing themselves to high temperatures and sometimes exercising in such temperatures to induce large amounts of fluid loss through sweat (Gann et al., 2015; Smith et al., 2000). The effects of dehydration on physiology and performance in humans has long been a topic of scientific investigation (Barr, 1999; Cheuvront & Kenefick, 2014; Cheuvront et al., 2010; González-Alonso et al., 1997; Montain & Coyle, 1992; Wall et al., 2013). Dehydration in combats sports is commonly followed by subsequent rehydration to attempt to regain weight before the event begins. The effects of dehydration with subsequent rehydration have been investigated but much less so than studies that have examined performance and physiology directly following dehydration (Burge, Carey, & Payne, 1993).

2.3 Dehydration, Performance and Physiology

Dehydration is body water loss from a hyperhydrated state to a euhydrated state or from a euhydrated state to a state of hypohydration. This can occur by two primary processes, the restriction of fluid ingestion, the loss of body water, or a combination of both. Such loss of body water mostly occur via sweat loss (McArdle et al., 2010). Many studies have examined the effects of dehydration on physiological function and performance within a range of sports from combat sports to cycling (Barr, 1999; Cheuvront & Kenefick, 2014; Cheuvront et al., 2010; González-Alonso et al., 1997; Hargreaves, Dillo, Angus, & Febbraio, 1996; McConell, Burge, Skinner, & Hargreaves, 1997; Sawka et al., 2007).

The influence of dehydration on physical performance is conflicting with studies typically reporting a decrease (Barr, Costill, & Fink, 1991; Cheuvront & Kenefick, 2014; Cheuvront et al., 2010; Hargreaves et al., 1996; Kraft et al., 2011; Sawka et al., 2007) or no change in performance (Wall et al., 2013; Zouhal et al., 2011). Indeed, Barr et al. (1991) found that dehydration reduced endurance performance in 6 h cycling time trials, whilst Zouhal et al. (2011) found an inverse relationship between percentage body weight change and finishing time in a 42 km marathon.

However, it should be noted that there are several factors which may influence the degree to which dehydration influences exercise performance. Of importance is the degree of hypohydration during exercise (Baker, Dougherty, Chow, & Kenney, 2007; Barr, 1999; McConnell et al., 1997; Murray, 2007), thermal stress during exercise (Cheung & McLellan, 1998; González-Alonso et al., 1997) and aerobic and anaerobic energy contribution to the exercise task (Barr, 1999; Jones et al., 2008). A literature review by Cheuvront and Kenefick (2014) examined literature on $\geq 2\%$ body mass loss via dehydration and effects on endurance (mostly aerobic) and strength and power (mostly anaerobic) performance and found that 53/60 studies reported decreased endurance performance and 177/276 studies reported decreased strength and power performance.

There are a number of proposed physiological mechanisms that could result in these changes in performance. It appears that dehydration of less than 2% has minimal influence on endurance capacity. However, when the degree of dehydration exceeds 2% a large number of studies have observed a decline in endurance performance, possibly due to decreased cardiac output (Cheuvront & Kenefick, 2014; González-Alonso et al., 1997; McConnell et al., 1997; Montain & Coyle, 1992; Sawka et al., 2007). Indeed, González-Alonso et al. (1997) observed a decrease in plasma volume and associated decrease in stroke volume during 2 h of cycling at 62-67% of maximal aerobic capacity VO_{2max} when participants were dehydrated by 4% of their body mass.

An alternative mechanism by which dehydration may influence exercise performance is via an associated reduction in glycogen availability. It has been found that ingesting fluid during prolonged exercise may reduce glycogen utilisation (Hargreaves et al., 1996; Meeusen, Watson, Hasegawa, Roelands, & Piacentini, 2006). Indeed, a recent study investigating rapid weight loss in MMA athletes found rapid weight loss to be associated with lower energy availability (Coswig, Fukuda, & Del Vecchio, 2015). Hargreaves et al. (1996) suggested a number of

methods by which dehydration can affect glycogen utilisation. These are that: i) fluid ingestion during exercise can minimise the normal exercise induced increase in epinephrine, ii) fluid ingestion causes reductions in muscle temperature which minimises glycogen utilisation, iii) hydration can improve cardiac output, thus increasing muscle blood flow and aerobic capacity reducing dependence on muscle glycogen.

Dehydration has also been found to greatly reduce the body's ability to regulate internal temperature which can reduce exercise performance (González-Alonso et al., 1997; Montain & Coyle, 1992; Sawka, 1992). Such reductions in thermoregulatory capacity have been proposed to be caused by changes in skin blood flow and sweat rate (Cheung & McLellan, 1998; González-Alonso et al., 1997; Montain & Coyle, 1992). Furthermore, dehydration has been found to alter plasma and intracellular electrolyte levels via sweat loss which can negatively affect thermoregulation and has been hypothesised to negatively affect muscle membrane contractility (Barr et al., 1991; McConell et al., 1997; Sjøgaard, 1985). It is unclear if athletes are in a state of dehydration during competition however there is research suggesting they could be (Jetton et al., 2013). If athletes are competing in a state of dehydration the mechanisms outlined could possibly affect performance.

2.4 Rapid Dehydration and Rehydration

Rapid rehydration is when individuals who have dehydrated aim to rehydrate over a relatively short period of time. It has been found that on average MMA athletes gained 4.4% of their body weight between being weighed and the competition (Jetton et al., 2013). There has been limited research on the effect of rapid dehydration followed by subsequent rehydration. Some research however has found rapid dehydration and rehydration to negatively affect performance both in reference to high intensity endurance and sports specific skills (Baker et al., 2007; Burge et al., 1993; Rankin, Ocel, & Craft, 1996). Rapid dehydration and rehydration has

been found to negatively affect anaerobic performance in both upper and lower body Wingate activity, maximal time trial performance and repeat sprint performance (Burge et al., 1993; Jones et al., 2008; Kraft et al., 2011). A study into dehydration and rehydration ranging from 1-4 % of total body weight in basketball players found a progressive decline in performance in a series of sports specific skill tests (Baker et al., 2007).

Some research has been carried out on rapid dehydration and rehydration in combat sports athletes (Artioli, Iglesias, et al., 2010; Choma, Sforzo, & Keller, 1998; Hall & Lane, 2001; Kumari & Chakraborty, 2011; Mendes et al., 2013; Moore et al., 1992; Reljic et al., 2015). While some of the results from these studies have been consistent with those found in other sports, others have deviated from this trend. Studies have investigated giving athletes recovery periods between 2 - 4 h after acute dehydration and found decrements in upper body, lower body, anaerobic and aerobic performance (Durkalec-Michalski et al., 2014; Franchini et al., 2012; Hall & Lane, 2001; Rankin et al., 1996). acute dehydration of at least 5 % body weight (BW) followed by rehydration has also been found to negatively affect cognition, decision making and mood in wrestlers and boxers (Choma et al., 1998; Hall & Lane, 2001). As previously mentioned not all studies show acute dehydration to cause negative effects. Some studies have found rapid dehydration and rehydration to have no effect on either anaerobic or aerobic performance (Artioli, Iglesias, et al., 2010; Reljic et al., 2015). Though it should be noted that many of the studies into combat sports, regardless of whether reporting positive and negative results, have had issues such as small sample sizes, poor control of the weight loss protocols and performance tests that are difficult to control or that are not relevant to combat sports competitions. At professional combat sports events (boxing, kickboxing, thai boxing and MMA) athletes are weighed 24 h prior to the event. While studies have shown that acute dehydration can negatively affect total haemoglobin mass and blood volume for more than 24 h (Reljic et al., 2015; Reljic et

al., 2013), there is no known research investigating the effects of acute dehydration on performance after a 24 h rehydration/recovery period.

Possible mechanisms that could cause a decrement in exercise performance as a result of acute dehydration have been explored. Inside the muscle tissue it has been proposed that changes in electrolyte balance can affect performance through losses in intracellular potassium. This reduction in intracellular potassium can cause hyperpolarisation of the muscle cell membrane thus decreasing muscle contractility by inhibiting calcium binding to troponin or by interfering with cross-bridge formation (Jones et al., 2008; Sjøgaard, 1985). As mentioned previously it has also been suggested that dehydration can increase sympathetic nervous system activity resulting in higher muscle glycogen utilization resulting in lower levels of muscle glycogen during exercise (Burge et al., 1993; Jones et al., 2008). Lower levels of muscle glycogen have been theorised to negatively affect performance. Muscle glycogen has been found to be 38% lower than baseline levels following acute dehydration, and higher carbohydrate diets during a 5 h re-feeding period have been found to mitigate performance decline (Rankin et al., 1996). Such reductions in muscle glycogen may negatively affect performance. The intensity of exercise during dehydration could affect the rate of glycogen depletion, there has been minimal research regarding the intensity of exercise during weight loss in combat sports. Research such as Artioli, Iglesias, et al. (2010) did not report controlling the intensity athletes used to lose weight whereas Smith et al. (2000) used 60 W cycling to lose weight. Exercise during such weight loss could affect muscle glycogen depletion and the current literature does not address its possible role in rapid dehydration and subsequent rehydration. Previously it has been hypothesised that hypohydration could result in changes to intracellular hydrogen (H^+) or phosphate (P_i) concentrations in the skeletal muscle, thus affecting performance. A study by Montain et al. (1998) investigated this hypothesis and found no difference in H^+ or P_i to explain the loss of muscular endurance. Whilst there are some proposed mechanisms there is insufficient evidence

to conclude which ones if any presented contribute to any decrements in performance and as such future research should be directed towards discovering the mechanisms involved.

2.5 Conclusion

Rapid weight loss is highly prevalent in multiple sports particularly combat sports with acute dehydration being a large component of rapid weight loss. The body of research available on acute dehydration and rehydration is inadequate given the increasing prevalence of combat sports. Indeed, combat sports account for ~ 25% of medals in the Olympics and are popular outside the Olympics in sports such as professional boxing, kickboxing and mixed martial arts which generate millions of spectators (Buse, 2006; Franchini et al., 2012). A high usage of acute dehydration has been found in such combat sports and given this requires a deeper scientific understanding (Brito et al., 2012; Crighton et al., 2015; Franchini et al., 2012). Future research should investigate the prevalence of such weight loss methods in MMA specifically and investigate the effects such weight loss has on performance in relation to MMA and other combat sports.

CHAPTER 3

METHODS

3.1 Participants

Fourteen highly trained male mixed martial arts athletes (age 23 ± 4 y, height 1.76 ± 0.4 m and body weight 76.8 ± 9.3 kg) with prior experience in weight cutting were recruited from local combat sports gyms to participate in this study. All athletes were informed of the procedures and risks associated with taking part in the study. Prior to data collection, written informed consent was obtained in accordance with the institution's Human Research Ethics Committee.

3.2 Procedures

Athletes completed three sessions, consisting of a familiarisation session and two experimental sessions. Throughout the study, training intensity, duration and frequency was controlled by the athletes and their coaches who were asked not to substantially alter their training schedules during the study period. During the familiarisation session participants completed the same series of performance tests in the same order that would be completed during experimental sessions, i.e. a vertical jump test, a medicine ball chest throw, a hand grip strength test and a repeated sprint sled test.

During the experimental sessions athletes performed either a dehydration protocol (DHY) involving prolonged (3 h) submaximal exercise in a heat chamber ($39.8 \pm 2.41^{\circ}\text{C}$ and humidity $22.78 \pm 6.5\%$.) or a control protocol (CONT) involving similar exercise in thermoneutral conditions ($25 \pm 5^{\circ}\text{C}$ and $31 \pm 10\%$ relative humidity). At 3 and 24 h following the completion of

the experimental conditions participants repeated the performance tests performed in the familiarisation session. A 3 and 24 h recovery was chosen as amateur athletes usually have from 2 to 4 h between being weighed and the competition and professional athletes usually compete the day following being weighed (Hall & Lane, 2001; Mendes et al., 2013). Athletes were free to consume food and fluid *ad libitum* following the each experimental condition. Each athlete was asked to record their nutritional intake in the 24 h prior to and following the first experimental session and then to replicate this diet during the second experimental session. The experimental sessions order (i.e intervention and control session) were randomised and counterbalanced using a Latin Square design. All experimental sessions were performed at the same time of day but were separated by at least fourteen days.

3.3 Dehydration and control protocols

During the DHY athletes wore a plastic sweat suit (plastic sweat suit, Wrap Yourself Slim, Australia) while cycling on a Velotron cycle ergometer (Velotron ergometer, Racermate, USA) at a set exercise intensity (60 W) in a climate chamber (set to 40°C and 40% relative humidity) with minimal fluid intake. The activity of cycling was chosen to minimise eccentric muscle damage and avoid any effect from the submaximal exercise on performance (O'Reilly et al., 1987). The cycle ergometer was individually adjusted to fit each athlete. In the final 2 min of every 20 min period during the experimental conditions athletes ceased cycling and measurements of body weight (BW), core temperature, tympanic temperature, rate of perceived exertion (RPE) and thermal sensation were recorded. The intent of the DHY trial was to achieve a weight loss of 5% BW following 3 h of submaximal exercise. If an athlete was close to achieving the stipulated weight reduction before the 3 h period was complete then less clothing was worn to slow weight loss so that the exercise time period was maintained. Likewise if athletes were likely to be over the 5% dehydration target they consumed a small volume of water

(250ml) during exercise, in order to achieve 5% dehydration. The relatively low power output of 60W was chosen during the DHY and CONT to increase core temperature and promote sweating but minimise muscle glycogen depletion as losses in glycogen has been hypothesised to cause decrements in performance (Smith et al., 2000). The CONT involved participants cycling for 3 h at 60W under thermoneutral conditions without wearing a plastic suit and without restrictions on water intake.

3.4 Measurements during Protocol

From the time that athletes entered the laboratory until the first performance testing session, core temperature and heart rate were continuously measured via gastrointestinal pill (HQinc, USA, CorTemp Ingestable core body temperature sensor) using an external data logger (HQinc, USA, CorTemp data recorder) and radio telemetry (Model S810i, Polar Electro Oy, Kempele, Finland), respectively. The gastrointestinal pill was ingested 4 h prior to arrival. Systolic and diastolic blood pressure were measured using an autonomic blood pressure monitor (Automatic blood pressure monitor, OMRON, Singapore).

Prior to the DHY/CONT, 20 min post DHY/CONT, 3 h and 24 h post DHY/CONT nude body weight, a urine sample, blood pressure, core temperature, tympanic temperature and heart rate were recorded along with blood samples that were acquired from the antecubital vein and via a finger prick blood sample (Figure 1).

To confirm euhydration status immediately prior to the DHY/CONT, both serum and urine osmolality were measured. A 6 ml blood sample was drawn from the antecubital vein, and urine was collected in a 30ml sterilised container. Both serum and urine osmolality were assessed with an Advanced 3250 single-sample osmometer (Advanced instruments, USA). Using part of the original urine sample the urine specific gravity was measured using a calibrated urinary

refractometer (Atago hand refractometer, model UNC-NE, Atago, Japan). In addition to these euhydration measures starting body weight was measured using floor scales (Mettler ID1 multirange, FSE, Australia). Based on previous literature (Ellershaw, Sutcliffe, & Saunders, 1995; Popowski et al., 2001), euhydration was defined as a serum osmolality $> 295 \text{ mOsm.kg}^{-1}$, urine osmolality $> 700 \text{ mOsm.kg}^{-1}$, a USG of > 1.020 and change of body weight less than 750g compared to the previous trial. If two or more of these measures were not achieved, it was proposed that the subject would ingest 600ml of water and the hydration tests would be repeated 30 min later to ensure euhydration. However, no athletes during the study were required to retake any of the hydration tests.

Athletes were seated for 5 min prior to blood sampling. A venous blood sample was collected from the antecubital vein into an 8 mL serum separating tube which was then spun at 12000 rpm for 15 min at 4°C in a centrifuge (Multifuge 3 S-R, Kendro, USA). A 250 µl sample of serum was then placed in an aliquot and analysed for osmolality as described in the euhydration section. Finger prick whole blood samples were collected using safety lancet (Unistik 2, Owen Mumford, Oxford, United Kingdom) into capillary tubes (Capilette 32 uL, Roche Diagnostics, Castle Hill NSW) and spun in a microcentrifuge (Centrifuge MPW-212, MPW med. Instruments, South Australia) at 3600 rpm to analyse haematocrit.

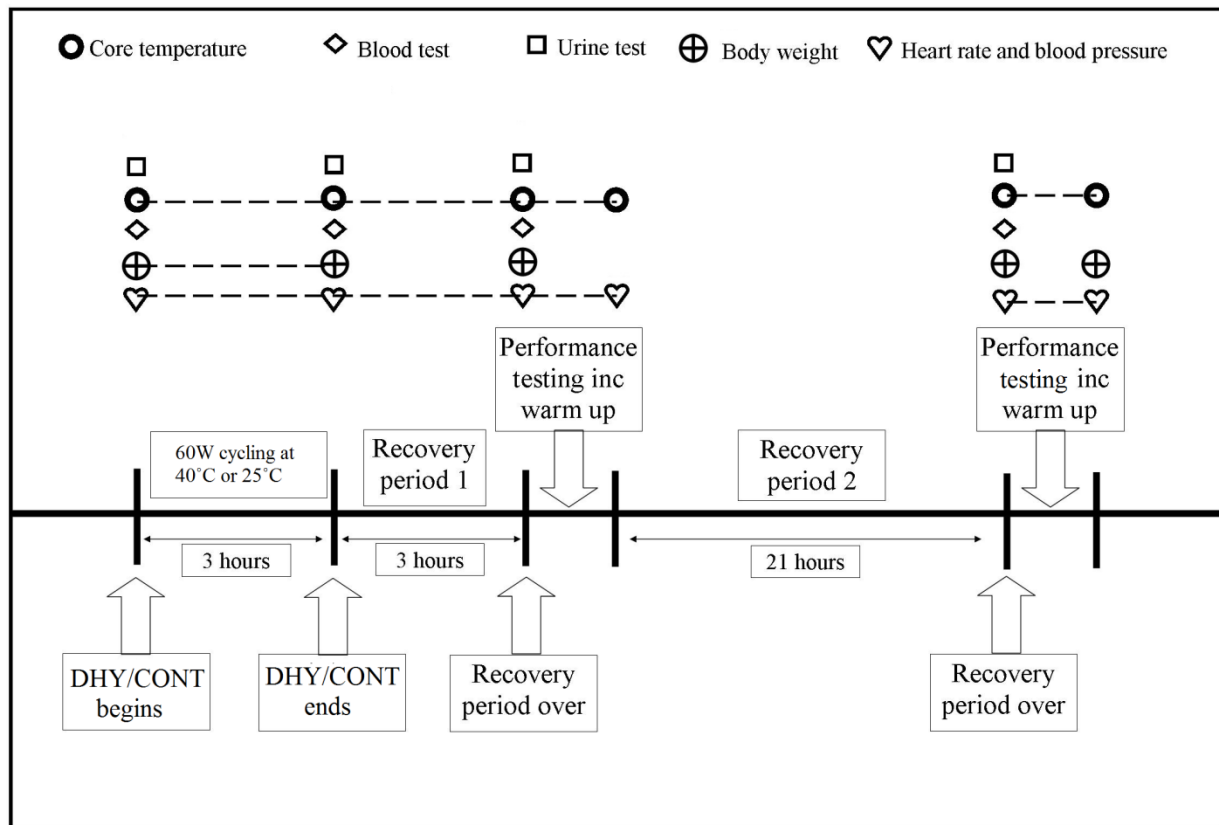


Figure 1. Schematic presentation of the experimental design.

3.5 Performance Tests

3.5.1 Vertical jump

As a measure of lower body power each athlete performed a vertical jump test that was measured using a Vertec (Yardstick, SWIFT, Australia). Standing arm reach was recorded after which participants performed three maximal counter movement jumps. All three jumps were recorded but the maximal of all three jumps was used for data analysis. The countermovement vertical jump test has been demonstrated to have high intersession (7 day separation) reliability a coefficient of variation of 4 to 5.6% and interclass correlation coefficients (ICCs) ranging from 0.87 to 0.93 (Moir, Shastri, & Connaboy, 2008).

3.5.2 Medicine ball chest throw

As a measure of maximal upper body power each athlete threw a 4 kg medicine ball as far as possible from a seated position. The athlete was seated on the floor with their back directly against the wall, was instructed to keep their back against a wall and to maintain this position at all times while throwing. A measuring tape with 1 cm increments was extended from this position perpendicular out from the wall along the ground to measure landing distance. Athletes held the medicine ball with both hands, brought it up to their chests and performed an explosive chest-type pass for maximum distance. Each athlete threw the ball outward and upward at approximately 30° above horizontal. Participants performed three throws with the maximal value being used for further data analysis. A similar testing procedure using a 5 kg medicine ball was found to have high test retest reliability between sessions (over 7 day separation between sessions) with an ICC of 0.93 and limits of agreement (LOA) of 0.23 m·s⁻¹.

3.5.3 Hand grip test

Each athlete's grip strength was assessed using a hand dynamometer (Hand dynamometer, Lafayette Instrument Company, United States). The dynamometer was adjusted for the subjects hand prior to testing, subject's then held the dynamometer in their dominant hand and down beside their hip and gripped maximally three times with 1 min rest between efforts. The maximal of all three trials was used for data analysis. Hand grip dynamometers are considered a reliable measure assuming the equipment and collection protocols are kept consistent (Innes, 1999).

3.5.4 Repeated sled push

In order to assess each athlete's repeated effort capacity they were required to push a sled (The Predator Sled, Aussie Strength Equipment, Australia) weighing 75% of their body mass

over a 10 m distance for a total of 30 efforts (Figure 2) and athletes were provided with strong verbal encouragement to give a maximal effort during each sprint. At the completion of each 10 m maximal effort the athlete was allowed 20 s to complete a 20 m recovery run outside of the timing gates before they were instructed to assume the start position for the next sprint effort. The time taken to complete each 10 m effort was recorded with infra-red wireless timing gates (Speedlight TT wireless timing system, Swift, Australia).

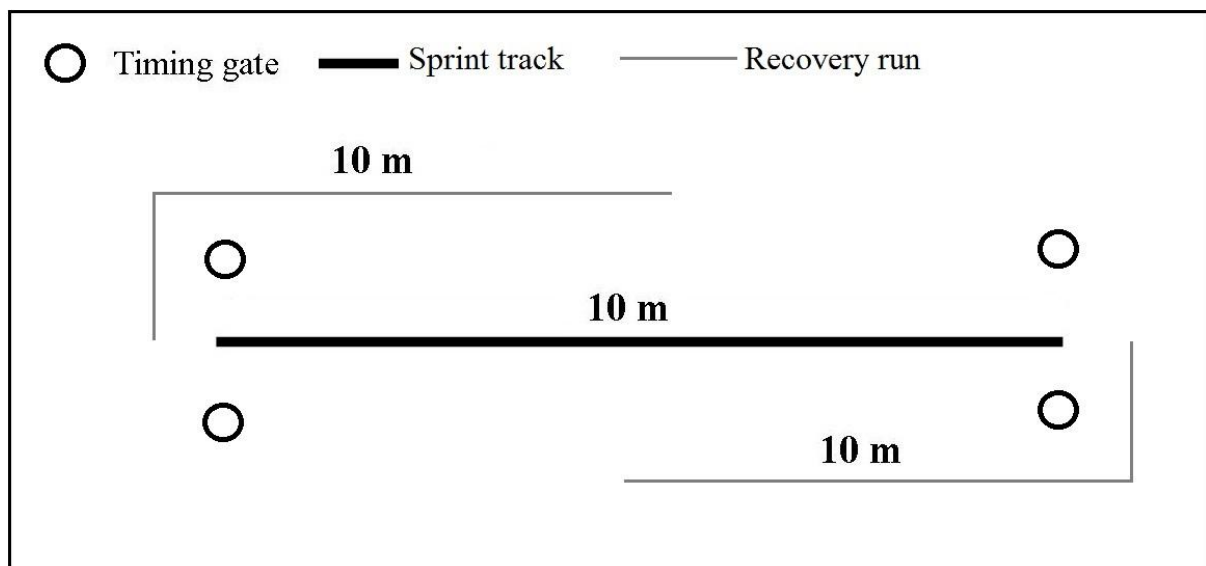


Figure 2. Set up of the repeat sled push test.

Prior to testing subjects completed two maximal runs with the sled unweighted as a warm up and to allow athletes to practice their technique. Heart rate was recorded continuously during the test and rate of perceived exertion RPE was recorded after each effort. Each sprint started with the sled past the timing gates but with the holding posts not breaking the light beam. At the end of each sprint the subjects were required to completely clear the gate with the sled and their entire body. The principle investigator re-positioned the sled after each effort. While athletes

were also free to choose their hand positioning on the sled the positioning chosen was used consistently throughout all sled push testing.

Pilot testing of the repeated sled push test was performed on two separate occasions to assess the reliability. The total time taken to complete the test (ICC, 0.97; CV%, 0.9; total error (TE), 0.42), the average 10 m sprint (ICC, 0.97; CV%, 4.0; TE, 0.4) and the peak 10 m sprint (ICC, 0.99; CV%, 2.5; TE, 0.32) were all found to be reliable. However, due to altered pacing between trials fatigue index was found to be unreliable which was one of the reasons for the inclusion of a familiarisation session.

The distances and recovery times were chosen based on pilot data and in order to achieve a high to low intensity ratio of 1:4 and a total duration of over 12 minutes which reflects MMA competitions (Del Vecchio et al., 2011). The primary intention of the repeated sled push test was to evaluate the physiological characteristics associated with MMA not necessarily MMA performance itself. The test was terminated when the subject completed all 30 sprints, reached volitional exhaustion (i.e. was unable to continue) or the sled stopped moving mid sprint for two sprints in a row. Sprint efforts, heart rate and RPE were organised into averages of five efforts for data analysis. Peak time was calculated based on the fastest 10 m sprint. The mean sprint time was calculated based on the average of all 10m sprints and fatigue index was calculated based on the difference between the averages of the first five and the last five 10 m sprint efforts. For each 10 m sprint effort meters per second was multiplied by 3.6 to give kilometres per hour ($\text{km}\cdot\text{h}^{-1}$) which was then used for data analysis.

3.6 Data Analysis

Data was assessed for normality and homogeneity. A total of 4 athletes who were unable to complete the performance test were excluded from data analysis for speed and time, total test

time, heart rate and RPE during the repeat sled push test. The data was checked for sphericity prior to testing for main effects. Performance data during the sled test (i.e. time to 10m, peak time, mean time and fatigue index) were compared between conditions (DHY and CONT) and over time (pre, immediately post, 3 h and 24 h recovery periods) using a two-way repeated measures ANOVA. Physiological data (i.e. hydration measures, blood measures, total haemoglobin mass and body weight), mean performance data for the hand grip test, vertical jump height and medicine ball chest throw distance were compared between time (pre, immediately post, 3 h and 24 h recovery periods) and condition (DHY and CONT) using a two way repeated measures ANOVA. Where significant condition and/or interaction effects were observed Tukey's LSD test was performed to determine the location of the differences. Pearsons correlation coefficients were calculated between physiological measures and average sprint speeds. Statistical analyses were performed using SPSS version 19.0 (SPAA Inc., Chicago IL, USA). All data was reported as mean (\pm SD) and statistical significance was assumed at $p < 0.05$.

CHAPTER 4

RESULTS

4.1 Repeated Sprint Test

4.1.1 Speed and time

A main condition effect ($N=10$, $F_{(1,516)}=13.903$, $P=0.001$) and significant main interaction effect ($N=10$, $F_{(15)}=4.936$, $P<0.001$) was found for sprint speed during the sled push test (Figure 3). Post hoc analyses revealed greater speeds at both 3 h and 24 h post CONT when compared to 3 h ($P=0.003$) and 24 h ($P=0.006$) post DHY with decrements in speed up to $24 \pm 21\%$. The post hoc analysis also revealed greater speeds 24 h post DHY when compared to 3 h post DHY with maximal decrements of $17 \pm 15\%$ ($P=0.01$). There were no significant differences found in sprint speed between 3 h and 24 h post CONT ($P=0.271$)(Figure 3).

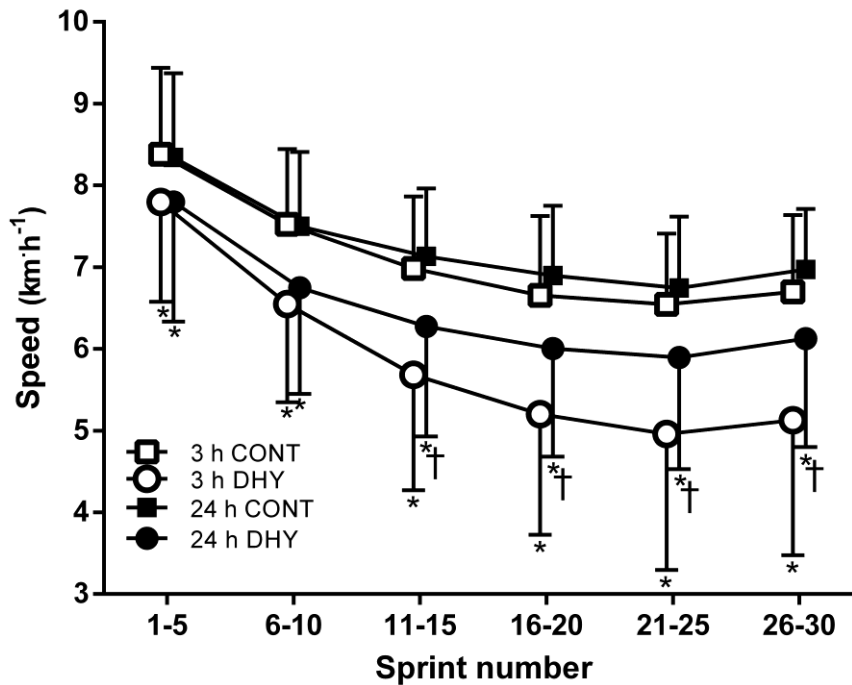


Figure 3. Sprint speed (Mean \pm SD) of the repeated sprint test with a sled for 3 h and 24 h post DHY/CONT for both control and intervention conditions. * = $P < 0.05$ compared to control condition at same time, † = $P < 0.05$ when 24 h compared to 3 h post DHY/CONT during same condition.

A significant main condition effect was found for the average sprint speed of the entire sled push test ($N=14$, $F_{(1)}=27.486$, $P < 0.001$). Post hoc analyses revealed greater speeds as large as $19 \pm 15\%$ at 3 h and 24 h post CONT when compared to 3 h ($P < 0.001$) and 24 h ($P=0.003$) post DHY, $10 \pm 16\%$ greater speeds were also found 24 h post DHY when compared to 3 h post DHY ($P=0.028$). No significant differences were found between 3 h and 24 h post CONT (0.42) (Table 1).

Table 1

Means and Standard Deviations of Performance Data from the Repeated Sprint Test using a Sled, Vertical Jump Test, Hand Grip Test and Medicine Ball Chest Throw.

	DHY		CONT	
	3 h post weight cut	24 h post weight cut	3 h post weight cut	24 h post weight cut
Average Sprint ($\text{km}\cdot\text{h}^{-1}$)	$5.65 \pm 1.3^*$	$6.36 \pm 1.44^{*\dagger}$	6.99 ± 0.85	7.12 ± 0.95
Peak Sprint ($\text{km}\cdot\text{h}^{-1}$)	$8.69 \pm 1.17^*$	$8.82 \pm 1.41^*$	9.14 ± 1.1	9.35 ± 1.06
Fatigue Index ($\text{km}\cdot\text{h}^{-1}$)	$-2.67 \pm 1.33^*$	$-1.67 \pm 0.94^\dagger$	-1.68 ± 1.07	-1.37 ± 0.7
Total Test Time (seconds)	$811 \pm 62^*$	$788 \pm 52^{*\dagger}$	759 ± 25	760 ± 30
Runs completed	$26.64 \pm 5.7^*$	29.21 ± 2.94	29.21 ± 2.94	29.29 ± 2.68
Vertical Jump (cm)	47.71 ± 7.84	47.5 ± 9.25	49.14 ± 8.4	48.5 ± 7.49
Hand Grip (Kg)	$51 \pm 8^*$	$54 \pm 9^\dagger$	53 ± 8	$56 \pm 10^\dagger$
Medicine Ball Chest Throw (cm)	454 ± 46	$449 \pm 44^*$	466 ± 49	474 ± 52

* = $P < 0.05$ when compared to CONT at same time point

\dagger = $P < 0.05$ when 24 h compared to 3 h post DHY/CONT during same condition

A significant main condition effect was found for the peak sprint speed ($N=14$, $F_{(1)}=10.382$, $P=0.007$). Post hoc analyses revealed greater peak speeds as large as $5 \pm 7\%$ 3 h and 24 h post CONT when compared to the 3 h ($P=0.025$) and 24 h ($P=0.026$) post DHY, no significant differences were found between 3 h and 24 h post CONT ($P=0.099$) and DHY ($P=0.612$) (Table 1).

4.1.2 Total test time

There was a significant main condition effect ($N=10$, $F_{(1)}=12.017$, $P=0.007$) and interaction effect ($N=10$, $F_{(1)}=7.302$, $P=0.024$) found in the total test time. Post hoc analyses revealed longer total test times 3 h and 24 h post DHY when compared to 3 h ($P=0.007$) and 24 h ($P=0.012$) post CONT with $7 \pm 6\%$ longer test times 3 post DHY. Longer total test times were found when comparing 3 h post DHY to 24 h post DHY ($P=0.023$) but no differences were found between 3 h post CONT and 24 h post CONT ($P=0.303$) (Table 1).

4.1.3 Fatigue index

There was a significant main condition effect found for the fatigue index ($N=10$, $F_{(1)}=6.298$, $P=0.033$). Post hoc analyses revealed a larger fatigue index 3 h post DHY compared to 3 h post CONT ($P=0.25$) and 3 h post DHY compared to 24 h post DHY ($P=0.014$). There were no significant differences between 24 h post DHY and 24 h post CONT ($P=0.213$), nor were there any significant differences between 3 h and 24 h post CONT ($P=0.295$) (Table 1).

4.1.4 Sprints completed

During performance testing 13 of the 14 participants were able to perform the 30 efforts of the repeated sled push both 3h and 24 h post CONT. However, only 10 of the 14 participants were able to perform the 30 efforts of the repeated sled push 3 h post DHY whilst 13 out of 14 could complete the test 24 h post DHY. There was a significant main condition effect found for total sprints completed ($N=14$, $F_{(1)}=4.83$, $P=0.047$). Post hoc analyses revealed significantly less runs completed in the 3 h post DHY compared to 3 h post CONT ($P<0.001$), no other significant differences were found (Table 1).

4.1.5 Heart rate during the repeated sprint test

A main condition effect was found for heart rate ($N=10$, $F_{(3)}=4.406$, $P=0.012$). Post hoc analysis revealed higher heart rates 3 h post DHY (average 171 bpm) compared to 24 h post DHY (average 164 bpm) ($P=0.006$). There was also a higher average heart rate during the 21-25 sprints of the 24 CONT when compared with 24 h post DHY (Figure 4).

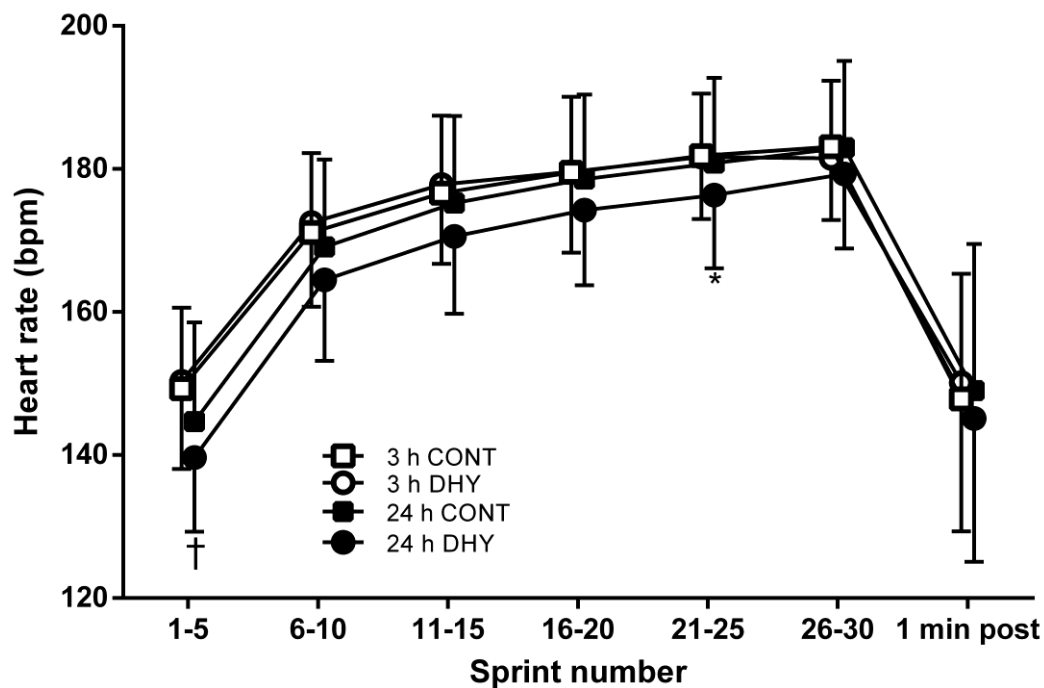


Figure 4. Heart rate (Mean \pm SD) during the repeated sprint test with a sled for 3 h and 24 h post DHY/CONT for both control and intervention conditions. * = $P < 0.05$ compared to control condition at same time, † = $P < 0.05$ when 24 h compared to 3 h post DHY/CONT during same condition.

4.1.6 Rate of Perceived Exertion (RPE)

A significant main condition effect was found for RPE during the repeat sled push ($N=10$, $F_{(3)}=9.756$, $P < 0.001$). Post hoc analyses revealed RPE was higher 3 h and 24 h post DHY when compared to 3 h and 24 h post CONT with some differences as large as $15 \pm 15\%$. RPE was

higher 3 h post DHY when compared to 24 h post DHY. No significant differences were found in RPE 3 h post CONT and 24 h post CONT (Figure 5).

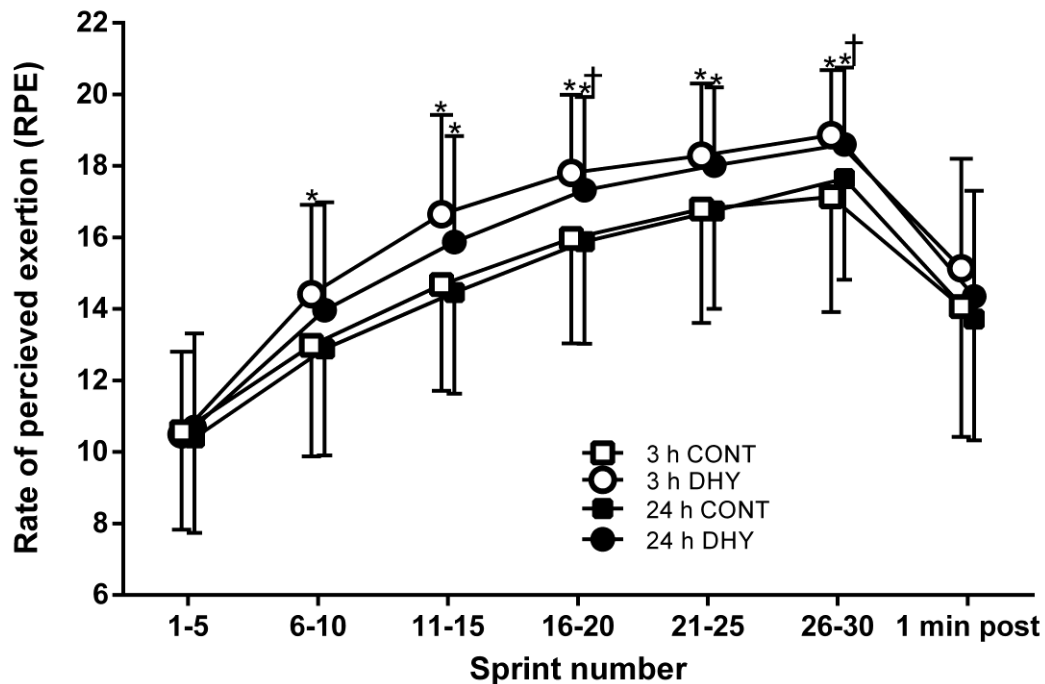


Figure 5. RPE (Mean \pm SD) during the repeated sprint test with a sled for 3 h and 24 h post DHY/CONT for both control and intervention conditions. * = $P < 0.05$ compared to control condition at same time, † = $P < 0.05$ when 24 h compared to 3 h post DHY/CONT during same condition.

4.2 Other Performance Tests

4.2.1 Vertical jump

No significant main effects were found for vertical jump height ($N=14$, $F_{(1)}=4.106$, $P=0.064$) (Table 1).

4.2.2 Hand grip strength

A significant main condition effect was found for hand grip strength ($N=14$, $F_{(1)}=7.712$, $P=0.016$). Post hoc analysis revealed $3 \pm 9\%$ greater forces 3 h post CONT compared to 3 h post

DHY (P=0.036). When comparing 24 h post DHY to 3 h post DHY a $4 \pm 7\%$ greater grip strength was observed (P=0.011) and when comparing 24 h post CONT to 3 h post CONT a $3 \pm 5\%$ greater grip strength was observed (P=0.043) (Table 1).

4.2.3 Medicine ball chest throw

A significant main condition effect was found for medicine chest ball throw distance (N=14, $F_{(1)}=9.264$, P=0.009). Post hoc analyses revealed on average $5 \pm 5\%$ greater distances were thrown 24 h post CONT compared to 24 h DHY. No other statistically significant differences were observed (Table 1).

4.3 Hydration Data

4.3.1 Body weight

A significant main condition effect (N=14, $F_{(1)}=50.158$, P=<0.001) and interaction effect (N=14, $F_{(2.863)}=13.552$, P=<0.001) was found for body weight. Post hoc analysis revealed lower body weights following the DHY compared to the CONT at all measured time points with $4.6 \pm 0.7\%$ lower body mass immediately post DHY than pre DHY (Table 2). A significant moderate correlation was found between change in DHY body mass compared to CONT 24 h post DHY and average sprint speed ($r = 0.532$ P = 0.05) whereas no significant correlation was found 3 h post DHY. No significant correlation was found between 20 min post DHY change in body weight and change in haematocrit ($r = 0.209$ P = 0.473). No significant correlation was found between 20 min post DHY change in body weight and change in serum osmolality ($r = -0.153$ P = 0.601) and no significant correlation was found between 20 min post DHY change in body weight and change in urine specific gravity ($r = 0.341$ P = 0.233).

4.3.2 Serum osmolality

A significant main condition effect ($N=14$, $F_{(1)}=12.283$, $P=0.004$) and interaction effect ($N=14$, $F_{(3)}=31.720$, $P<0.001$) was found for Serum mOsm. Post hoc analyses revealed $4 \pm 2\%$ greater serum mOsm 20 min post DHY compared to 20 min post CONT ($P<0.001$) (Table 2). No significant correlations were observed between serum osmolality and average sprint speed 3 h or 24 h post DHY.

4.3.3 Haematocrit

A significant interaction effect was found for haematocrit ($N=14$, $F_{(3)}=17.733$, $P<0.001$). Post hoc analyses revealed a higher haematocrit pre CONT compared to the pre DHY ($P=0.030$). 20 min post DHY haematocrit was $6 \pm 6\%$ greater when compared to 20 min post CONT ($P=0.003$) (Table 2). No significant correlations were observed between haematocrit and average sprint speed 3 h or 24 h post DHY.

4.3.4 Urine osmolality

There were no significant main effects found for urine osmolality ($N=14$, $F_{(1)}=1.766$, $P=0.207$) (Table 2).

4.3.5 Urine specific gravity (USG)

A significant main condition effect was found for USG ($N=14$, $F_{(1)}=16.791$, $P=0.001$). Post hoc analyses revealed that USG was significantly greater 20 min and 24 h post DHY compared with 20 min ($P=0.009$) and 24 h ($P=0.028$) post CONT with maximal differences of 1

$\pm 1\%$. No significant correlations were observed between USG and average sprint speed 3 h or 24 h post DHY.

Table 2

Means and Standard Deviations of Measures Regarding Hydration Status

	DHY					CONT				
	Pre	0 min post	20 min post	3 h post	24 h post	Pre	0 min post	20 min post	3 h post	24 h post
Body Weight (kg)	76.6 ± 9.7	73.1 ± 9*	74.2 ± 9.2*	75.5 ± 9.5*	76.1 ± 9.4*	76.8 ± 9.3	76.1 ± 9.3	76.2 ± 9.4	76.5 ± 9.5	76.5 ± 9.5
Serum mOsm/kg	288 ± 4	N/A	299 ± 6*	289 ± 3	290 ± 5	289 ± 4	N/A	288 ± 4	289 ± 4	290 ± 3
Haematocrit	44 ± 3*	N/A	47 ± 3*	45 ± 2	44 ± 2	45 ± 3	N/A	45 ± 3	44 ± 3	44 ± 3
Urine mOsm/kg	646 ± 284	N/A	603 ± 200	660 ± 319	792 ± 348	598 ± 285.19	N/A	650 ± 288	594 ± 378	652 ± 230
Urine Specific Gravity	1.02 ± 0.01	N/A	1.025 ± 0.01*	1.019 ± 0.01	1.022 ± 0.01*	1.015 ± 0.01	N/A	1.016 ± 0.01	1.016 ± 0.01	1.017 ± 0.01

* = P<0.05 when compared to CONT at same time point

N/A = Variable wasn't recorded at this time

4.4 Cardiovascular and Thermal Data

4.4.1 Heart rate

There was a significant main condition effect ($N=14$, $F_{(1)}=42.745$, $P<0.001$) and interaction effect ($N=14$, $F_{(1,689)}=22.788$, $P<0.001$) for heart rate. Post hoc analysis revealed heart rate was higher 0 min, 20 min and 3 h post DHY compared with 0 min, 20 min and 3 h post CONT (Table 3). Prior to the first performance test 3 h post DHY heart rate was $15 \pm 20\%$ higher than 3 h post CONT. No significant correlations were observed between resting heart rate and average sprint speed 3 h or 24 h post DHY.

4.4.2 Blood pressure

There were no significant main effects in systolic blood pressure between the CONT and DHY ($N=14$, $F_{(1)}=7.509$, $P=0.06$). There were also no significant main effects in diastolic blood pressure between the CONT and DHY ($N=14$, $F_{(1)}=0.915$, $P=0.356$).

4.4.3 Core temperature

There was a significant main condition effect ($N=12$, $F_{(1)}=21.054$, $P=0.001$) and interaction effect ($N=12$, $F_{(1,759)}=14.84$, $P<0.001$) for core temperature. 24 h post DHY was excluded due to small sample size as most athletes had passed the Cortemp pill by that time point. Post hoc analysis revealed core temperature was higher 0 min and 20 min post DHY when compared with 0 min ($P<0.001$) and 20 min ($P=0.008$) post CONT with core temperature being over 39°C immediately post DHY (Table 3). No significant correlations were observed between core temperature and average sprint speed 3 h DHY.

4.4.4 Tympanic temperature

There was a significant main condition effect ($N=14$, $F_{(1)}=104.923$, $P<0.001$) and interaction effect ($N=14$, $F_{(4)}=23.869$, $P<0.001$) for tympanic temperature. Post hoc analysis revealed tympanic temperature was significantly higher 0 min, 20 min and 3 h post weight DHY compared with 0 min ($P<0.001$), 20 min ($P=0.016$) and 3 h post ($P=0.015$) CONT with peak differences of $5 \pm 2\%$ (Table 3). No significant correlations were observed between tympanic temperature and average sprint speed 3 h or 24 h post DHY.

Table 3

Means and Standard Deviations of Cardiovascular and Thermal Data

	DHY					CONT				
	Pre	0 min post	20 min post	3 h post	24 h post	Pre	0 min post	20 min post	3 h post	24 h post
Heart Rate (bpm)	75 ± 15	155 ± 20*	97 ± 19*	85 ± 22*	66 ± 14	71 ± 11	105 ± 20	72 ± 13	74 ± 15	67 ± 11
Core Temperature (°C)	37.09 ± 0.44	39.06 ± 0.94*	38.55 ± 0.81*	37.37 ± 0.26	N/A	37.05 ± 0.51	37.6 ± 0.39	37.52 ± 0.46	37.3 ± 0.46	N/A
Tympanic Temperature (°C)	36.13 ± 0.55	38.5 ± 0.68*	36.74 ± 0.6*	36.68 ± 0.29*	35.99 ± 0.45	35.99 ± 0.42	36.59 ± 0.32	36.21 ± 0.52	36.39 ± 0.42	36.2 ± 0.4
Systolic Blood Pressure (mm Hg)	124 ± 4	N/A	122 ± 12	124 ± 10	127 ± 10	124 ± 10	N/A	123 ± 6	126 ± 9	128 ± 10
Diastolic Blood Pressure (mm Hg)	71 ± 10	N/A	73 ± 9	70 ± 9	69 ± 8	70 ± 7	N/A	69 ± 10	70 ± 9	71 ± 8

* = P<0.05 when compared to control group at same time point

N/A = Variable wasn't recorded at this time

CHAPTER 5

DISCUSSION

The purpose of this study was to examine the influence of 5% dehydration of body mass achieved by 3 h of sub maximal exercise, on physical performance, body temperature and hydration status at 3 h and 24 h following exercise. The main observations from this study were that 5% dehydration achieved by 3 h of submaximal exercise in the heat results in: i) notable dehydration 3 h and 24 h post DHY as evidenced by a significant reduction in body weight and elevated haematocrit, USG and serum osmolality, when compared with the CONT, ii) reduced aerobic and anaerobic performance both 3 h and 24 h post DHY (i.e repeat sprint performance, grip strength, medicine ball throw) when compared CONT. Furthermore, iii) core and tympanic temperatures were greater during the DHY when compared with CONT.

DHY resulted in significant dehydration and heat stress compared with CONT. Each athlete lost on average 4.7% body mass during the DHY but only 0.9% during the CONT protocol. Alongside this reduction in body mass, the DHY also resulted in significantly greater haematocrit, serum mOsm, USG, tympanic and core temperature, compared with CONT. There were no significant correlations between change in hydration markers and changes in body weight 20 min post DHY which could indicate the current methods of measuring hydration are insufficient in cases of acute dehydration. Previous studies into combat sports and acute weight loss protocols reported athletes using similar methods to the present study with a similar magnitude of body weight loss meaning the results of the present study could represent the

effects of such weight loss in competitions (Brito et al., 2012; Crighton et al., 2015; Hall & Lane, 2001; Kiningham & Gorenflo, 2001; Smith et al., 2000).

In the present study it was found that the athletes were hypohydrated immediately after 3 h of exercise in the heat. However, the degree of hydration prior to performance testing at 3 h and 24 h post protocol is less clear. In fact 3 h following the DHY protocol, body weight was still significantly lower than CONT suggesting dehydration. However, other markers such as haematocrit, serum mOsm and USG were not significantly different from the CONT thus not suggesting dehydration. It was further observed that 24 h post DHY there was a small difference in body weight and USG indicating athletes could have been dehydrated but again haematocrit and serum mOsm were no different at 24 h post between conditions which suggested euhydration. Given that all of these measures may be used to indicate an individual's hydration status there is some uncertainty as to the degree of rehydration that occurred during recovery in the present study. In reference to the hydration guidelines outlined by previous research only one measure suggested dehydration 3 h post DHY and two measures suggested dehydration 24 h post DHY (Armstrong, 2007; Ellershaw et al., 1995; Popowski et al., 2001). Interestingly, the USG results in the present study are similar to previous research investigating MMA athletes suggesting that athletes were dehydrated 24 h post being weighed (Jetton et al., 2013). Collectively, these results indicate that caution should be taken when using any one measure to determine hydration status. Indeed, accurately measuring hydration can be difficult (Armstrong, 2007) and given the variation in the data observed in the present study it is unclear whether hydration had returned to baseline 3 h and 24 h post DHY protocol. Even if athletes had reached baseline hydration levels it does not necessarily indicate that other physiological changes that occurred within the body during high levels of dehydration had also returned to baseline. It should be noted that the purpose of this study was to examine the effects of dehydration followed by *ad libitum* fluid and food intake on subsequent performance. This was done to provide the

greatest degree of ecological validity and information regarding the possible influence on athletic performance, rather than the precise mechanisms responsible. Given that severe dehydration can influence many physiological processes (Cheuvront et al., 2010; Maughan, 1991; Sawka et al., 2007), future research investigating the physiological alterations and time course of recovery from severe dehydration is warranted.

As expected, the dehydration observed in this study was associated with a decline in anaerobic and aerobic performance. Indeed, the specific repeat sled push protocol in this study was developed to stress both aerobic and anaerobic metabolism. The present study observed a 19% reduction in average speed over the repeated sled push test alongside a 5% reduction in peak speed. A 6% reduction in average speed of the first five sprints during the repeat sled push test was observed when comparing at 3 h post between conditions. The decrements in repeat sled push test performance were still being observed 24 h post DHY protocol with a 10% reduction in average speed, a 5% reduction in peak sprint time and a 6% reduction in average speed of the first five sprints. Further to these performance changes in the repeat sled push test, an increase in total test time at both 3 h and 24 h post DHY compared with the CONT was observed alongside a significantly larger fatigue index 3 h post DHY protocol. Furthermore, due to exhaustion less athletes were able to complete the repeat sled push test 3 h post DHY. Similar reductions in high intensity exercise performance have been observed in previous studies using rowing, cycling and boxing protocols (Burge et al., 1993; Cheuvront et al., 2010; Hall & Lane, 2001; Kraft et al., 2011; Moore et al., 1992). Further possible evidence for a reduction in anaerobic performance in the present study was a reduction in grip strength at 3 h and medicine ball throw at 24 h following DHY when compared with CONT. No significant differences in vertical jump were observed. A decrement in power of the medicine ball chest throw but not the vertical jump could suggest changes in neuromuscular function and warrants further investigation. The performance testing results in the present study align with previous research which found dehydration and

rehydration negatively affecting anaerobic performance (Jones et al., 2008; Kraft et al., 2011; Schoffstall, Branch, Leutholtz, & Swain, 2001). Some of the variables showed a large variation in results, this demonstrates that some athletes were more affected than others. It has been hypothesised that athletes may develop a resistance to rapid weight loss though a study by Mendes et al. (2013) did not confirm this hypothesis. It is also possible that differences in diet could contribute the variation in results as diet was not controlled between athletes (Rankin et al., 1996).

Given that both the anaerobic and aerobic systems significantly contribute to combat sports performance (Burge et al., 1993; Cheuvront et al., 2010; Jones et al., 2008) the results of the present study suggest that a rapid reduction in body weight via dehydration may compromise exercise capacity even 24 h following the weight loss. Such findings are important because acute dehydration is highly prevalent in many combat sports (Brito et al., 2012; Crighton et al., 2015) and athletes are weighed for competitions on either the same day or the day before the competition. In regards to being weighed on the same day or the day before a competition the present study has observed a decline in aerobic and anaerobic performance in such time frames, which could lead to a reduction in an athlete's ability to perform high intensity efforts and recover from these high intensity efforts (Kraft et al., 2011). Considering these findings, the magnitude and methods of current weight loss strategies most commonly utilised may require re-evaluation by athletes and coaching staff in order to maximise competition performance. It is unclear whether the decrements in performance are greater than any potential benefit from competing in a lighter weight class and as such should be the subject of future investigation, as athletes believe rapid weight loss to be an important part of competitive success (Durkalec-Michalski et al., 2014).

Increases in cardiovascular strain have been proposed to explain the decrements in aerobic performance associated with dehydration (Judelson et al., 2007; McArdle et al., 2010;

Murray, 2007). The present study observed on average $15 \pm 20\%$ higher heart rates 3 h post DHY suggesting a lower blood volume which could negatively affect aerobic performance by reducing cardiac output (Cheuvront et al., 2010; Judelson et al., 2007; Montain & Coyle, 1992). Resting tympanic and core temperatures were within normal ranges immediately prior to performance testing at both 3 h and 24 h post DHY/CONT with tympanic being on average 1% higher 3h post DHY and no significantly difference 24 h post DHY. These results indicate subjects were not under any form of heat stress prior to performance testing however as temperature was not tested during performance testing it is possible that thermoregulation could have been negatively affected during testing. If thermoregulation was negatively influenced it could have increased cardiovascular strain due to an increased requirement of skin blood flow and accelerated central fatigue (Cheung & Sleivert, 2004; Cheuvront et al., 2010; Judelson et al., 2007; Sawka, Cheuvront, & Kenefick, 2012).

In addition to changes in cardiovascular function, dehydration has been found to influence neuromuscular and metabolic function which can negatively affect performance (Ftaiti, Grélot, Coudreuse, & Nicol, 2001; Judelson et al., 2007; Murray, 2007). Previous literature has found that losses of electrolytes via sweat can affect nervous function such as hyperpolarising the muscle membrane electrochemical potential thus reducing muscle contractility (Jones et al., 2008; Sjøgaard, 1985). Indeed, the present study observed an increase in serum osmolality, haematocrit and USG alongside a decrease in body weight suggesting a large portion of body water was lost via sweat during the DHY. However, as the present study did not measure electrolyte balance it is unclear as to whether electrolytes affected performance. Metabolic changes as a result of dehydration have been found to lower muscle glycogen due to stimulation of the sympathetic nervous system and thus theorised to affect exercise performance (Judelson et al., 2007; Rankin et al., 1996). While it is likely that these mechanisms would have contributed to the decrements in exercise performance the present study did not have any specific measures

for neuromuscular or metabolic variables so it is unclear if they contributed to the decline in performance.

A large body of literature has examined the influence dehydration and thermal stress has on central drive and pacing (Abbiss & Laursen, 2008; Judelson et al., 2007; Tucker & Noakes, 2009). Thermal stress has been found to influence pacing in athletes through central drive (Lambert, Gibson, & Noakes, 2005; Sawka et al., 2012). Perception of exertion has been observed to influence pacing and exercise performance (Abbiss & Laursen, 2008; Lambert et al., 2005). The present study observed a higher perceived exertion at both 3 h and 24 h post DHY which could have influenced pacing and exercise performance. The cause of this increased perception of exertion is unclear and should be the subject of future research. A change in the perception of exertion could have been caused by a nocebo effect as it was impossible to blind subjects to the intervention they underwent and thus could have affected the present study's results. It is worth noting that even if a nocebo effect is present during acute dehydration it is still an effect of the process of losing such weight which negatively affects performance. As such, these findings have implications for applied sport science. Further research is needed to better understand the precise mechanisms responsible for such performance decrements.

5.1 Conclusion

In summary, this thesis examined how acute dehydration of 5% body mass, followed by a period of rehydration influences performance and physiology in mixed martial arts athletes. The present study was conducted with the aim of improving the scientific understanding of rapid dehydration followed by rehydration after 3 h and 24 h recovery periods and its effects on performance and physiology. This thesis concludes the following:

- i) Acute dehydration of 5% body mass possibly has a negative influence on performance both 3 h and 24 h after the weight was lost.
- ii) It is unclear whether athletes rehydrate adequately within 3 h and 24 h of rapid weight loss of 5% body mass.
- iii) There are likely other physiological mechanisms that were not examined in the present study influencing performance 3 h and 24 h post weight loss

Overall, the findings of this thesis suggest that acute dehydration of 5% body mass using dehydration could influence high intensity exercise performance after short (3 h) and longer (24 h) recovery periods. While we developed a battery of tests intended to examine physical characteristics relative to MMA athletes, the findings of the present study may be of importance to a large number of sports that are divided by weight classes. The mechanisms behind such performance decrements are unclear and should be the subject of future research. Acute dehydration is a common method used in weight restricted sports and this study presents information that indicates that current weight loss strategies are not conducive to optimal performance meaning athletes and coaches should reconsider these current practices.

5.2 Future Research Directions

With the results of the present study suggestions can be made for the future research and those directions include further investigation into:

- i) Further research to confirm possible performance decrements in high intensity exercise performance after short (2-4 h) and long (24 h) recovery periods following rapid weight loss using dehydration.

- ii) The effects of acute dehydration on physiological measurements such as muscle glycogen and plasma electrolyte balance.
- iii) The effects of acute dehydration on neuromuscular fatigue
- iv) The prevalence of weight loss methods and the magnitude of such weight loss specifically in MMA athletes.

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