EFFECT OF DEHYDRATION ON GOLF RELATED PERFORMANCE

BY

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LIST OF ABBREVIATIONS

ACSM	Amercian College of Sports Medicine
BML	Body Mass Loss
BRUMS	Brunel University Mood Scale
FIR	Fairway in Regulation
GIR	Green in Regulation
Pgl	Plasma Glucose
Posm	Plasma Osmolality
TBW	Total Body Water
Usg	Urine Specific Gravity
Uosm	Urine Osmolality

KESAN DEHIDRASI KE ATAS PRESTASI BERKAITAN PERMAINAN GOLF

ABSTRAK

Dehidrasi sebelum ini dilaporkan boleh mengurangkan prestasi bagi kedua-dua fungsi kognisi dan yang berkaitan sukan, dengan kebanyakan kajian yang dijalankan dalam keadaan iklim sederhana. Sehingga kini belum ada kajian yang memfokuskan kepada kesan dehidrasi ke atas prestasi berkaitan permainan golf dalam keadaan panas dan lembap. Objektif kajian ini adalah untuk mengkaji kesan dehidrasi terhadap prestasi permainan golf termasuk status penghidratan, kemahiran motor, psikomotor dan prestasi kognitif para pemain golf dalam persekitaran panas dan lembap (29.42 ± 1.59°C, 80.5 ± 5.9% RH).

Kajian ini menggunakan reka bentuk pindah silang dan uji kaji terkawal gelap ganda terawak dan merekrut seramai 17 orang pemain golf lelaki dewasa dengan handikap <15. Para pemain dibahagikan secara rawak kepada kumpulan dan diberikan salah satu daripada ujian berikut: i) tiada pengambilan air (no fluid, NF), ii) pengambilan air (water, W), iii) pengambilan larutan elektrolit karbohidrat (carbohydrate-electrolyte solution, CES). Bagi kes taburan data tidak normal, ujian Wilcoxon *signed-ranked* digunakan untuk menilai perbezaan statistik manakala BRUMS dipiawaikan kepada skor z. Pengukuran berulang ujian satu hala ANOVA dan perbandingan berganda post hoc Bonferroni digunakan untuk menentukan kesan dehidrasi ke atas prestasi terpilih yang diukur di antara ketiga-tiga uji kaji.

Penemuan kajian menunjukkan kehilangan jisim badan yang signifikan dalam uji kaji NF berbanding uji kaji W dan CES (p = 0.001). Paras glukosa plasma berkurangan secara signifikan dalam uji kaji NF (p = 0.012), W (p = 0.004) dan CES

(p = 0.003) selepas permainan 18 lubang golf berikutnya. Kadar dahaga meningkat secara signifikan selepas permainan golf dalam ketiga-tiga uji kaji (p = 0.001) tetapi lebih tinggi secara signifikan dalam uji kaji NF berbanding dengan uji kaji W (p = 0.019) dan CES (p = 0.007). Analisis kadar denyutan jantung menunjukkan peningkatan yang signifikan semasa permainan enam lubang terakhir dalam uji kaji NF apabila para pemain berada pada tee mula berbanding dengan uji kaji W (p = 0.005) dan CES (p = 0.012) dan semasa para pemain berada pada kawasan hijau berbanding dengan uji kaji W (p = 0.004) dan CES (p = 0.024).

Permainan golf tidak menunjukkan perbezaan dalam skor keseluruhan, tempoh dan bilangan langkah di antara ketiga-tiga uji kaji, bagaimanapun uji kaji NF menunjukkan bilangan pukulan leret (putts) yang tinggi secara signifikan berbanding dengan uji kaji W (p = 0.008). Uji kaji NF juga menunjukkan ketepatan pukulan sungkit (chipping) terjejas secara signifikan (p = 0.035) dan ketepatan jarak yang tidak diketahui apabila dibandingkan dengan uji kaji CES (p = 0.046). Kognisi melalui taksiran BRUMS, menunjukkan peningkatan ketegangan yang signifikan (p = 0.005) dan depresi (p = 0.001) dalam uji kaji NF dibandingkan dengan pra nilai. Tambahan pula, analisis lanjutan BRUMS menunjukkan peningkatan keletihan yang signifikan tanpa mengambil kira keadaan percubaan. Peningkatan signifikan dalam kadar penggunaan tenaga yang boleh dilihat (p = 0.001) ditunjukkan selepas permainan 18 lubang golf dalam kesemua uji kaji, walau bagaimanapun tidak signifikan di antara setiap uji kaji. Ralat penentuan jarak menunjukkan keputusan yang bercampur dengan jumlah skor ralat yang lemah secara signifikan bagi penentuan jarak sasaran yang tidak diketahui dalam uji kaji NF berbanding dengan uji kaji W (p = 0.005) dan CES (p = 0.001).

Kesimpulannya, persekitaran yang panas dan lembap tanpa pengambilan cecair sepanjang permainan 18 lubang golf menyebabkan kehilangan jisim badan yang signifikan yang menjejaskan psikomotor dan prestasi kognisi dibandingkan dengan pengambilan CES atau W. Kajian ini turut menyimpulkan bahawa tiada perbezaan dalam pengambilan CES atau W ke atas prestasi golf.

EFFECT OF DEHYDRATION ON GOLF RELATED PERFORMANCE

ABSTRACT

Dehydration has previously been reported to impair both cognition and sports related performance, with most studies conducted in temperate conditions. To our knowledge there have been no studies focusing on the effect of dehydration on golf related performance in warm and humid conditions. The objective of the present study was to investigate the effects of dehydration on golf related performance including hydration status, motor skill, psychomotor and cognitive performance of golfers in a warm and humid environment (29.42 ± 1.59°C, 80.5 ± 5.9% RH).

The study used a double blind randomized controlled trial cross-over design and recruited 17 adult male golf players with handicaps <15. Players were randomly allocated into flights and assigned to one of the following trials: i). no fluid (NF) ingestion, ii). Water (W) ingestion, iii). carbohydrate-electrolyte solution (CES) ingestion. For statistical analysis, non-usually distributed data were analysed using Wilcoxon signed-ranked, while the BRUMS was standardised by z-scores. Repeated measures of one-way ANOVA and post-hoc Bonferroni's multiple-comparison were used to determine effects of dehydration on selected performance measures between the three trials.

The findings of the study revealed a significant body mass loss in the NF trial compared to W and CES trials (p = 0.001). Plasma glucose was significantly reduced in NF (p = 0.012), W (p = 0.004) and CES (p = 0.003) following 18 holes of golf. Thirst rating increased significantly after the game of golf in all three trials (p = 0.001) but was significantly higher in the NF trial compared to W (p = 0.019) and CES (p = 0.007). Analysis of heart rate showed a significant increase during the last

six holes in the NF trial at tee-off compared to W (p = 0.005) and CES (p = 0.012) and when players were on the green compared to W (p = 0.004) and CES (p = 0.024).

Golf play showed no differences in overall score, duration and number of steps between the three trials, however, the NF trial showed a significantly higher number of putts compared to W (p = 0.008). The NF trial also revealed a significant impaired chipping accuracy (p = 0.035) and unknown distance accuracy when compared to the CES (p = 0.046) trial. Cognition, as assessed through BRUMS, showed a significant increase in tension (p = 0.005) and depression (p = 0.001) in the NF trial compared pre-values. Moreover, further analysis of BRUMS showed a significant increase in fatigue regardless of trial conditions. A significant increase in rating of perceived exertion (p = 0.001) was shown following 18 holes of golf in all three trials, however, with no significance between trials. Distance judgement error showed mixed results with significantly poorer total error scores for the unknown target distance judgement in the NF trial compared to W (p = 0.005) and CES (p = 0.001).

In conclusion, warm and humid environment with no fluid ingestion during 18 holes of golf resulted in a significant body mass loss which impaired psychomotor and cognition performance compared CES or W ingestion. The study also concluded that there were no differences in the ingestion of CES or W on golf performance.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Golf is a sport that is enjoyed throughout the world, with an estimated 55 million people playing on a regular basis (Farrally et al., 2003). It is a sport that is associated with a variety of weather conditions; a fact that can be seen when looking at tournament locations and schedules on all the major professional tours. During a golf season, players will experience extreme changes in temperature and humidity during and between tournaments. For instance, the European Tour visits Italy, USA and Malaysia within a one month period for an estimated prize of over €7,000,000. Therefore, overcoming the challenges of different weather conditions, particularly when in warm and humid conditions, may be pivotal in aiding performance.

To date, the majority of research related to golf focuses on optimising golf performance through equipment technology, psychological and biomechanical development to gain greater golf performance (Farrally et al., 2003). It has only been within the past decade that an influx of research has started investigating into the physiological demands of golf (Doan et al., 2006; Lephart et al., 2007; Sell et al., 2007; Hayes et al., 2008; Peterson, 2008; Stevenson et al., 2009; Smith et al., 2012). However, this may be attributed to the complexity in standardising physical demands associated with playing golf. Nevertheless, Hayes et al. (2008) recorded the physiological demands of playing golf in order to reproduce a laboratory based simulation of a round of golf and reported golf as a high volume with low to moderate aerobic exercise intensity.

In another study, Wells et al. (2009) investigated the physical attributes required for better golf-related skilled performance. The study reported significant correlation between abdominal endurance, average drive and putt distances. Furthermore, a correlation was found between the sit and reach tests and drive carry distance. Although golf is perceived to have low-energy rate expenditure (Ainsworth, 2000) and primarily aerobic based (Hayes et al., 2008), there are other physical demands required for optimal golfing performance such as strength, power, flexibility and balance (Doan et al., 2006; Lephart et al., 2007; Sell et al., 2007; Wells et al., 2009).

Unfortunately, there is limited research on the benefits for golf related performance (Stevenson et al., 2009, Smith et al., 2012). This may be due to the fact that golf is perceived as a low to moderate aerobic exercise intensity (Farrelly et al., 2003; Broman & Johnsson, 2004; Kobriger et al., 2006; Hayes et al., 2008). On the other hand, Stevenson et al. (2009) studied the effect of carbohydrate and caffeine (CHO+CAF) versus a non-energy placebo for putting performance. The study concluded a better putting performance in the CHO+CAF ingestion trial. This evidence suggests that in skilled golfers the ingestion of a CHO+CAF supplement prior to and during 18 holes of golf significantly increases putting motor skill performance with also greater reports in cognition (e.g. increased alertness and concentration).

The current literature related to the cognitive performance in golf suggest that players must be able to synchronise both global and fine motor control in order to generate high velocities within millimetres of accuracy, to optimise performance. For greater golf performance, it is likely that golf players require an enhanced development of automaticity in relation to biomechanics, motor skills and greater cognitive abilities (Hume et al., 2005; Thomas & Over, 1994). Therefore in effect, the ability to perform a golf swing requires a high demand for psycho-motor performance (Smith et al., 2010). Skilled golf players have showed significantly superior cognitive development compared to less skilled players (Lane & Jarrett, 2005) with cognitive training reported to lower golf handicap (Thomas & Fogarty, 1997). Thomas & Over (1994) observed that of the 165 men with handicaps ranging from 5 to 27, that the lower handicap players possessed greater cognitive traits of better concentration during golf, commitment to playing golf, fewer negative cues and greater automaticity in psychomotor performance.

Maughan (2003) reported that both physical and mental performance are adversely affected in a dehydrated state. Several studies have reported declined motor skill and cognition performances following exposure to heat and exercise that induced dehydration of approximately 2% body mass loss (Cian et al., 2000, D'Anci et al., 2009). In a golfing context, Smith et al. (2012) investigated the influence of dehydration on golf specific cognition performance. In order to induce dehydration the protocol used a 12 hour fluid restriction prior to performance measures. The study revealed that a significant over-estimation of distance judgement and impaired psychomotor performance in the dehydrated trial when compared to the hydrated trail, highlighting the importance of hydration on sports specific tasks within golf. However, according to Noakes (2007), studies that have induced dehydration through external influences (e.g. fluid restriction, heat exposure, exercise) prior to exercise do not replicate normal sporting behaviour (unless within a weight category sport). Therefore, the consequences on anticipation (i.e. pacing) to exercise could affect the validity of any study investigating the influence of dehydration on sports performance (Edwards & Noakes, 2009). Similarly, despite Stevenson et al.'s (2009) suggestion of better performance from CHO+CAF supplementation for putting performance in golf, the study could not represent overall golf performance through the use of a single measure, as skills such as tee-shots, approach shots and putting all require different strategies and club selections.

In summary, all of the previous studies in either controlled laboratory or field based settings conclude that dehydration through heat, exercise and no fluid ingestion have an adverse effect upon sporting performance (Maughan, 2003; D'Anci et al., 2009; Smith et al., 2012) particularly in sports that are likely to take place in humid environments and where a high level of cognitive performance is required (Carrasco, 2008). Due to the nature of golf performance, it would seem imperative to maintain hydration during golf as golf is of high volume and prolonged duration, with the potential for dehydration higher in warm and humid conditions. Yet, there is a lack of literature regarding the gains of adequate hydration during an 18 hole round of golf or to provide any foundation for hydration strategies for golf performance. Furthermore, most studies have used single performance assessment parameters while investigating the effect of hydration strategies in golf (Stevenson et al., 2009; Smith et al., 2012). Therefore, the aim of the present study was to add depth to the current literature on the effect of dehydration on golf performance. This would include investigating the effect of dehydration on multiple golf related motor skills, psychomotor and cognition performances related to golf. The results might provide much needed applied evidence for future interventions of hydration in golf.

1.2 Purpose of the Study

The purpose of the study was to investigate the effect of dehydration on golf related performance, particularly in warm and humid Malaysian environment.

1.3 Study Objectives

1. To investigate the effects of no fluid during golf in a warm and humid environment.
2. To assess the effects of dehydration on the golf related skill performance of golfers.
3. To study the effects of dehydration on the golf related cognitive performance of golfers.

1.4 Hypothesis

1). A significant decrease in overall golf related performance during the no fluid (NF) ingestion trial compared to water (W) and a carbohydrate-electrolyte solution (CES) ingestion trial.

2). The no fluid (NF) ingestion trial to have impaired physiological, psychomotor, motor skill and cognitive golf related performance compared to the water (W) and a carbohydrate-electrolyte solution (CES) ingestion trials.

3). The carbohydrate-electrolyte solution (CES) ingestion trial to have a greater golf related performance compared to the water (W) ingestion trial across all of the psychophysiological test battery.

1.5 Study Terminology

Body Mass Loss (BML)	- Body mass loss is a parameter used in hydration assessment, where the change in body mass loss is estimated from the difference between pre- and post- nude body mass.
Cognition	- The mental process of sensory information.
Dehydration	- A hydration status that is over 2% body mass loss (BML) with increasing severity correlated to higher body mass loss.
Euhydration	- A measure of hydration status where an individual maintains a fluid balance.
Fairways in regulation (FIR)	- A scoring measure used to assess tee-off accuracy where the ball must land on the fairway to be deemed successful.
Green in regulation (GIR)	- A scoring measure used to assess if a golf player is on the putting green in the allocated number of strokes.
Hypohydration	- A hydration status that is below 2% body mass loss (BML).
Motor Skill Performance	- An intentional act that requires the precise learned movements of a motor or muscular component.
Number of Putts	- The total number of putt attempts taken during 18 holes of golf.

Osmolality	- A measure of solutes that contributes to a solution's osmotic pressure.
Psychomotor Performance	- A combination of sensory (cognition) process and a motor activity.
Specific Gravity	- A measure of concentration of all chemical particles in a solution.
Voluntary Dehydration	- Behaviour attributed to entering a state of dehydration, either as a result of known or unknown adequate fluid ingestion.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Dehydration has been shown to have detrimental effects upon a variety of psychophysiological measures including heart rate, motor skill and mood status (McKay et al., 1997; Smith et al., 2012). Recently, dehydration has become the focus of research to investigate dehydration on sporting performance through the use of methods including diuretic (Watson et al., 2005), fluid restriction (Gopinathan et al., 1988; Hoffmann et al., 1995; D'Anci et al., 2009; Stevenson et al., 2009; Logan-Sprenger et al., 2012; Smith et al., 2012) and heat exposure (Maughan et al., 2010). However to date, it is unclear when dehydration starts to affect sporting performance as a 2% body mass loss (BML) threshold has been debated extensively as a cut-off. Of note, voluntary dehydration through reframing from drinking during exercise has negative implications on sports performance (Noakes, 2007). Physiological explanations such as hyperthermia, reduced skin blood flow and cardiovascular strain (e.g. increased heart rate) have been largely associated with dehydration and provide an explanation for diminished sports performance (Noakes, 2007). However, the frequently reported decrease in cognitive function (e.g. mood status, decision making and reaction time) may suggests that the influence of dehydration exceeds physiological explanations. Although, the negative effect of dehydration on skill based performance is not a new concept, the influence of dehydration on golf has received limited documentation (Seung Kon et al., 2005; Stevenson et al., 2009; Smith et al., 2012). Therefore, the present study aims to extend the growing literature on the impact of dehydration on psychophysiological measures in golf. The present review of literature concentrates on the implications of dehydration on psychophysiological measures in sporting performance, with particular focus in golf.

2.2 Dehydration Overview

Water equates up to 50-65% body mass and is regulated within a euhydrated boundary of approximately 0.5% total body water (TBW). The body's homeostasis allows minor fluctuations on either side of the TBW continuum and results in mainly physiological responses to regain balance. For instance, maintaining water equilibrium occurs on a daily basis and is greatly affected by lifestyle. A substantial water imbalance comes when exercising especially in the heat and can result in copious water loss predominately through sweat (Maughan, 2003). Mild voluntary dehydration, in which an individual fails to maintain fluid balance (e.g. sweating or respiration) in response to their environment, is a primary consequence associated with higher reports of headache (Shirreffs et al., 2004), lack of concentration (Patel et al., 2007) and tiredness (Szinnai et al., 2005) and if allowed to continue can be fatal beyond 10-15% body mass loss (Maughan, 2003). Water replacement strategies to attenuate water loss are essential to prevent such symptoms. This primarily consists of the use of foods high in water content or direct fluid ingestion. The importance of preventing dehydration through adequate fluid replacement not only enhances sports performance but may be associated with greater health benefits such as reduced hypertension, coronary heart disease and urinary infections (Popkin et al., 2010).

2.2.1 Hydration Status Assessment

Many sporting organisations have recommended athletes to evaluate their own fluid balance through the use of sweat loss, fluid intake and/or body mass (Armstrong et al., 1998; Armstrong, 2005). These methods are the most common assessments used for assessing hydration status due to their simplicity and low cost compared to laboratory urinalysis (e.g. plasma osmolality). Body mass loss (BML) has been previously described by D'Anci et al., (2009) to be a good predictor for hydration status and has been used in several studies investigating hydration status in sport (Dougherty et al., 2006; Stevenson et al., 2009; Carvalho et al., 2011; Logan-Sprenger et al., 2012; Smith et al., 2012).

Urine specific gravity (U_{sg}) is a measure of the density of urine versus the density of water. Urine specific gravity is considered to be a valid method for hydration status (Armstrong et al., 1998; Shireffs & Maughan, 1998; Popowski et al., 2001; Armstrong, 2005) and sensitive to changes in hydration (Oppliger et al., 2005). The National Collegiate Athletic Association (NCAA) provide guidelines for U_{sg} to identify hydration status in athletes and that a score value >1.020 indicates dehydration and is an effective cut-off for sport (Bartok et al., 2003). However, currently there is no defined U_{sg} value or cut-off for detecting hydration status across all sports. This is attributed to either the inability to define hydration or the different behaviour reported between athletes in varying sports. One such study by Shirreffs & Maughan (1998) investigated the effectiveness of day to day assessments of hydration in athletes. The study used 29 athletes, from a variety of sports, who undertook training in warm weather conditions. The study revealed that athletes, particularly in weight categories, reported higher U_{sg} compared to non-weight category sports and suggested that this was due to their behaviour towards dehydration in order to achieve a required weight (Webster et al., 1990).

In another study Stover et al. (2006) investigated the use of such a cut-off for recreational exercisers. The study revealed that the use of a <1.020 cut-off originally designed for athletes by the NCAA, resulted in a higher number of recreational exercisers reporting to training in a dehydrated state. Instead, the mean U_{sg} and standard deviation of the group was used to determine the hydration status more appropriately; a suggestion first made by Armstrong et al. (1994). As a result, a wider urine specific gravity value between 1.011 and 1.025 was suggested for determining hydration status and is in accordance with other studies for non-elite players (Armstrong et al., 1998, Popowski et al., 2001; Cheuvront et al., 2010; Hamouti et al., 2010).

The use of urine specific gravity (U_{sg}) and urine osmolality (U_{osm}) together are deemed good measures for the assessment of hydration status (Oppliger et al., 2005) as the correlation between U_{sg} and U_{osm} has been reported to be strongly correlated particularly when U_{sg} is <1.030 and U_{osm} is <1050 $mOsm.kg^{-1}$ (Armstrong et al., 1998; Hann & Waldreus, 2013). A study by Popowski et al. (2001) suggested values of U_{osm} between 284 to 289 $mOsm.kg^{-1}$ resulted in a hydration status. The report further emphasised that a higher U_{osm} was correlated to an increase in dehydration severity with a score >643 $mOsm.kg^{-1}$ resulting in a dehydrated status. These findings are similar to Shirreffs & Maughan (1998) who reported an average U_{osm} of 924 ± 99 $mOsm.kg^{-1}$ from the first morning's urine sample of hypohydrated athletes and concluded that a score more than 716 $mOsm.kg^{-1}$ was a good indicator for a hypohydration state.

Another hydration method, plasma osmolality (P_{osm}) has been suggested to be the gold standard method for predicting hydration status (Cheuvront et al., 2010). Consistent incremental rises have been reported in plasma osmolality (P_{osm}) through progressive dehydration up to 5% BML with U_{sg} and U_{osm} reported to "lag" behind P_{osm} (Oppliger & Bartok, 2002; Oppliger et al., 2005). The ACSM provide a consensus for the identification of euhydration, that states a value of <290 $mOsm.kg^{-1}$ represents a hydrated state and that a cut-off of >300 $mOsm.kg^{-1}$ could be used to predict a state of dehydration (Sawka et al., 2007). However such a consensus, which has resulted from a range of research using a variety of methodologies prior to the assessment of hydration, could mislead the evaluation of P_{osm} for hydration status. A study by Sollanek et al. (2011) investigated the impact of two common contrasting methods for evaluating hydration. The study used a total of 30 subjects, who were required to drink 1 litre of water and sports drink 12 hours prior to blood sampling, followed by a repeated sample after an acute ingestion of 500 ml of water. The results from the study showed that the majority either reported a normal (30%) or border line (53%) elevated plasma osmolality (285 to 300 $mOsm.kg^{-1}$) after the 12 hour fluid ingestion method and that the subsequent ingestion of 500 ml of water significantly diluted plasma osmolality after 90 minutes. The study recommended that the ingestion of a larger amount of water (>500 ml) over a shorter time period could result in a reduction in plasma osmolality.

2.2.2 Onset of Dehydration

Over the past decade the precise boundary in adults for categorising the severity and onset of dehydration has been contested. This is despite the vast academic research providing a threshold of 2% BML associated with poorer psychomotor performance as a result of dehydration (Noakes, 2007; Tables 2.1 & 2.2).

In support of the wealth of literature surrounding a threshold of 2% BML, both negative motor function and cognitive function (e.g. rating of fatigue and tiredness) over that of motor–skill performance (e.g. reaction time) have been correlated with dehydration of >2% BML (Table 2.1). In addition, Gopinathan et al., (1988) reported that the onset of declined cognitive performance resulted when a 2% BML was achieved and that poorer performance was correlated to the severity of dehydration. The study by Gopinathan et al., (1988) suggests that dehydration of 2% BML impairs brain function with psychomotor performance deteriorating prior to any detected physiological response (Epstein et al., 1980; Szinnai et al., 2005).

Table 2.1 Induced dehydration on psychomotor performance.

Reference	Performance	Dehydration Status/Method	Outcome
Epstein et al., (1980)	Skilled based performance	2.5% BML Climatic chamber	Reduced accuracy and speed of complex tasks.
Derave et al., (1998)	Postural Stability	2.7% BML, 3% BML Induced exercise and heat exposure	Reduced postural stability
Baker et al., (2006)	Basketball	1 - 4% BML	Progressively reduced accuracy, shooting time and number of shots.
Carrasco (2008)	Surfing Performance	3.9% BML	20.3% Performance Reduction
Smith et al., (2012)	Golf accuracy and Distance Judgement	1.45% BML	Reduced ball carry, shot accuracy and distance judgement

BML: body mass loss; VO_{2max}: maximum oxygen consumption.

The substantial wealth of documented studies (Table 2.1) concerning the onset of dehydration has allowed for numerical definitions of dehydration, however, these are still debated. Nevertheless, for the present study hypohydration is defined as <2% BML (Gopinathan et al., 1988) with severe dehydration >5% BML (Noakes et al., 1988) and dehydration between 2 to 5% BML (Derave et al., 1998; Szinnai et al., 2005).

Studies that have induced dehydration have used heat exposure, exercise, diuretic use or prolonged voluntary dehydration (Nielsen et al., 1981; Gopinathan et al., 1988; Szinnai et al., 2005; Watson et al., 2005; Smith et al., 2012). However, the use of such study designs has opened the debate over the validity of protocols that result in significant dehydration and do not simulate "normal" practice prior to performance assessment (Noakes, 2007). For instance, protocols that involve fasting for prolonged periods prior to performance assessment tend to reduce plasma osmolality, which is detected by the brain. This has been documented to result in under-performance through pacing; a situation in which an individual sub-consciously reduce performance due to inappropriate preparation (Edwards & Noakes, 2009). Thus, in essence only no fluid ingestion during the course of exercise provides an insight into the effect of dehydration on performance and reduces the effects of cofounders such as pacing for cause and effect analysis (Cian et al., 2000).

Self perceived thirst has been suggested to be a preventative mechanism detected by both physiological and psychological changes with increases in body mass loss (BML) correlated to higher self reported thirst ratings (Greenleaf, 1992). In one such study Maresh et al. (2004) used 10 males (21 ± 1 years) who participated in walking for 90 minutes in the heat (33 ºC, 56% RH). Each participant was required to attend four separate trial days in either a euhydrated or hypohydrated state (-3.8 ±

0.2 BML) and revealed higher thirst ratings in the hypohydrated trial following low to moderate intensity exercise and heat exposure. A consequence of the higher self observed thirst rating found when dehydrated have also been shown to impair cognition and motor skill performance (Gopinathan et al., 1988; Below et al., 1995; McGregor et al., 1999; Devlin et al., 2001; Maughan, 2003; Cheuvront et al., 2003; Maughan, 2004; Baker et al., 2007; Grandjean & Grandjean, 2007; Maughan et al., 2010).

In contrast, a review by Noakes (2007) suggested that the concentration on reductionism; a term used to break down a phenomena (e.g. dehydration) into small components, is a too simplistic model to explain the reduced performance associated with dehydration. This is because trained individuals who drink to their own thirst response have been documented to maintain performance in the presence of significant BML (Noakes, 1993; Landers et al., 2001; Sharwood et al., 2004; Cheuvront & Sawka, 2005). Therefore, the brain's protective mechanism to maintain hydration through perceptions of thirst suggests that a numerical definition (e.g. 2% BML) may not be suitable for athletic or experienced individuals (Noakes, 1993; Noakes & Martin, 2002; Noakes, 2007).

Nevertheless, it is accepted that no fluid ingestion for prolonged periods, regardless of the environment, will result in increased risk of dehydration and thus psycho-physiological stress. Therefore, the present study aims to address the issues highlighted by Noakes (2007) in the present study design so as to provide a meaningful analysis of dehydration on golf performance.

2.2.3 Physiological Responses to Dehydration

Hyperthermia, cardiovascular strain, increased glycogen utilization and reduced skeletal muscle blood flow describe the complex combination of physiological responses that may provide biological basis for impaired performance while dehydrated (Sawka & Young, 2006; Noakes, 2007). The implications of these physiological responses are discussed below.

2.2.3.1 Influence of Dehydration on Thermoregulation

The ability of the body to adapt to the environment in order to maintain a core temperature of 37 °C within fine boundaries is controlled by the thermoregulatory system (Maughan et al., 2004). Similar to the TBW continuum, there are physiologically safe limits to which the body can tolerate thermal distortion and if exceeded results in physiological responses to gain or dissipate heat. For instance, high environmental temperature directly reduces the efficiency of the body to maintain thermoregulation (Maughan, 2003; Maughan et al., 2007) and is amplified when exercising in such conditions (Gonzalez-Alonso et al., 1994; Gonzalez-Alonso et al., 2008). It has been documented that voluntary fatigue occurs at approximately 40 °C (Nielsen et al., 1993; Nybo & Nielsen, 2001) and that poorer performance (e.g. time to exhaustion) is directly affected by ambient temperatures (Parkin et al., 1999), pre-exercise core temperatures (Gonzalez-Alonso et al., 1998) and hydration status (Latzka et al., 1998; Jeukendrup, 2004). This has led to the investigation of both pre-cooling strategies to act as a temperature sink for improved performance (Gonzalez-Alonso et al., 1998) along with carbohydrate ingestion for better performance in different ambient temperature (Fabbraio et al., 1996).

When exercising in a high temperature environment, evaporation (e.g. sweating) becomes the singular mechanism for the body to dissipate heat (Maughan, 2003). This leads to a greater sweat secretion that lowers core temperature at the expense of water loss resulting in induced dehydration.

A large skin-ambient temperature gradient is required to maintain constant evaporative effectiveness (Maughan et al., 2007; Williams et al., 2007). However, in warm and humid environments this is reduced and necessitates an increase in blood flow to the skin and away from the brain and skeletal muscles, resulting in enhanced ratings of fatigue and exertion (Maughan et al., 2007). Another concern for athletes that exercise in a warm and humid environment is that heat dissipation through the water vapour gradient from the skin is highest during dry conditions (Maughan et al., 2007). Therefore, when exercising in a warm and humid environment, the efficiency of sweating to reduce core temperature contributes to the onset of dehydration and negative associated performance (Gonzalez-Alonso et al., 1998; Gonzalez-Alonso et al., 2008).

2.2.3.2 Cardiovascular Response to Dehydration

A physiological consideration for poorer performance during either prolonged water restriction (Szinnai et al., 2005), exercise (Armstrong et al., 1998) or diuretic use (Watson et al., 2005) is the relationship between dehydration and cardiovascular stress (e.g. increase blood osmolality). For instance, exercise-induced dehydration through episodes of low to moderate intensity (e.g. cycling 55%-60% VO_{2max}) in temperate environments have reported decreased body mass loss (2% BML) with significant elevations in heart rate compared to hydrated subjects (Derave et al., 1998; Popkin et al., 2010). In addition, sensations of thirst have not been reported to occur until >2% BML (Adolph & Associates, 1947) which would inevitably lead to an unawareness of current individual state of hydration. Therefore, such a situation may delay water intake and result in increased heart rate, reduced blood volume and low cardiac output (Sawka & Pandolf, 1990; Gonzalez-Alonso et al., 1998; Popkin et al., 2010).

As a response to dehydration, an increase in heart rate to combat a decrease in stroke volume and cardiac output occur. This occurs in conjunction with blood vessels that aid the shunting of blood flow away from the skeletal muscles and towards the skin for regulating temperature (Maughan, 2003; Maughan et al., 2007).

The body is able to store fluid within either the intracellular (e.g. inside cells) or extracellular (e.g. interstitial fluid) compartments. One of the most abundant bodily fluids is plasma which accounts for up to 20% of extracellular fluid. Plasma predominantly contributes towards fluid loss, as the majority of water is lost through sweating and results in reduced blood volume and increased plasma osmolality (Armstrong et al., 1998; Popkin et al., 2010) even prior to 2% BML during prolonged water abstinence (Szinnai et al., 2005).

Due to the low to moderate cardiovascular demands associated with golf (Broman & Johnsson, 2004), the use of no fluid ingestion and environmental changes could contribute towards a decrease in body mass loss and increased cardiovascular strain during 18 holes of golf in a warm and humid environment. The use of no fluid ingestion over a prolonged period (e.g. >12 hours) prior to golf performance has resulted in a significant ($p<0.05$) increase in body mass loss and heart rate (Petersen, 2008; Smith et al., 2012). However, to the author's knowledge there are no documented reports investigating the responses to no fluid ingestion compared to fluid ingestion on cardiovascular strain in golf (e.g. heart rate). Therefore, the present study will be the first to document the cardiovascular response to dehydration during 18 holes of golf in a warm and humid environment. This may add depth to the existing literature regarding the potential % BML and severity of dehydration during water restriction in golf.

2.2.4 Influence of Dehydration on Cognition

Self-reported changes in cognitive function help to identify impaired brain function. Impaired cognitive function results in reduced short term memory, attention, tiredness and concentration (Cian et al., 2000; Cian et al., 2001; Shirreffs et al., 2004; Szinnai et al., 2004; Armstrong et al., 2012) and has been reported to initiate at 1.5% BML (Lieberman, 2012).

The literature on negative mood and cognition during episodes of dehydration are reported (Table 2.2). However, the frequent use of exercise to induce dehydration cannot exclude influential parameters such as fatigue associated with negative mood (D'Anci et al., 2009). This may provide an explanation for the declined mood status reported during dehydration (Table 2.2) and following 18 holes of golf (Lane & Jarrett, 2005). This suggestion is similar to previous studies that have reported minimal changes towards negative mood status during dehydration as a result of prolonged no fluid ingestion without exercise (Shirreffs et al., 2004; Petri et al., 2006). Ganio et al. (2011) used 26 adult males to complete three bouts of 40 minutes walking in warm laboratory environment (27.7 ± 0.9 ºC, 42 ± 12% RH). The study method included exercise-induced dehydration with a diuretic, without a diuretic (placebo) and while maintaining euhydration. The study reported a 1% BML in both the diuretic and non-diuretic protocols, with tension significantly increased at rest ($p<0.05$) and fatigue significant only after exercise ($p<0.05$). Therefore, changes towards negative mood status may be associated with exercise (e.g. golf), which may result in higher reports of fatigue leading to poorer performance. In one such study, Seung Kon et al. (2005) assessed self ratings of RPE and fatigue on six male professional golfers during three different putting trials. The study reported that the fluid ingestion trial significantly lowered self reported RPE and fatigue, which resulted in better putting performance. Therefore, the study suggested that the better putting performance was as a result of fluid ingestion and provides an insight into the potential for better golf performance from fluid ingestion.

Maughan (2003) reported poorer cognition performance of reduced alertness and attention with higher self reported headaches following prolonged (37 hour) no fluid ingestion to induce dehydration of 2.86% body mass loss. Similarly, Derave et al. (1998) showed an impaired motor skill performance when a 2.7% BML resulted from no fluid ingestion during continuous low to moderate cycling (56-63% $V0_{2max}$) for 2 hours. The application of no fluid ingestion over 24 hours to result in a significant cognitive impairment may be deemed impractical as it does not reflect normal behaviour prior to performance (Shirreffs et al., 2004; Noakes, 2007). Nevertheless, these studies illustrate the importance of regular water ingestion for the maintenance of cognitive function regardless of activity level.

The influence of dehydration on reduced cognition has been highlighted by Cohen (1983) and later through Barr's Workspace theory (Barr, 1993); this theory is based on the hypothesis that cognition has a limited capacity and that complex task require a higher cognitive demand (Kennedy & Scholey, 2004). The suggestion that dehydration competes for "executive" space could explain impaired cognition associated with complex tasks in a dehydrated state (Table 2.2).

Table. 2.2 Influence of dehydration on cognition.

Reference	Hydration Status	Cognitive Performance	
		↑	↓
Gopinathan et al., (1988)	1,2,3 and 4% BML	-	Short-term memory: Incremental impairment over 2% BML
Cian et al., (2000)	2.8% BML	Fatigue	Short-term memory
Shirreffs et al., (2004)	2.7% BML	Reports of headache	Concentration & Alertness
Szinnai et al., (2005)	2.6% BML	Tiredness & effort	Alertness
Patel et al., (2007)	2.5% BML	Dizziness, headache & fatigue	Concentration
D'Anci et al., (2009)	2.0% BML	Thirst ratings	Attention & mood
Ganio et al., (2011)	1.0% BML	Anxiety, tension & fatigue	Working memory response

% BML: percentage body mass loss; ↑: increase in performance; ↓: decrease in performance.

Alternatively, despite the relationship documented between poorer cognition and dehydration (Wilson & Morley, 2003), some athletes seem to endure the effect of dehydration on cognition when allowed to drink to their own thirst (Smith et al., 2000; Landers et al., 2001; Sharwood et al., 2004; Cheuvront & Sawka, 2005). This supports the fact that the thirst response is a tool (Noakes, 2007) used by the brain to improve fluid balance during episodes of dehydration (D'Anci et al., 2009). On the other hand, according to Barr's Workspace Theory (1993) the ability to respond to a thirst response even as a tool would reduce executive space. This would result in a higher cognitive demand due to a higher thirst drive reported during dehydration (Maresh et al., 2004). Therefore, hydration strategies to minimise additional cognition demand regardless of their nature may aid to improve cognition.

Kennedy & Scholey (2004) suggested that an increase in glucose is needed due to greater brain function to perform complex skills. Similarly, better golf specific motor skills (e.g. putting) have been documented to correlate with endogenous availability of glucose compared to a non energy placebo trial (Stevenson et al., 2009). The same relationship has been documented for cognitive performance (D’Anci et al., 2009; Stevenson et al., 2009). Collectively, these studies suggest that tasks high in cognitive demand and multi joint coordinated movements (e.g. golf swing) could result in better performance from glucose ingestion. In contrast, the ingestion of glucose has not consistently shown a positive effect on all areas of cognition during varying complex tasks (D’Anci et al., 2009), while the degree of improvement compared to episodes of water restriction has yet to be documented in golf performance.

More research is required to understand the effect of dehydration on cognition for golf performance, specifically in decision making. Recently, Smith et al. (2012) documented the impact of mild dehydration on cognitive function in low handicap golfers. The study used distance judgements totalling a distance of 2588 m following water restriction in simulated golf. The authors reported that dehydration resulted in a significant overestimation of distance (2677 ± 209 m) compared to euhydrated state (2600 ± 81 m) denoting the importance of adequate hydration on cognition during golf. However, the use of static pictures for assessing distance along with the single cognitive test of distance judgement may provide a too simplistic assessment of cognitive function during dehydration in golf. Therefore, future research should focus on using a battery of indices that use distance judgement during golf play.

2.2.5 Influence of Dehydration on Skill Performance

The skilled performance under conditions of dehydration has mainly been investigated in high intensity sports in relation to accuracy. In one such study, Davey et al. (2002) reported a significant decline in tennis serve and ground stroke accuracy of 30% and 69%, respectively during hypohydration of 1.5% BML after maximal fatigue. Similarly, the higher reported fatigue following golf play (Stevenson et al., 2009) and that fatigue impairs multi joint performance (Gauchard et al., 2002; Royal et al., 2006; Tripp et al., 2004) could suggest that dehydration could increase subjective fatigue ratings in golf players that impair performance skill.

Superior skill based performance has been reported to rely upon a combination of psychomotor and cognitive functions (Carrasco, 2008). However, some studies have not used a combined psychophysiological measure during skilled performance to assess the influence of dehydration (Davey et al., 2002), despite the wealth of documented evidence supporting the correlation between dehydration and impaired cognition performance (Table 2.2). Therefore, it is important the decision to include a psycho-physiological test battery to further understand the decline in performance. Furthermore, this would decrease validity issues that would confound effects of no fluid ingestion on sports performance (Carvalho et al., 2011).

Contrasting reports have come from studies that have included a psychophysiological measure for performance assessment. For instance, Carvalho et al. (2011) investigated the benefit of fluid ingestion over that of no fluid ingestion and reported increased perceived exertion (RPE) without significant impaired basketball performance. On the other hand, McGregor et al. (1999) and Edwards et al. (2007) reported a maintained concentration level but impaired psychomotor ability during soccer based skills (e.g. dribbling) when players were dehydrated compared to euhydrated. These studies suggest that concentration while dehydrated was not impaired and that the player's concentration level had a limited influence on skilled soccer performance. However, all of the above studies did not use a multi-cognitive or sports specific cognition test battery and as a result could underestimate the depth of impairment in cognition. Therefore, further research that uses a cognitive test battery must ensure sports specificity and consider the broad range of cognition associated in the sport.

To the authors' knowledge, there are two preceding articles that investigate the influence of fluid ingestion on golf related performance. One of these by Stevenson et al. (2009) using 20 male, middle handicap (15 ± 4) golfers investigated the effect of carbohydrate-caffeine solution vs. water placebo during putting performance. The players were required to complete the simulated golf protocol devised by Hayes et al. (2008) with skilled performance assessed through two meter and five meter putts. The study reported that putting performance of the caffeine-carbohydrate solution trial was significantly improved over two meters ($p<0.05$) and during the last 6 holes of 18 holes completed ($p<0.05$). The additional breakdown of the results reported that the water placebo trial significantly increased the number of putts over two meters ($p<0.01$) with increases in the total distance missed over both two meter and five meter distances ($p<0.01$). This study provides primary evidence for the application of ingestion of a caffeine-carbohydrate solution to positively improved putting performance. However, the use of a single golf specific motor-skill measure (e.g. putting) by Stevenson et al. (2009) cannot evaluate the overall golf performance. Therefore, as golf performance requires the ability to perform a variety of skill related tasks (e.g. tee shots and iron play). Future research regarding dehydration should widen to include such skill performance.