

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

Effects of exercise-induced dehydration on cognitive ability, muscular endurance and surfing performance

A thesis presented in partial fulfilment of the requirements for
the degree of

Master of Science
in
Sport and Exercise Science

Massey University, Auckland, New Zealand

Alexander Jason Carrasco

2008

ACKNOWLEDGEMENT

This research was made possible by the generosity of the participants who allowed me to assess their hydration status, cognitive ability, muscular endurance and surfing performance. I thank them for their time and commitment.

Thanks also to Dr Ajmol Ali and Dr Andrew Foskett for their supervision and support in helping generate this body of work.

ABSTRACT

The aim of this study was to measure the degree of dehydration experienced during surf practice and examine the effect this might have on surfing performance, cognitive function and muscular endurance of elite surfers. Twelve male national and international level surfers volunteered to take part in the study. Their mean (\pm SD) age, body mass, height and surfing experience were 27.0 ± 3.3 years, 73.2 ± 7.1 kg, 1.7 ± 0.05 m and 21.0 ± 3.1 years, respectively.

The participants were randomly assigned to one of two trials: no fluid ingestion (NF) or fluid ingestion (FI) during 100 min of surf practice in a steamer wetsuit. The experiment was designed to emulate not only the physical and cognitive demands of surfing but also the ambient environment in which it takes place. Before and immediately after surf practice, the participants had their hydration status measured, completed a cognitive test battery and upper and lower-body muscular endurance tests. Surfing performance was assessed during the first and last 20 min of practice.

At the conclusion of the NF trial, participants showed a $3.9 \pm 0.7\%$ body mass (BM) loss, this was significantly greater ($P < 0.05$) than the $1.6 \pm 0.7\%$ BM loss seen at the end of the FI trial. In the NF trial, surfing performance decreased by $20.3 \pm 7.1\%$, but showed a slight improvement in the FI trial ($1.9 \pm 10.2\%$). Of the six cognitive domains assessed (short-term memory, information processing speed, working memory, attention, visuomotor skill and visual acuity) all were significantly impaired when at a $3.9 \pm 0.7\%$ BM loss ($P < 0.05$) yet were unaffected at a $1.6 \pm 0.7\%$ BM loss. Information

processing speed and working memory were the most strongly correlated to surfing performance ($r = 0.74$; $P < 0.05$). At the conclusion of the NF trial upper and lower-body muscular endurance were diminished by $21.2 \pm 5.5\%$ and $4.4 \pm 5.8\%$, respectively. At the conclusion of the FI trial upper-body muscular endurance was reduced by $17.0 \pm 4.1\%$ while lower-body muscular endurance was marginally better ($1 \pm 3\%$). There was a significant difference in muscular endurance capacity between trials yet no significant correlation was observed between muscular endurance and surfing performance.

The findings of this study suggest that surf practice for 100 min in a steamer wetsuit results in BM loss severe enough to significantly impair surfing performance, cognitive function and muscular endurance. Yet, when water is consumed during surf practice, surfing performance, cognitive function and lower body (but not upper-body) muscular endurance is maintained.

Keywords: fluid ingestion, surf training, steamer wetsuit, hypohydration.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENT	i
ABSTRACT	ii
TABLE OF CONTENTS	iv
LIST OF FIGURES	vii
LIST OF TABLE	viii
CHAPTER 1 INTRODUCTION	1
1.1 Statement of the hypotheses	5
CHAPTER 2 REVIEW OF LITERATURE	6
2.1 Evolution of surfing	6
2.2 The surfing process	11
2.2.1 Paddling out	12
2.2.2 Wave selection	13
2.2.3 Catching a wave	14
2.2.4 Prone to standing	15
2.2.5 Wave riding	16
2.3 Physical characteristics of surfers	17
2.3.1 Age	17
2.3.2 Anthropometry	18
2.4 Aerobic and anaerobic demands of surfing	21

2.5 Physiological characteristics of surfers	24
2.5.1 Peak oxygen uptake	24
2.5.2 Heart rate recovery	27
2.5.3 Temperature regulation during surfing	28
2.7 Dehydration	31
2.6.1 The role of water	31
2.6.2 Exercise induced dehydration	32
2.6.3 Effects on neuromuscular ability	33
2.6.4 Effects on performance	34
2.6.5 Effects on cognitive function	37
2.6.6 Dehydration in aquatic environments	39
2.6.7 Dehydration in surfing	40
2.7 Summary	42
 CHAPTER 3 METHODS	 43
3.1 Participants and criteria for selection	43
3.2 Description of measurements used	44
3.2.1 Hydration status and height	44
3.2.2 Cognitive function	46
3.2.3 Muscular endurance	47
3.2.4 Surfing performance	47
3.2.5 Environmental conditions	48
3.3 Surfing protocol	49
3.4 Familiarisation session	50

3.5 Experimental design and protocol	51
3.5.1 Experimental environment	51
3.5.2 Experimental protocol	51
3.6 Statistical analysis	53
CHAPTER 4 RESULTS	54
4.1 Environmental conditions	54
4.2 Hydration status	54
4.3 Performance parameters	56
4.3.1 Surfing performance	56
4.3.2 Short-term memory test	57
4.3.3 Paced serial addition test	58
4.3.4 Trail making test	59
4.3.5 One-min push-up test	60
4.3.6 One-min step-up test	61
CHAPTER 5 DISCUSSION	63
5.1 Conclusion	76
5.2 Limitations	78
5.3 Recommendations for future research	80
REFERENCES	81
APPENDICES A: Questionnaires and consent forms	97
APPENDICES B: Tests and surfing performance scores	102

LIST OF FIGURES

	Page
2.1 Traversing across a wave	7
2.2 Bottom turning a short board	8
2.3 Taking-off on a large wave	8
2.4 Bottom-turning on a large wave	8
2.5 Professional surfer performing a backhand aerial	9
2.5 Small waves of California	10
2.6 Large waves of Hawaii	10
2.7 Percentage of time spent paddling, stationary and wave riding	13
2.8 Somatoplot of elite athletes for different aquatic sports	19
2.9 Heart rate zones during a 20-min competitive surfing session	22
2.10 Steamer wetsuit	29
2.11 Spring-suit wetsuit	29
3.1 Diagrammatic representation of the beaches used	50
3.2. Schematic representation of the experimental protocol	51
4.1 Delta difference in body mass between both experimental conditions	55
4.2 Delta difference in wave scores under both experimental conditions	56
4.3 Delta difference in short-term memory under both experimental conditions	57
4.4 Delta difference in arithmetic ability under both experimental conditions	58
4.5 Delta difference in trail marking ability under both experimental conditions	59
4.6 Delta difference in push-up ability under both experimental conditions	60
4.7 Delta difference in step-up ability under both experimental conditions	61

LIST OF TABLES

	Page
2.1 The physical characteristics of elite surfers, aquatic athletes and alpine skiers.	18
2.2 Peak oxygen uptake ($\dot{V}O_{2\text{peak}}$) values for upper-body untrained males	25
2.3 Lower-body Peak oxygen uptake for endurance-trained athletes	26
2.4. Peak oxygen uptake values for upper-body trained male athlete	26
5.1 Reduction in body mass experienced in intermittent sports	64

CHAPTER 1 INTRODUCTION

Exercise-induced dehydration refers to hypohydration that develops during the course of an exercise session, and is usually of greatest relevance to participants in endurance activities (Kleiner, 1999). Vigorous exercise, particularly in hot or humid environments, leads to increased sweat rates, that when exceeding water intake, results in both intracellular and extracellular fluid volume deficits (Nielsen et al., 1990). It also results in plasma hypertonicity and plasma hypovolemia, both of which adversely affect the body's ability to dissipate heat and perform tasks (Sawka and Pandolf, 1992).

Of concern, and the primary focus of this thesis, is the effect of exercise-induced dehydration on elite surfers during practice. It is widely accepted that hours of continuous sub-maximal exercise, in hot humid conditions with restricted fluid intake, will cause dehydration (Coyle and Montain, 1992). This can lead to decreased neuromuscular ability (Kleiner, 1999) and cognitive function (Cain et al., 2000), which could adversely affect surfing performance.

Elite surfers practice between 1 to 5 hours per session several times a day (Stapelberg, 1996; Mendez-Villanueva and Bishop, 2005). During the course of a practice session they will generally be performing one of three activities: paddling, maintaining position or wave riding (Meir et al., 1991). Paddling is a repetitive and physically demanding process required to move the surfer from the shoreline to the take-off zone and then onto waves (Lowdon, 1994). It is an upper-body endurance activity of mixed intensity and

accounts for approximately 45–50% of a surfing session (Meir et al., 1991). Maintaining position is a low intensity activity relying more on skill than physical effort (Burrow, 2005). It requires the surfer to identify superior waves and accounts for 35–40% of a practice session (Meir et al., 1991; Mendez-Villanueva and Bishop, 2005). Wave riding is a high intensity anaerobic activity that is a mixture of physical prowess and skill. During the wave riding process the surfer attempts to perform controlled powerful manoeuvres in the most critical section of the wave (Burrow, 2005). This requires a combination of lower-body muscular endurance to manoeuvre the surfboard and skill to correctly respond to visual and proprioceptive cues (Burrow, 2005). Unlike paddling and maintaining position, wave riding accounts for less than 5% of practice (Meir et al., 1991; Mendez-Villanueva and Bishop, 2005). The remainder of a surfing session is shared between various other activities such as duck diving and retrieving the board after falling off (Lowdon, 1994).

In surfing, and other aquatic activities where heat loss can be extreme, participants use wetsuits to limit the amount of heat loss experienced during water exposure (Burrow, 2005; Wakabayashi et al., 2007). The wetsuit acts as a thermal insulator, trapping metabolic heat by creating a semi-impermeable barrier between the skin's surface area and the external environment (Webster, 1990). It has long been thought that conducting physical activity whilst wearing a wetsuit in an aquatic environment poses little to no threat of heat stress or hyperthermia. This is due to the wetsuit's inability to restrict water entry, which leads to metabolic heat being rapidly conducted away from the body to the water (Wolf et al., 1985; Shiraki et al., 1986; Yeon et al., 1987; Wakabayashi et al., 2007). Moreover, several studies have reported that moderate exercise, particularly in

turbulent wave conditions, increases water entry into the wetsuit and accelerates convective heat loss (Veicsteinas et al., 1982; Wolf et al., 1985; Cotter and Taylor, 1995). However, with advancements in materials and the methods used to join neoprene panels, wetsuits seem to be increasingly more efficient at restricting water entry and thus insulating body heat. The problem posed is the body may not be able to compensate for the added heat stress and thus be predisposed to the adverse physiological and psychological effects associated with uncompensable heat-stress (Givoni, 1972; Gonzalez, 1998). Such effects have been observed in wrestling and boxing where the use of thermorestrictive clothing in conjunction with exercise is often employed to 'make weight' (Yankanich et al., 1998). This practice, which is usually combined with fluid restriction, typically results in severe hypohydration (<4%), reduced anaerobic capacity, hyperthermia and has been the cause of several deaths (Webster et al., 1990; Yankanich et al., 1998; Smith et al., 2000).

Aquatic environments are also known to exacerbate fluid loss (Lollgen et al., 1981; Norsk et al., 1993). Hydrostatic pressure, as a result of water immersion, causes an initial increase in plasma volume, a release of atrial natriuretic peptide (ANP), but no change in arginine vasopressin (AVP; Hope et al., 2001). It is this unaltered AVP level that leads to an increase in diuresis, sodium excretion (Greenleaf et al., 1983, Hope et al., 2001) and subsequently a decrease in total body fluid (Norsk et al., 1993). Interestingly, the effects of water immersion on fluid loss are intensified when in salt water as opposed to fresh water (Hertig et al., 1962).

Given that surfing is an endurance-based sport, conducted whilst wearing a wetsuit, in an environment known to exacerbate fluid loss, it would seem logical that surfers would take measures to prevent hypohydration. Unfortunately, research in this area has identified this as not being the case (Felder et al., 1998). In a study conducted by Felder et al., (1998) on the nutritional practices of elite female surfers, it was found that in the 4-day lead-up to the Rip Curl Bells Beach Classic (one of the largest events on the professional tour), competitors made little to no attempt to hydrate prior to, during, or after training. It is well known that fluid consumption can attenuate performance declines in endurance and intermittent sports (Sawka and Pandolf, 1990; McGregor et al., 1999; Chevront et al., 2003) and the reported lack of adequate hydration during surf training may have adverse effects on neuromuscular ability, cognitive function and ultimately surfing performance.

The effects of hypohydration on neuromuscular ability are largely dependent on the level of hypohydration and heat stress experienced (Gonzalez-Alonso et al., 1998; Barr, 1999). It is widely accepted that moderate hypohydration (2-3%) alone does not significantly alter isometric strength (Greiwe et al, 1998) or anaerobic performance (Jacobs, 1980). Yet, it does decrease muscular endurance and maximal aerobic power (Sawka and Pandolf, 1990). When exercise is conducted at a submaximal intensity with moderate heat stress, there is a marked increase in cardiovascular strain and a significant reduction in cardiac output (Montain et al, 1998). When severe hypohydration (>5%) is combined with heat stress, not only is aerobic capacity reduced (Coyle, 2004) but also isometric strength, anaerobic capacity, lactate threshold and aerobic power (Webster, 1990).

Research conducted on time-based sports such as running, swimming and cycling, has shown that impaired neuromuscular ability adversely effects performance (Bosco, 1974; Barr, 1999; Kleiner, 1999). However, sports (such as surfing) that predominately rely on decision-making, reaction time, short-term memory, proprioception and information processing ability may be more susceptible to declines in cognitive function rather than neuromuscular ability (Smith et al., 2000). If this is the case, then at a 2-3% hypohydrated state, reaction time, short-term memory, tracking ability, working memory, information processing speed and attention, could be significantly compromised (Gopinathan et al., 1998; Cain et al., 2000). And, as has been established in the game of soccer, a sport that relies on skill and not physical prowess alone, exercise induced hypohydration has been found to significantly reduce skill performance (McGregor et al., 1999).

Therefore, the aim of this study is twofold: firstly to identify the degree of dehydration incurred during surf training in a steamer wetsuit; and secondly to examine the affects this has on surfing performance.

1.1 Statement of hypotheses

It is hypothesised that the intensity, ambient environment, and absence of fluid intake during current surf training will result in a 3-4 % dehydrated state. Furthermore, it is hypothesised that at this state of dehydration, cognitive function, muscular endurance and surfing performance will be adversely affected.

The following review of literature explores the progression of surfing from a recreational activity to a mainstream competitive sport, identifies the physical and cognitive demands of surfing along with the physical and physiological characteristics of today's elite surfer. As the hydration status of elite surfers is of primary interest, the review examines the causes of fatigue and the effects dehydration may have on athletic performance, cognitive function, and muscular ability.

2.1 The evolution of surfing

The origins of surfing date back several hundred years and, although the ocean environment has changed very little, innovations in materials and high participation rates have brought about dramatic changes in technique, training and physiological demands. One such change was the advent of the fin. This seemingly small design modification enabled surfers to traverse across the wave's face and perform balance related tricks such as 'hanging ten' and 'walking the plank' (refer to Figure 2.1).

During these early years of surfing, only those living in warm climates conducive to aquatic activities participated in the sport. However, with the introduction of the wetsuit, those living in colder climates were able to withstand water conditions previously deemed too cold for surfing (Young, 2000). The increase in accessibility led to a boom in participation and in 1964 the first world champion was crowned. The judging criteria

primarily focused on riding distance and style but took into account turning and wave selection (Young, 2000).

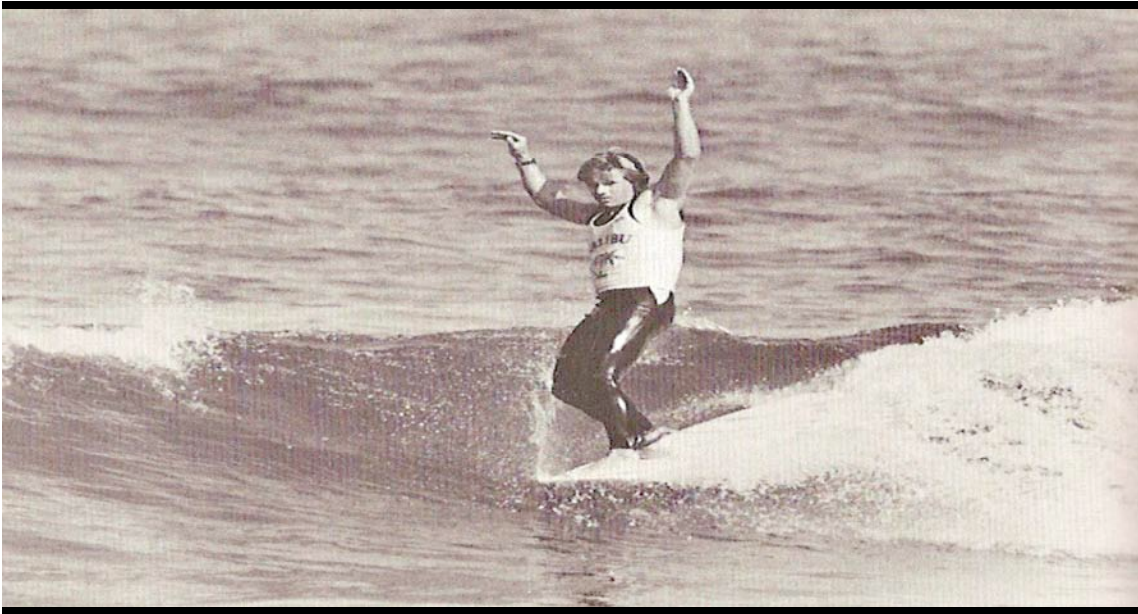


Fig. 2.1 Traversing across a wave whilst ‘walking the plank’ (photo from Young, 2000)

In the late 1960s and early 1970s competitive surfing had become increasingly more popular. The need for a competitive advantage was such that it led to the development of boards that were not only lighter and easier to turn but far shorter in length, known as Short Boards. The Short Board allowed the surfer to rebound off the top of the wave, turn back into the white water and maintain stability while inside the curl of the wave (Figure 2.2). This agile, wave-powered style of surfing all but rendered the Long Board obsolete (Young, 2000). However, as the Short Board was less buoyant, it required greater physical effort to paddle and larger waves to generate the required speed to maintain board stability (Young, 2000).



Fig. 2.2 Bottom turning a short board during the early 1970s (photo from Young, 2000)

Another seemingly small inclusion that had a profound impact on the sport was the invention of the leg rope (Young, 2000). With the added sense of security gained from being attached to the board, surfers began to ride waves previously considered too large and/or unsafe (Figures 2.3 and 2.4). It also had an effect on the physical demands, as surfers were no longer swimming to the shore to retrieve their boards.



Fig. 2.3 Taking-off on a large wave



Fig. 2.4 Bottom-turning on a large wave



Fig. 2.5 Professional surfer performing a backhand aerial (Burrows, 2005)

Surfing is now a truly international sport and maneuvers once thought impossible are now commonplace (Figure 2.5). This fast, somewhat gymnastic new style has led to a more mainstream, commercial surfing culture – one that is professional, lucrative and demanding - both physically and mentally (Burrows, 2005). Each year, there are two concurrent World Surfing Tours for both male and female short-board professional surfers. For male surfers, there are 48 World Qualifying Series (WQS) events held in 16 countries and 10 World Championship Tour (WCT) events held in 9 countries. For female surfers, there are 16 WQS events held in 9 countries and 7 WCT events held in 4 countries.

As a professional surfer has to be excellent in every condition - big or small, left or right, sand or reef – they need to get as much exposure to as large a variety of conditions as possible (Burrows, 2005). Perhaps one of the drawbacks with this type of professional

tour is that it creates ‘all rounders’ rather than specialists. This is not to say that there are not events that are suited to specialist surfers but they are few and far between with nominal amounts of prize money. Therefore, if an athlete wants to pursue a professional career in surfing, they have to be good in all conditions be it the small high-performance waves of California (Figure 2.6) or the life-threatening waves of Hawaii (Figure 2.7).



Fig. 2.6 Small waves of California



Fig. 2.7 Large waves of Hawaii

2.2 The surfing process

Surfing is a sport that requires more than just physical prowess alone – it relies on the ability to appropriately assess and respond to a wide range of environmental and proprioceptive cues (Young, 2000; Burrow, 2005). In surfing, performance is largely dictated by the quality of wave chosen and the degree of difficulty in each manoeuvre (Burrow, 2005). To achieve a high score the surfer needs to identify superior waves, locate the best place to take-off, anticipate the breaking speed of that wave and be able to respond to a variety of visual and proprioceptive cues during the wave-riding process (Lowdon, 1994; Burrow, 2005).

There is invariably a physical component involved but how important it is to surfing performance has not been addressed. Up until now, the limited research in this field has focused on the neuromuscular aspects of performance and attempted to identify relationships between certain physiological parameters with surfing performance (Lowdon and Peterman, 1980; Meir et al., 1991; Mendez-Villanueva et al., 2003; Mendez-Villanueva et al., 2005). What has failed to be considered is the degree to which skill affects performance. Therefore, the following review of the demands of surfing examines not only the physical but also the cognitive/skill required for superior performance.

2.2.1 Paddling out

Prior to entering the water, the surfer will assess the conditions, identifying rips, currents, take-off areas and paddle-out routes (Burrow, 2005). And, much like a golfer chooses a club, a surfer selects the appropriate board, wetsuit and wax for the conditions. Once in the water they negotiate a way through the breaking zone (often evading other surfers), time their paddle to avoid large waves and locate the take-off zone from the water (Young, 2000; Burrow, 2005).

To move out past the breaking waves and into a position to catch waves, a surfer needs to paddle the surfboard at varying speeds. Paddling is predominately an upper body aerobic exercise, requiring isometric muscle contractions of the neck and trunk extensors to fixate the shoulder for effective strokes (Lowdon, 1994). Muscular endurance is required for long, sustained bouts of paddling while muscular strength is needed to catch waves and push through wave turbulence. According to Meir et al., (1991) 44% of a typical recreational surfing session is spent paddling. Mendez-Villanueva et al., (2003) reported a slightly higher paddling rate of 51% during a competitive surfing heat. However, the range was somewhat greater than that observed in recreational surfing (Figure 2.7). This is possibly a by-product of the different wave conditions used in each study, the result of strategic paddling ploys employed during competition or due to a higher frequency of rides during competition.

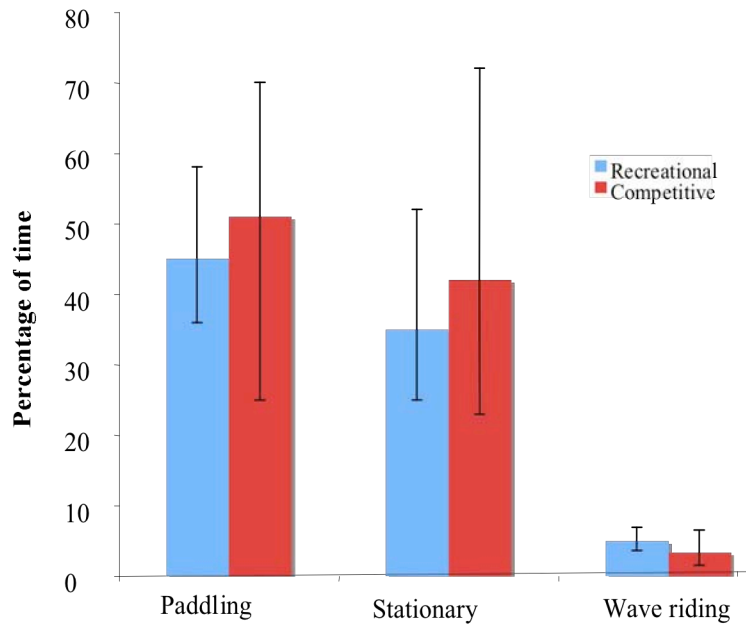


Fig. 2.7 Percentage of time spent paddling, stationary and wave riding during recreational and competitive surfing (derived from Meir et al., 1991 and Mendez-Villanueva et al., 2003).

2.2.2 Wave selection

Wave selection is fundamental to superior performance as it dictates the surfer's scoring potential (Young, 2000; Burrow, 2005). It relies not only on the ability to locate the best position in the line-up and recognise subtle variations in swell shape and direction, but also to predict how these variations will affect the wave's breaking pattern (Young, 2000; Burrow, 2005). In many ways, this is not too dissimilar to the way a soccer player maintains field position, anticipates the play and times their run. The earlier the surfer can identify a superior wave, the greater their chance of gaining wave priority. A surfer gains priority when they are closest to the breaking part of the wave (known as the inside position). This is the case in both competitive and recreational surfing and results in a

great deal of strategic paddling ploys commonly referred to as hassling (Lowdon, 1994; Burrow, 2005). This aspect of surfing is likely to rely on cognitive processes such as information processing speed, working memory and attention, which if impaired, is likely to greatly reduce surfing performance.

2.2.3 Catching waves

Once the wave has been selected and the inside position achieved, the surfer is faced with the task of catching the wave. As the inside position is held by the surfer closest to the breaking part of the wave, catching waves without compromising take-off speed or position on the wave's face is a difficult task (particularly on fast breaking waves). Therefore, to correctly catch a wave, the surfer needs to focus on visual and proprioceptive cues (e.g. variations in wave steepness and board speed) and correctly respond to these subtle differences (Lowdon 1994; Burrow, 2005). The steepness of the take-off is affected by many variables (e.g. tide, shape of sandbank or reef, wind and wave chop) and, as these variables are constantly in a state of change, the surfer needs to apply the same level of analysis to each wave (Lowdon, 1994). This is likely to rely on cognitive processes such as attention, working memory, information processing speed, visuomotor skills and visual acuity to quickly and correctly respond to these environmental variables.

The physical effort in catching waves is largely dictated by the surfer's position over the sand/reef break. When their position is correct, catching a wave only requires a short burst of paddle speed. However, incorrect positioning or competition for the inside

position may require several seconds of maximal paddle speed. Furthermore, as this process is repeated throughout a surfing session, it is likely that wave catching requires a high level of upper-body muscular endurance (Meir et al., 1991; Mendez-Villanueva and Bishop, 2005). Given the degree of cognitive and physical effort necessary to correctly catch waves, it is not uncommon for elite surfers to make errors and severely reduce their scoring potential (Lowdon, 1994; Burrow, 2005).

2.2.4 Prone to standing

Once the wave has been selected and caught, the surfer moves from a prone position to standing up. This movement should preferably occur before the wave breaks and is commonly referred to as 'jumping up'. This is a fast, full-body movement that requires coordination (placing feet in the correct position), upper-body strength (raising the body off the board) and flexibility to bring the legs underneath the torso without lifting the hands off the surfboard (Lowdon, 1988; Young, 2000). To achieve this the pectoral muscles and triceps brachii contract concentrically to lift the torso, while the iliopsoas muscles contract concentrically to bring the thighs underneath the torso. To move the body from a crouched to a standing position the quadriceps muscles and hamstring muscles contract concentrically (Lowdon, 1994). Even though this only takes a few seconds it is repeated many times during a surfing session and therefore requires a level of anaerobic muscular endurance (Lowdon, 1994).

2.2.5 Wave riding

At this point the surfer is now faced with the task of riding the wave. The goal of wave riding, as defined by the association of surfing professional (www.aspworldtour.com, 2007), is to "...perform radical controlled manoeuvres in the critical section of a wave with speed, power and flow... The surfer who executes these criteria with the maximum degree of difficulty and commitment on a wave shall be rewarded with the higher score." With the shape of the wave and the speed of the board constantly in a state of change, the surfer has to rely on information processing speed (the speed at which a person is able to change latent information into manifest information; Lehl and Fischer, 1988) and working memory (the ability to store and manipulate information; Baddeley, 1996), to quickly identify superior sections, respond to environmental cues (i.e. wave steepness, changes in water colour, variations in breaking patterns) and initiate complex movement sequences.

To manipulate board speed and direction, the surfer applies varying degrees of downward force (primarily through muscular contractions of the legs) to specific areas of the surfboard. According to Meir et al., (1991) wave riding accounts for approximately 3 min of a 60-min session, with the average wave lasting 10 seconds. However, the fact that the researchers used small participant numbers and lacked variety in wave conditions makes their findings difficult to extrapolate to other circumstances. Nevertheless, the emphasis placed on powerful manoeuvring in the judging criteria, along with the findings of Meir et al., (1991), suggests that wave riding is a lower-body anaerobic endurance activity.

2.3 Physical characteristics of surfers

Surfing is a dynamic activity with no set duration or intensity. Typically, surfers will train for 1 to 2 hours although, when the wave conditions are excellent, a training session can last for in excess of 5 hours (Mendez-Villanueva and Bishop, 2005). The intensity of a training session is largely dictated by the size and quality of the waves (Meir et al., 1991; Burrow, 2005). When wave quality is poor or when the break is crowded with other surfers, there are likely to be extended periods of low-intensity activity (Meir et al., 1991). Equally, in quality waves or when the break is not crowded, there is likely to be a higher frequency of wave riding and a reduction in recovery time (Mendez-Villanueva and Bishop, 2005). Surf training also requires a great deal of strategic thinking, coordination and timing, adaptable to a wide range of environmental conditions (Burrow, 2005). The physiological demands these variables place on upper and lower-body muscular contractions, coordination and cognition may have led to the development of physical characteristics specific to surfing (Mendez-Villanueva and Bishop, 2005)

2.3.1 Age

Today's professional surfer is typically in their mid to late 20's and somewhat older than elite swimmers, water polo players, freshwater paddlers, alpine skiers and professional surfers of the 1970's (Table 2.1). According to Mendez-Villanueva and Bishop (2005) the increase in mean age from the 1970's to today is a by-product of a sport that requires mastery of competitive prowess, technical skill and/or ever-increasing financial incentives. However, it may simply be the due to a more arduous qualifying process.

2.3.2 Anthropometry

As seen in Tables 2.1 and 2.2 elite surfers are typically shorter in stature and lighter in body mass than other aquatic athletes such as swimmers and freshwater paddlers. Interestingly, they tend to share physical characteristics more akin to elite alpine skiers (Table 2.1). This may be due to surfing and skiing sharing similar rider control variables (controlling the apparatus through weight distribution at the feet) and similar forces acting on them whilst riding (gravity, longitudinal friction and resistance force - often associated with the centripetal force essential for turning; Hirano and Tada, 1994).

Table 2.1 The physical characteristics of elite surfers, aquatic athletes and alpine skiers.

Male Athletes	Source	N	Height ± SD (cm)	BM ± SD (kg)	Age ± SD (y)
Professional surfers	ASP (2007)	45	175.4 ± 5.2	73.8 ± 7.0	25.9 ± 4.8
Professional surfers	ASP (2003)	45	174.7 ± 6.1	72.6 ± 8.2	27.5 ± 3.6
Professional surfers	Lowdon and Petman (1980)	76	173.6 ± 5.9	67.9 ± 7.2	22.2 ± 3.2
Alpine skiers	Anderson et al., (1988)	10	176.9 ± 2.3	71.9 ± 4.1	21.0 ± 2.0
Freshwater paddlers	Garcia-Rovés et al., (2000)	7	180.7 ± 5.2	81.0 ± 4.2	22.3 ± 2.8
Swimmers	Carter and Marfell-Jones (1994)	15	183.8 ± 7.1	86.1 ± 8.4	20.4 ± 1.3
Water polo players	Carter and Marfell-Jones (1994)	20	186.5 ± 6.5	86.1 ± 7.1	25.2 ± 2.3
Female Athletes					
Professional Surfers	ASP (2007)	17	165.2 ± 7.2	57.4 ± 7.0	28.0 ± 4.5
Professional Surfers	ASP (2003)	17	162.0 ± 4.9	56.3 ± 7.7	26.7 ± 4.4
Professional surfers	Felder et al., (1998)	10	166.2 ± 6.7	57.9 ± 8.3	23.3 ± 3.3
Professional surfers	Lowdon and Petman (1980)	14	165.7 ± 4.9	59.3 ± 6.7	21.6 ± 3.4
Alpine skiers	Anderson et al., (1988)	10	165.1 ± 4.5	59.4 ± 0.8	19.5 ± 1.8
Freshwater paddlers	Garcia-Rovés et al., (2000)	6	168.2 ± 3.6	64.4 ± 3.2	19.0 ± 1.5
Olympic swimmers	Burke et al., (1996)	12	172.0 ± 6.0	62.5 ± 8.1	20.5 ± 2.6
Water polo players	Carter and Marfell-Jones (1994)	20	171.3 ± 5.9	64.8 ± 7.2	23.7 ± 3.4

The morphology of elite surfers was measured by Lowdon (1980) using a 7-point somatotype scale (Figure 2.8). After assessing 76 male and 14 female world-class surfers, it was found that the average male surfer has a somatotype reading of 2.6 endomorphic, 5.2 mesomorphic and 2.6 ectomorphic (i.e. 2.6, 5.2, 2.6). The average elite female has a somatotype reading of 3.9, 4.1, 2.6. When compared with other aquatic sports male surfers have a similar morphology to male water-polo players (2.5, 5.3, 2.4) and long-distance swimmers (2.5, 5.3, 2.3). Female surfers tend to be a little more endomorphic and quite alike to female water-polo players (3.6, 3.9, 2.8) and female divers (3.5, 3.8, 2.7).

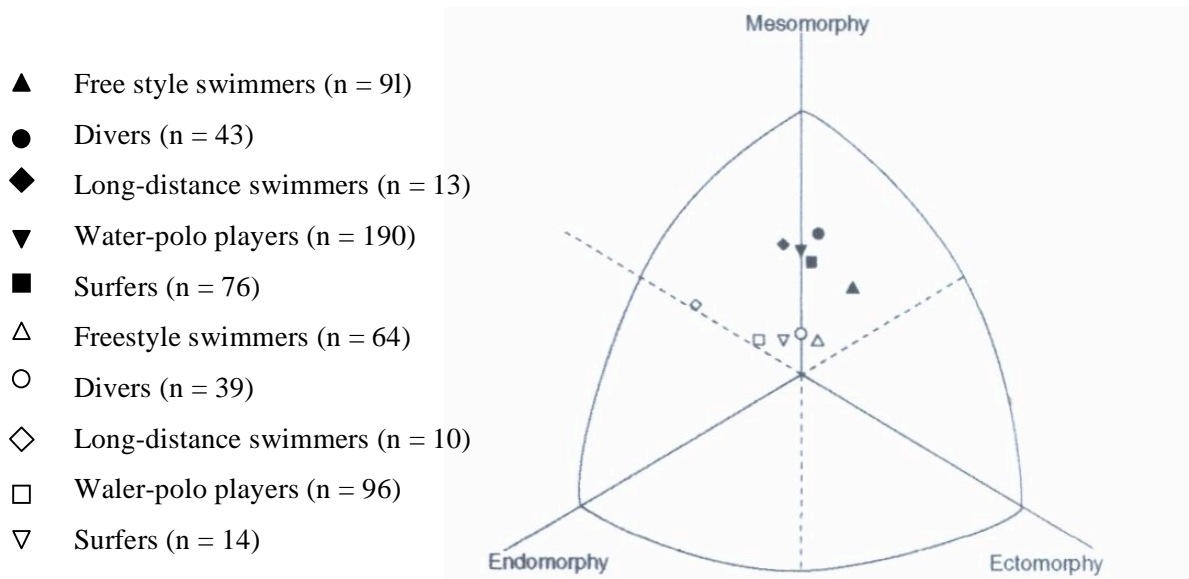


Fig. 2.8 Somatoplot of female (filled symbols) and male (outline symbols) elite athletes from different aquatic sports (derived from Lowdon, 1980)

The mean body fat percentage for elite male surfers was measured by Lowdon and Peteman (1980) and reported to be 10.5%. These values are similar to the 10.2 and 9.8% body fat observed in elite freshwater paddlers (Garcia-Rovés et al., 2000) and alpine skiers (Anderson and Montgomery, 1988), respectively. The mean percentage of body fat

recorded for elite water polo players (Smith et al., 1998) and Brazilian international swimmers (Paschoal and Amancio, 2004) were slightly higher at 11.5 and 11.5%, respectively. Elite triathletes (Frentsos and Baer, 1997), Olympic swimmers (Lowdon and Peteman., 1980) and Kenyan long-distance runners (Veronique et al., 2003) show considerably lower body fat percentages at 8.0% and 6.6%, respectively. When compared with the 14.6% body fat observed by Lowdon and Peteman (1980) for college male students, it would seem that elite surfers have a body fat percentage somewhere between the average male and world-class endurance athlete. However, the methods used to assess body fat percentage were different in each study, making the comparisons less than reliable.

The mean body fat percentage for professional female surfers was assessed by Lowdon and Peteman (1980) and Felder et al., (1998) and found to be 19.5 and 22.0%, respectively. These values are similar to the 21.0 and 21.2% body fat observed in middle-distance swimmers (Carter and Marfell-Jones, 1994) and alpine skiers (Anderson and Montgomery, 1988), respectively. Interestingly, Carter and Marfell-Jones (1994) found elite water polo players and long distance swimmers have somewhat higher body fat percentages at 24.0 and 27.0%, respectively, whereas marathon runners (Lowdon and Peteman, 1980) and flat-water paddlers (Garcia-Rovés et al., 2000) have considerably less body fat at 11.0 and 13.2%, respectively.

The considerably higher levels of body fat reported for female surfers, long-distance swimmers and alpine skiers may be a physiological adaptation to sports that are conducted in wet, windy and cold environments (Lowdon and Peteman, 1980).

Furthermore, the proportionally higher levels of body fat observed in water polo and long-distance swimmers may be a physiological adaptation to sports that benefit from increased body flotation (Meir et al, 1991).

2.4 Aerobic and anaerobic demands of surfing

Meir et al., (1991) designed a study to assess the physical intensity of recreational surfing. To achieve this heart rate (HR) data obtained during laboratory $\dot{V}O_{2\text{peak}}$ swim bench ergometer trials were compared with HR data recorded whilst surfing. To ascertain the physiological demands of different aspects of surfing, the researchers video-recorded each trial and later matched HR data with the corresponding activity (e.g. HR achieved when paddling). The mean HR_{peak} achieved during the laboratory trial was $180 \text{ beat}\cdot\text{min}^{-1}$, while the mean HR_{peak} during surfing was $171 \text{ beat}\cdot\text{min}^{-1}$. This represented 95% of the laboratory HR_{peak} and highlights the anaerobic element of surfing. The mean HR value for the total time spent surfing was $135 \text{ beat}\cdot\text{min}^{-1}$, representing 75% of the laboratory HR_{peak} , thus suggesting that surfing is an aerobic exercise conducted at an intensity similar to swimming and middle distance running (Lowdon and Peteman, 1980). Of the different components of surfing, it was found that the mean HR whilst paddling, stationary and wave riding was 143, 127 and $171 \text{ beat}\cdot\text{min}^{-1}$, respectively. This represented 79, 71 and 95%, respectively, of the laboratory HR_{peak} . From their results, Meir et al., (1991) concluded that recreational surfing is predominately an upper-body aerobic activity with short periods of anaerobic exercise during wave riding and at certain points in the paddling process (e.g. catching waves). These findings correspond with the

reported high mean $\dot{V}O_{2\text{peak}}$ of elite surfers (refer to section 2.5.1), and suggests that surfing, even at a recreational intensity, requires a high level of aerobic and anaerobic endurance.

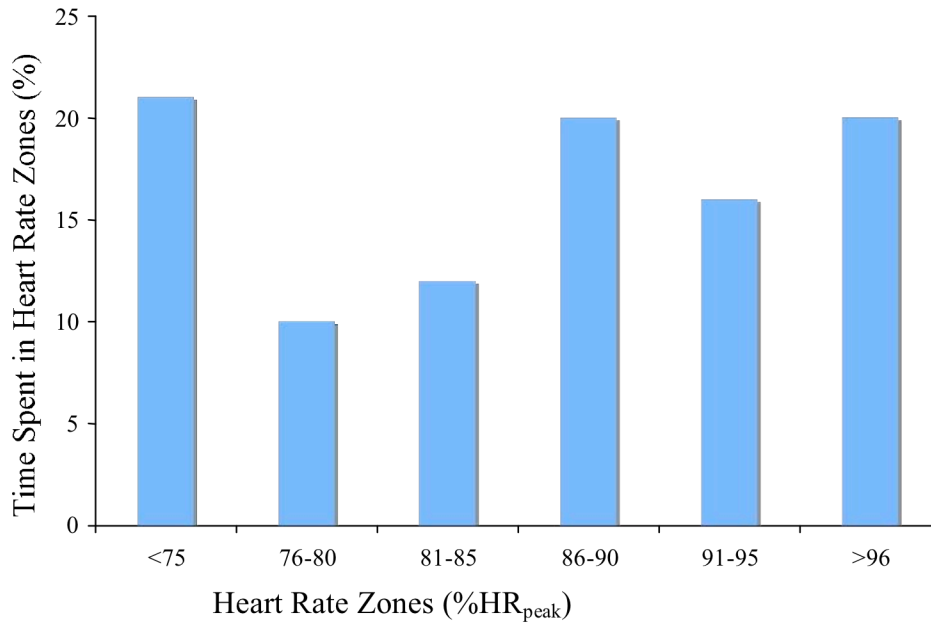


Fig. 2.9 Heart rate zones recorded during a 20-min competitive surfing session. Data is represented as a percentage of the laboratory HR_{peak} values achieved on a swim bench ergometer (derived from Mendez-Villanueva et al., 2003)

More recently, Mendez-Villanueva et al., (2003) assessed the physiological demands of a competitive surfing session. The researchers compared the HR data obtained during laboratory $\dot{V}O_{2\text{peak}}$ swim bench trials against the HR achieved whilst surfing (Figure 2.9). The mean laboratory HR_{peak} was 176 beat·min⁻¹ while the mean surfing HR was 146 beat·min⁻¹. This was 84% of the laboratory HR_{peak} with approximately 30% (of the 20 min surfing heat) conducted at near HR_{peak}, a further 50% between 75 and 90% HR_{peak} and the remainder under 75% HR_{peak}. These findings support those of Meir et al., (1991)

suggesting that the physical demands of both competitive and recreational surfing are predominately aerobic with intermittent bouts of high intensity anaerobic exercise.

Assessing the physical intensity of a dynamic aquatic sport, that takes place in an unstable and unpredictable environment, is a difficult task. However, in their attempts to do so, both Meir et al., (1991) and Mendez-Villanueva et al., (2003) failed to account for the well-known effects of hydrostatic pressure, ambient temperature, hydration status and cognitive stress have on heart rate response and, therefore, questions the validity of their findings. Future research in this field needs to develop more inventive methods to attempt to control for these confounding variables.

2.5 Physiological characteristics of surfers

Surfing is a sport that relies on two different fitness components, one being upper-body endurance for extended periods of paddling and the other anaerobic endurance for wave riding and short bursts of paddling speed. As a surfing session can last in excess of 5 hours (Mendez-Villanueva and Bishop, 2005) and has been found to be conducted at a mean intensity of 70 to 80% HR_{peak} (Meir et al., 1991; Mendez-Villanueva et al, 2003), it is hardly surprising that elite surfers display physiological characteristics specific to the sport of surfing. Currently there is a limited amount of research on the physiological characteristics of surfers and, of the research that does exist, the focus has been primarily on muscular endurance. Therefore, the following section concentrates on physical characteristics associated with aerobic exercise.

2.5.1 Peak oxygen uptake

Surfing is a sport that relies predominately on upper-body muscular endurance to paddle a surfer beyond the breakers and onto a wave (Lowdon, 1994; Mendez-Villanueva et al., 2005a). Therefore, to assess the physiological adaptations that may have occurred as a result of this, the measures need to be specific to the task (Mendez-Villanueva and Bishop, 2005). The conventional method of assessing $\dot{V}O_{2peak}$ is through the use of a cycle ergometer or treadmill yet surfing, being predominately an upper-body endurance activity, requires specificity in methods of measurement. Therefore, much of the

available data on the peak oxygen uptake of surfers has been conducted on arm-crank ergometers or tethered boards.

Table 2.2 Peak oxygen uptake ($\dot{V}O_{2\text{peak}}$) values for upper-body untrained males

Study	<i>N</i>	Age (y) mean \pm SD	$\dot{V}O_{2\text{peak}}$ ($\text{L}\cdot\text{min}^{-1}$)	$\dot{V}O_{2\text{peak}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)
Taylor et al., (2002)	16	24.5 \pm 4.5	2.91	37.94
Bhambhani et al., (1998)	15	25.2 \pm 5.3	2.77	37.70
Koppo et al., (2002).	10	21.3 \pm 2.5	2.74	37.10
Kang et al., (1997)	8	21.0 \pm 8.5	2.24	31.32
Schneider et al., (1999)	6	28.0 \pm 4.9	2.90	36.00
Schneider et al.,(2002)]	10	21.6 \pm 5.1	2.08	25.77

Although the upper-body $\dot{V}O_{2\text{peak}}$ of untrained males seem substantially lower than those of trained athletes (Tables 2.2 and 2.4), the methods used are inherently biased towards athletes that participate in sports that have a large upper-body endurance component (e.g. surfing and swimming). Participants that are untrained in upper-body exercise usually achieve values that represent around 73% of the estimated $\dot{V}O_{2\text{peak}}$ that would have been achieved using conventional methods (Bhambhani et al., 1998). This is due to peripheral factors such as lower stroke volume, reduced muscle blood flow, lowered oxidative capacity and a reduced potential to generate muscular tension and perform work (Bhambhani et al., 1998). Conversely, athletes that participate in sports that rely on upperbody endurance are generally able to achieve arm-cranking $\dot{V}O_{2\text{peak}}$ values that account for close to 90% of what they would have achieved using conventional $\dot{V}O_{2\text{peak}}$ assessment methods (Sawka, 1986).

Table 2.3 Lower-body Peak oxygen uptake for endurance-trained athletes

Athletes and Study	N	Age (y)	$\dot{V}O_{2peak}$
		Mean + SD	(ml·kg ⁻¹ ·min ⁻¹)
Male middle distance runners (Billat et al., 2002)	13	27.4 ± 4.1	74.70
Professional male surfers (Lowdon and Peteman, 1980)	76	22.2 ± 3.2	70.20
Female middle distance runners (Billat et al., 2002)	7	26.3 ± 3.4	68.60
Male alpine skiing team (Anderson and Montgomery, 1988)	12	21.8	66.60
Professional female surfers (Lowdon and Peteman 1980)	14	21.6 ± 3.4	62.20
Male water-polo players (Gazorla et al., 1988)	8	20.8	60.80
Female alpine skiing team (Anderson et al., 1988)	13	19.5	52.70

Table 2.4. Peak oxygen uptake values for upper-body trained male athletes

Athletes and Study	N	Age (y)	$\dot{V}O_{2peak}$
		Mean + SD	(ml·kg ⁻¹ ·min ⁻¹)
Australian state level surfers (Meir et al., 1991)	6	21.2 ± 2.8	54.20
Elite white-water kayakers (Leveque et al., 2002)	7	22 ± 1.9	54.00
European level surfers (Mendez-Villanueva et al., 2005)	7	25.6 ± 3.4	50.00
Regional level surfers (Mendez-Villanueva et al., 2005)	6	26.5 ± 3.6	47.93
College swimmers (Swaine, 1997)	12	19.8 ± 3.1	43.69
Surf lifesavers (Morton et al., 1997)	7	21.0 ± 1.0	40.38
College swimmers (Swaine et al., 1999)	12	22.0 ± 2.4	39.19
College swimmers (Konstantaki and Swaine, 1999)	9	21.0 ± 4.0	38.27
College swimmers (Bernard et al., 1997)	14	21.0 ± 4.0	38.00

Despite the inherent limitations of drawing comparisons between different studies, it would seem that surfers have a considerably higher $\dot{V}O_{2peak}$ than untrained athletes and slightly higher than that of elite white-water paddlers. When compared to the $\dot{V}O_{2peak}$

derived from traditional methods (lower-body), elite surfers seem to share a similar aerobic capacity to Nordic skiers, middle-distance runners and long-distance runners (Table 2.3). This suggests that the repetitive nature of wave riding or other lower-body activities associated with surfing, such as skateboarding (or possibly beach running), have a high aerobic component.

2.5.2 Heart rate recovery

As there is a general relationship between aerobic fitness and HR recovery following standard exercise, rapid recovery or repayment of oxygen debt is another indicator of cardio-respiratory fitness (Lowdon and Petman, 1980).

The mean HR recovery times of professional surfers after 5 min of submaximal cycling (on a cycle ergometer) were 77 beat·min⁻¹ for males and 76 beat·min⁻¹ for females (Lowdon and Petman, 1980). By comparison, the average recovery HR of male Olympic pentathletes - in a near identical study - were 100 beat·min⁻¹ (Hagerman et al., 1970). Pentathletes compete in running, swimming, fencing, riding and shooting events and have been shown to have some of the best HR recovery values amongst Olympic athletes (Hagerman et al., 1970). Although this data is somewhat outdated, the reported HR recovery times of professional surfers suggest that the intermittent nature of surfing, which has changed very little, leads to a heightened ability to recover from short bouts of physical activity.

When the available data on the oxygen uptake capacity and HR recovery time of elite surfers is combined it would seem that a high level of cardio-respiratory fitness is a physiological characteristic synonymous with surfing.

Surfing has evolved into a highly competitive international sport, one that relies on the ability to maintain performance for several hours, at an intensity of 70-80% HR_{peak} in a wide range of environmental conditions. Consequently, today's elite surfer displays physical characteristics akin to athletes in other rider-control sports (e.g. height and body mass of skiers), yet the physiological characteristics of endurance-based athletes (e.g. $\dot{V}O_{2peak}$ of middle distance runners). However, unlike most athletes involved in these types of sports, surfers do not hydrate during practice (Felder et al., 1998) and also wear heat restrictive clothing (wetsuits) known to exacerbate sweat rates (Webster, 1990)

2.5.3 Temperature regulation during surfing

The thermal conductance of water is approximately 25 times greater than that of air (Wakabayashi et al., 2006). Therefore, to avoid excessive body heat loss, particularly in cool water conditions, surfers will often train in a wetsuit. The two standard types of wetsuits used are steamers (Figure 2.10) and spring suits (Figure 2.11; Burrow, 2005). Steamers are cool-water wetsuits (<22°C), typically used in winter or during early morning surfing sessions (Burrow, 2005). They are available in a variety of thicknesses ranging from 2 x 3 mm to 5 x 6 mm. As they are designed to prevent water entry, seams are typically glued, blind stitched and taped (Burrow, 2005). The spring suit is a warm-water wetsuit (>24°C) and used during the summer months (Burrow, 2005). There are a variety of thicknesses ranging from 1-2 x 3 mm. The stitching can be either flatlock

(which allows water seepage) or sealed in the same manner as the steamer. Elite surfers typically train in the sealed spring suit (Burrow, 2005, www.oneill.com). Regardless of the stitching the exposed limbs greatly increases the amount of conductive heat loss (Wolf et al., 1985). It is worth noting that although there are guidelines for the appropriate water temperature to use these wetsuits in, surfers still wear steamers during warm summer days and spring suits in cold winter conditions. This may be due to individual differences in body fat percentage and thus insulative capacity (Wakabayashi et al., 2006).



Fig. 2.10 Steamer wetsuit (www.oneill.com)



Fig. 2.11 Spring suit (www.oneill.com)

To counter the high thermal conductivity of water, the wetsuit creates a barrier between the external environment and the surface area of the skin. It also provides insulation by heating a thin layer of water between skin and suit with trapped metabolic heat (Wolff et al., 1985). According to Arieli et al., (1997) the insulative quality of a suit is dependent on the degree of water that passes through it (known as flushing). If the suit is unable to

prevent flushing, then insulative water will be replaced by cool water and heat will be rapidly conducted away from the body (Wolff et al., 1985). This is supported by Yeon et al., (1987), who found that wave turbulence increased flushing and subsequently decreased the total insulation of dry suits by 14%. However, as much of the available research on wetsuits and immersion is from studies conducted in the 1980's and 1990's, there is the possibility that innovations in materials and construction techniques have led to suits that are less prone to flushing and more effective at insulating body heat.

Today's wetsuits are made from a mixture of neoprene, spandex, titanium and wool fibres (Burrow, 2005). The stitching (blind stitching) does not penetrate the entire panel (as it once did) and the combination of glue and taping makes the joints watertight (www.oneill.com; www.ripcurl.com). The neck, arm and leg holes which were previously reported as sites of flushing (Wolff et al., 1985; Yeon et al., 1987) are now made from extremely flexible single-sided neoprene that is able to contract around these body parts and prevent water entry (www.oneill.com; www.ripcurl.com).

Given that wetsuits are becoming increasingly more efficient at insulating metabolic heat, there is the possibility that during high levels of physical work, the surfer will not be able to adequately dissipate metabolic heat and as such regulate core temperature. In sports such as wrestling several athletes have died of hyperthermia-induced complications as a result of excessive exercise in rubberised suits (Webster, 1990). Yet no research has been conducted on the potential risks of surfing in a wetsuit or the effects of dehydration on surfing performance.

2.6 Dehydration

2.6.1 *The role of water*

Water molecules fill practically every space in and between all cells in the human body (Barr, 1999). Not only do water molecules fill space but they also assist in forming the structures of macromolecules such as glycogen and proteins (McArdle et al., 1996). As the main fluid in the body water acts as a solvent for vitamins, glucose, minerals, amino acids and many other nutrients (McArdle et al., 1996). The digestion, absorption, transportation and use of nutrients also largely rely on water (Barr, 1993). The safe elimination of toxins and waste products and whole-body thermoregulation is critically dependent on it (Barr, 1993). From energy production to joint lubrication to cognitive function to reproduction, there is no system in the body that does not depend on water.

Water loss during daily living, even without perspiration, is approximately 4% of total body weight in adults per day. In a 70-kg adult this is equivalent to 2.5 to 3 L·day⁻¹. Body water deficit (hypohydration) can be acute – as from a bout of intense exercise – or chronic – resulting from less than adequate rehydration of daily water losses over a period of time. Both degrees of hypohydration are defined as a 1% or greater loss of body water as a result of fluid loss (Kristal-Boneh et al., 1988) Hydration is achieved through the consumption of solid foods, oxidation and fluid intake; and each contributes to maintaining body fluid homeostasis (euhydration). For example, solid foods contribute 1.5%, oxidation 0.2% and fluid intake 2.3% to maintaining a euhydrated state (Barr, 1999).

2.6.2 Exercise-induced dehydration

Exercise-induced dehydration refers to dehydration that develops during the course of an exercise session and by definition is usually of greatest relevance to participants in endurance activities. Vigorous exercise, particularly in hot or humid environments, leads to increased sweating rates (Barr et al., 1991). Sweat rates that exceed water intake result in both intracellular and extracellular fluid volume deficits. They also result in plasma hypertonicity and plasma hypovolemia, both of which adversely affect the bodies' ability to dissipate heat (Kleiner, 1999). Sweat rates of 1 to 2 L·h⁻¹ are typical of most persons performing moderately hard exercise with sweat rates in excess of 2 L·h⁻¹ not uncommon when the ambient temperature is high (Maughan et al., 2004).

Dehydration is exacerbated by environmental conditions that increase fluid losses (heat, humidity and lack of wind), by fluid restriction during exercise, by higher intensity activities that require the dissipation of more metabolic heat and by clothing designed to insulate the body (Webster, 1990; Galloway and Maughan, 1997; Kleiner, 1999). The effect ambient temperature has on sweat losses was highlighted in Armstrong et al's., (1985) study on middle and long distance runners. It was observed that the degree of dehydration experienced during laboratory and field-based endurance running was quite different. During laboratory trials, participants elicited peak sweat rates of 2.79 L·h⁻¹ while in severe, hot-wet field conditions, peak sweat rates were as high as 3.71 L·h⁻¹.

In sports such as boxing and wrestling, where athletes use rapid weight-loss techniques to qualify for lower weight divisions, the practice of exercising in heat restrictive clothing is common (Webster, 1990). The rationale behind this practice is that sweat rates will be

increased if metabolic heat (produced when exercising) is trapped close to the skin's surface (Choma et al., 1998). In a study conducted by Smith et al., (2000), on the effects of rapid weight loss on a boxing-related task, participants achieved a 3.8% dehydrated state through low intensity exercise in heat restrictive clothing. The participants wore chemical warfare clothing (hooded plastic top and bottoms) beneath a tracksuit during repeat bouts of lower intensity cycling in a heated room (40°C). A similar method of dehydration was explored in Webster's (1990) study on the rapid weight loss strategies employed by wrestlers. The 7 participants in this study were required to perform high intensity bouts of dry land exercise whilst wearing rubberized sweat suits. At the conclusion of the weight loss protocol, participants had achieved a 4.9% reduction in body mass. As it is common practice for surfers to wear wetsuits whilst surfing it is possible that the thermo-restrictive qualities of the wetsuit (particularly the steamer wetsuit) will exacerbate sweat rates and lead to fluid losses comparable to those reported in rapid weight-loss studies.

2.6.3 Effects on neuromuscular ability

The effects of dehydration and heat stress on neuromuscular ability are varied. Moderate dehydration (2-3% BM loss) alone does not significantly alter isometric strength and endurance (Greiwe et al., 1998) or anaerobic performance (Jacobs, 1980). However, it does decrease muscular endurance and maximal aerobic power (Sawaka and Pandolf, 1990). Exercise conducted at a sub-maximal intensity with little heat stress induces an elevation in heart rate and a drop in stroke volume, but has little effect on cardiac output relative to euhydrated levels (González-Alonso et al., 2000). Interestingly, when exercise is conducted at a sub-maximal intensity with moderate heat stress there is a marked

increase in cardiovascular strain and a significant reduction in cardiac output. This dehydration-mediated decline in cardiac output and endurance capacity during heat stress is greater during high intensity ($>65\% \dot{V}O_{2\max}$) than during low intensity ($<25\% \dot{V}O_{2\max}$) exercise (Montain et al., 1998).

Webster (1990) found that rapid weight loss by means of fluid restriction and exercising in a rubberized suit significantly reduced muscular strength, anaerobic power, anaerobic capacity, the lactate threshold and aerobic power. As surfing is a sport that relies on aerobic endurance for paddling and anaerobic endurance for wave riding (Meir et al., 1991) it is likely the dehydration resulting from surfing in a wetsuit will adversely affect performance. However, as no research to date has addressed dehydration in surfing, the effects (if any) of wearing a wetsuit during surf practice are unknown.

2.6.4 Effects on performance

As there are no studies to date on the effects of dehydration on surfing performance, the following section examines other skill-based sports that are likely to depend on the integrity of muscle endurance, cardio-respiratory endurance and cognitive function for superior performance.

In a study conducted by Hoffman et al., (1995) on the effects of water restriction during a modified game of basketball, it was observed that at the end of a simulated 2-on-2 full-court basketball game, vertical jump was largely unchanged but anaerobic power and field-goal shooting were reduced by 19% and 8.1%, respectively. In an earlier paper,

Dawson et al., (1985) assessed the performance of tennis players when 2.4% dehydrated and found that their serve, groundstroke, volleying accuracy and hitting power were all significantly reduced. Davey et al., (2002) also reported dramatic declines in groundstroke hitting and service accuracy (69% and 30%, respectively) at the conclusion of 35 min of high intensity simulated tennis play. The level of dehydration reached was 1.5% yet the test was to volitional fatigue and depleted substrates may have been the cause for the large performance declines. Unfortunately, these studies do not assess the cognitive processes likely to contribute to performance (e.g. attention, working memory and visual acuity) and as cognition is known to be adversely affected by mild dehydration (Gopinathan et al. 1988; Cian et al., (2000), this seems to be quite an oversight. However, a few studies, such as McGregor et al., 1999 and Edwards et al., 2007, have assessed the effect of dehydration on performance using both physical and cognitive tests.

McGregor et al., (1999) assessed the effects of fluid ingestion on soccer skill and mental concentration after 90 min of soccer-related exercise. At the conclusion of the no fluid trial, the duration and intensity of the exercise protocol resulted in 2.4% dehydration, a significant reduction in the soccer skill (dribbling a ball between cones) but no reduction in mental concentration. Therefore, these findings suggest that this was not the case when fluid was ingested as hydration status and performance (both physical and cognitive) remained largely unchanged. Suggesting that cognitive ability had little to no bearing on the soccer skill.

Like McGregor et al., (1999), Edwards et al., (2007) used a similar study design to measure the influence of dehydration on soccer match play and mental concentration. In

their study, participants were required to perform 45 min of submaximal exercise on a cycle ergometer followed by a 45-min soccer match. Pre and post sports-specific and mental concentration tests showed that when 1.4 – 2% dehydrated, endurance capacity was significantly reduced while mental concentration was maintained. Once again, these findings seem to suggest that cognitive function is not only unaffected by mild dehydration but also has little bearing on performance.

Although it is an encouraging sign that both the McGregor et al., (1999) and Edwards et al., (2007) research assessed cognitive function, a single mental skills test (pre and post exercise 1-min number identification task) is too simplistic a measure to adequately assess the cognitive demands associated with soccer performance. Furthermore, despite the large body of research suggesting exercise increases information processing speed and decision-making ability (Mc-Glynn et al., 1979; Paas & Adam, 1991; Chmura et al., 1994; Delignieres et al., 1994; Brisswalter et al., 1995; Adam et al., 1997; McMorris et al., 1999), neither study made adjustments to account for this. As both investigations reported slightly lower post-exercise mental concentration scores, and given that exercise actually stimulates cognitive function, the effect dehydration has on cognitive ability may have been under reported.

To better understand the effect of dehydration on skilled performance, future research needs to employ not only physical test but also more rigorous cognitive testing batteries that accurately assess the cognitive components of that particular sport.

2.6.5 Effects on cognitive function

A commonly referenced paper on the effects of dehydration on cognitive function is the Gopinathan et al., (1988) study. In their experiment, the researchers recruited 11 physically active males aged 20 – 25 years to undergo a graded dehydration protocol where participants were tested at 1, 2, 3 and 4% dehydration. Dehydration was achieved by performing continuous moderate work (step-ups) in a hot/dry ambient environment. No fluid was administered during the trial and a 60-min rest period was given before cognitive tests were conducted. As physical performance was not being measured the researchers made no attempts to replenish substrates. It was concluded that impairments in short-term memory, working memory, information processing speed, motor speed and attention were proportional to the degree of dehydration and significant ($P < 0.001$) at a 2% dehydrated state.

These findings seem to be most relevant to continuous moderate intensity sports conducted in hot/dry ambient conditions, where the body's ability to regulate core temperature is compromised (i.e. endurance-based sports conducive to heat stress). Yet, due to the duration, physical intensity and ambient conditions imposed by Gopinathan et al., (1988), the findings may not be applicable to sports that are highly intensive, short in duration or take place in a cool ambient environment. As surfing is predominately a moderate intensity endurance-based sport (Meir et al., 1991), and exercising in rubberised-suits has been found to cause heat stress (Webster, 1990), it is possible that the findings of Gopinathan et al., (1988) are applicable to the sport of surfing. Although the affect a dehydrated-mediated compromise in cognitive ability would have on surfing performance is yet to be researched, the somewhat unpredictable nature of surfing and the

emphasis placed on wave selection seems to suggest that maintaining the integrity of particular cognitive domains (e.g. information processing speed and working memory) would play an important role in superior performance.

Cian et al., (2000) also assessed the effect of hydration status and method of dehydration on cognitive ability. Eight healthy male endurance-trained athletes, aged 24-30 years participated in 4 separate trials: euhydrated, hyperhydrated, dehydrated by heat or dehydrated through exercise. Participants that were in the dehydrated trials reached 2 - 3% body mass loss by means of passive heat exposure or exercise. Once dehydrated participants completed a 40-min cognitive test battery. It was concluded that at a 2-3% dehydrated state (regardless of the means), reaction time, short-term memory, tracking ability and psychomotor skills are significantly compromised. Whether the purported decline in cognitive ability has an adverse effect on athletic performance is unclear. However, assuming that some sports are more cognitively intensive than others, there is the possibility that those sports may be significantly affected by moderate dehydration (2-3%), particularly when coupled with heat stress.

In spite of the reported adverse effects dehydration has on cognitive function, some athletes have been found to be able to withstand the deleterious effects of dehydration. Choma et al., (1998) observed only a small reduction in cognitive function among experienced wrestlers when they were at a 6.2% dehydrated state. Landers et al., (2001) found no effect on cognitive function when 6.4% dehydrated. And, even though Smith et al., (2000) reported a 26% reduction in boxing performance, 1 participant was able to maintain boxing performance at 3.8% dehydration.

2.6.6 Dehydration in aquatic environments

To attenuate the adverse neuromuscular and cognitive effects associated with dehydration, athletes are encouraged to match sweat losses with fluid consumption (Noakes et al., 1993; Kleiner, 1999; Sawka and Montain, 2000; Coyle, 2004). Even though the benefits of consuming enough fluid during exercise to maintain body weight has been demonstrated (Kleiner, 1999), most endurance athletes do not voluntarily match their fluid intake during exercise with their fluid losses (voluntary dehydration) and thus become moderately (2-3%) to substantially (>4%) dehydrated (Noakes, 1993).

It is not clear why humans, as compared to most other species, fail to match fluid intake losses when fluids are freely available (Noakes, 1993). In most cases, voluntary fluid intakes are considerably less than could be emptied from the stomach and are also below sweat rates (Barr, 1999). Although exercise has been found to increase the thirst drive exercise in some environments, such as in water, have been found to suppress thirst drive (Kleiner, 1999) and exacerbate dehydration (Stocks et al., 2004). Adding to this are increases in fluid loss associated with the aquatic environment (Hinghofer-Szalkay et al., 1987; Norsk et al., 1993). According to Wilcock et al., (2006) the compressive force applied to the body by water causes fluid to move from intracellular and interstitial space into intravascular space. This results in haemodilution and the displacement of blood stored in the body's abdomen, leading to an increase in plasma volume and the subsequent release of atrial natriuretic peptide (ANP) without any change in arginine vasopressin (AVP). Hope et al., (2001) further explains that it is this unaltered AVP level that leads to an increase in diuresis, sodium excretion and subsequently a decrease in total body fluid.

2.6.7 Dehydration in surfing

The dehydrating qualities of an aquatic environment, combined with the duration of a surfing session (Meir et al., 1991), the intensity in which it is conducted (Mendez-Villanueva and Bishop, 2005) and the insulating qualities of a wetsuit (Webster, 1990), suggest that adequate fluid regimes are a necessary part of surf practice. However, the little research conducted in this area suggests this is not the case (Felder et al., 1998). In a study conducted by Felder et al., (1998) it was reported that on training days female professional surfers consume between 443 and 998 g of fluid. Unfortunately, the researchers did not record the duration of training or the type of wetsuit worn. However, it is likely that as the assessment was in the lead up to the Rip Curl Bells Beach Classic the participants were training throughout the day (adapting to wave conditions) in wetsuits typical of the region i.e. steamers (Campbell, 1982; Carroll, 1991).

Given that sweat rates in excess of $2 \text{ L}\cdot\text{h}^{-1}$ are not uncommon when exercise is conducted in high ambient temperatures (Maughan et al., 2004), the fluid intake of the participants in the Felder et al., (1989) paper is cause for concern. Although the study only assessed female professional surfers, and hydration status was not the focus, it does draw attention to the lack of adequate hydration regimes in surfing and the potential for moderate to severe dehydration. Moreover, female professional surfers are subjected to the same environmental variables (e.g. wave conditions, wind, sun, hydrostatic pressure, ambient temperature, etc...), compete in the same events (this was the case at the time of the study), use the same type of equipment and are assessed against the same performance criterion as their male counterparts. Therefore, the lack of fluid intake of female professional surfers may also represent those of male professional surfers.

The effect of dehydration on surfing performance has not been researched yet it is conceivable that impairments in cognitive function (e.g. attention and information processing speed) may lead to errors in wave selection, wave catching and wave riding. It is also possible that a reduction in muscular endurance capacity will reduce speed of paddle and wave riding ability.

2.7 Summary

Surfing has progressed from the large boards and stylish, relaxed surfing techniques of the Malibu era, to a faster, technically difficult and highly competitive sport. As surfing tends to be practiced daily and requires a combination of rider control for wave riding and upper-body muscular endurance for paddling, elite surfers tend to be shorter, lighter and more aerobically fit than other aquatic athletes. The short stature and light body mass are likely to aid balance and board speed while extended bouts of paddling may explain the high levels of aerobic fitness.

The duration, intensity, thermorestrictive qualities of wetsuits and lack of fluid intake during practice are likely to result in severe dehydration. From the limited amount of research conducted on dehydration and cognitive function, few papers have measured more than one cognitive domain. Of those that have, it would seem that when slightly dehydrated (2-3% body mass loss) cognitive ability and endurance capacity are adversely affected. When a greater degree of dehydration is reached (3-4% body mass), neuromuscular ability is adversely affected. Interestingly, in some cases, athletes that regularly train in a dehydrated state do not experience the same deleterious effects. Whether elite surfers experience a level of dehydration severe enough to compromise surfing performance has not been researched. However, it is possible that the duration and intensity of surf practice (particularly in a steamer wetsuit) could result in a level of dehydration severe enough to adversely affect cognitive function, muscular endurance and possibly surfing performance.

CHAPTER 3 **METHODS**

In designing the parameters to assess the effects of dehydration on surfing performance, the transient nature of surf conditions along with the emphasis placed on wave selection and the mandatory execution of complex movement sequences also had to be taken into consideration. Therefore, surfing performance alone was not used as the only indicator of depleted efficacy of the surf training session; cognitive function and muscular strength endurance were also assessed.

3.1 Participants and criteria for selection

Twelve Australian national and international-level surfers volunteered to take part in the investigation. The participants' mean age, body mass, height and surfing experience was 27.0 ± 3.3 y, 73.2 ± 7.1 kg, 1.7 ± 0.05 m and 21.0 ± 3.1 y, respectively. Criteria for selection was based on participants being male, having at least 5 years competitive surfing experience, a minimum of 2 entries into World Qualifying Series (WQS) events and no known medical conditions that would be exacerbated by participating in the experiment. The study was approved by, and conducted in accordance with the guidelines stipulated by, the Massey University Human Ethics Committee.

3.2 Description of measurements used

3.2.1 Hydration status and height

Hydration status was monitored by urine specific gravity (U_{sg}) and body mass (BM). The degree of fluid loss (FL) during surf practice was estimated by correcting for substrate oxidation and metabolic water loss. However, due to the field-based nature of the study, it was not possible to assess BM loss as a result of urination or evaporative loss from the lungs. Therefore, the estimated FL during each trial was likely to be inaccurate.

To attain hydration status, athletes were first asked to void approximately 100 ml of mid-flow urine into a clear specimen container (model 1205007-EP, Sarstedt, Australia) at which point a clinical refractometer (model 2734-E02, Atago Sur-ne, Japan) was used to assess U_{sg} . Prior to being weighed participants were asked to empty their bladder (if possible). All participants were weighed (in their underwear) on a digital weight scale (model TBF-531, Tanita, Japan) with a precision of 0.02 kg. At the conclusion of the training session, participants thoroughly towel dried themselves and hydration status was reassessed using the same protocol. The percentage change in BM was calculated using the following formula (Cox et al., 2002):

$$\% \text{ change in BM} = 100 \times \left(\frac{\text{Post-exercise body mass (g)} - \text{pre-exercise body mass (g)}}{\text{Pre-exercise body mass (g)}} \right)$$

In order to calculate FL several assumptions had to be made. They were as follows: total energy expenditure for 100 min of surf practice (EE) was approximately 3370 kJ (Meir et al., 1991); the respiratory exchange ratio was 0.85 (Meir et al., 1991) and as such, energy would be equally derived from fat and CHO (Rogers et al., 1997); each gram of fat and CHO equalled 35 kJ and 17 kJ of energy, respectively (Rogers et al., 1997); and, for every gram of glycogen oxidised 2.7 grams of water was lost (Rogers et al., 1997). Based on these assumptions the following formulae were used to assess FL (Rogers et al., 1997):

$$\text{Fat oxidised (g)} = \left(\frac{\text{EE (kJ)} \times 0.5}{\text{Energy from 1 gram of fat (kJ)}} \right)$$

$$\text{CHO oxidised (g)} = \left(\frac{\text{EE (kJ)} \times 0.5}{\text{Energy from 1 gram of CHO (kJ)}} \right)$$

$$\text{Metabolic water loss (g)} = \text{CHO oxidised (g)} \times \text{water oxidised per gram of glycogen (g)}$$

$$\text{Total substrate oxidation (g)} = \text{Fat oxidation (g)} + \text{CHO oxidation (g)} + \text{Water loss (g)}$$

$$\text{Total fluid loss (kg)} = \text{Post-exercise BM (kg)} - \text{total substrate oxidation (kg)}$$

Bare foot height was measured using a stadiometer (model 214, Seca, China) with a precision of 1 mm.

3.2.2 Cognitive function

Short-term memory was gauged using a modification of the short-term memory test (STM) devised by Schultes et al., (2005; refer to Appendix B, page 102). Two separate lists each containing 15 words were used. Word lists comprised of 5 words that belong to one of three semantic categories: surfing-related words like ‘floater’ and ‘surfboard’; neutral words like ‘stick’ and ‘tree’; and emotional words like ‘mother’ and ‘friend’. The words of different categories had been matched for frequency and length. Words were presented orally at a rate of one word per second. At the completion of each list, and a subsequent break of 1 min, the participants were required to recall all words remembered from the preceding list within 1 min. All tests were timed using a handheld stopwatch (Ergo 100, Aussie fit, Australia).

Working memory and information processing speed was evaluated using a paced serial addition test (Gopinathan et al, 1988; refer to Appendix B, page 102). Thirty random, single and double-digit numbers were grouped into six sets (5 digits per set). Each set was read to the participant at a fixed rate of 1 number every 2 s. The participants were instructed to add the 5 consecutive numbers read to them and write down the total sum of those numbers. They were given 5 s to write down their answer before the next strand was read out.

Attention, visuomotor skills and visual acuity were determined using a trail-making test (Reitan, 1958; Appendix B, page 102). Participants were presented with a test sheet containing 48 randomly scattered symbols - half being consecutive numbers and the other half consecutive letters of the English alphabet. They were allocated 60 s to trace a trail

through these symbols in correct order (alternating between number and letter) without lifting the pen off the paper.

3.2.3 Muscular endurance

Lower body strength endurance was measured using a modified version of Astrand and Rodahl's (1977) 1-min step test. Participants performed as many step-ups as possible within a 60-s period. The step was 0.48 m high and on level ground. A complete step was defined as having an upward phase (the stepping leg reaching full extension at the knee) and a downward phase (the heel and toes of the foot of the stepping leg completely touching the ground). Participants were assessed on total correct step-ups completed in 1 min after which they were given a 1 min rest before the next test.

Upper-body strength endurance was determined using a 1-min push-up test (Baumgartner et al., 2002). Each participant was given 1 min to complete as many push-ups as possible. A full push-up was defined as having a downward phase (chest lowered 7.5 cm from the floor) and an upward phase (arms fully extended at the elbow). Participants were assessed on total correct push-ups completed in 1 min.

3.2.4 Surfing performance

Participants were allocated 20 min to catch up to 10 waves with the two highest scoring waves tallied for a total score out of 20. Participants were alerted of the beginning and ending of each assessment by whistle and flag. A green flag and 2 consecutive whistles indicated the analysis had started. A red flag and two consecutive whistles indicated that

the analysis had finished. Results of the judges' scores were represented as the mean total score for each wave. The judging criterion was based on the surfer's ability to perform radical controlled manoeuvres in the critical section of a wave with speed, power and flow to maximize scoring potential. Innovative / progressive surfing, as well as variety of repertoire (manoeuvres), was taken into consideration when rewarding points for waves ridden. The surfer who executed these criteria with the maximum degree of difficulty and commitment on the wave was rewarded with the higher score (www.aspworldtour.com, 2007). The same 3 judges were used for each trial. All 3 judges had judged WQS (world Qualifying Series) and Billabong Pro-Junior Series events. Generally, wave scores between 1-3 were poor, 4-5 average, 6-7 good, 8-9 excellent and 10 perfect. A score of 10 was achievable in all trials as the judging scale was adapted to the conditions.

3.2.5 Environmental conditions

Wave size and wave quality were the parameters used to define surf conditions. Water temperature and wetsuit type were the measures used to define environmental conditions. Data for these determinates was obtained from *The Manly Daily* surf report and Manly Hydraulics Laboratory (www.mhl.nsw.gov.au). For wave quality, the researcher (in consultation with the surfer) rated the conditions out of 10, with 10 being perfect and 1 being poor. To ensure continuity between trials, participants were asked to wear the same wetsuit (sealed seamed steamer) in both trials.

3.3 Surfing protocol

During the surfing protocol participants were required to wear a 2 x 3 mm sealed seamed steamer wetsuit (their own) and train for 100 min in small waves 1 – 1.5 m (2-4 foot) of average quality (5-6 out of a possible 10). The steamer wetsuit was selected as it is commonly used along Sydney's Northern Beaches (particularly during morning surfs) and as such, likely to represent normal practice. The duration of 100 min was chosen as it was considered to be the length of a typical surfing session for most elite surfers (these assertions were based on researcher's 27 years of experience).

Participants were judged during the first and last 20 min of the 100-min training session. In the no fluid trial (NF), participants remained in the water for the whole 100 min. In the fluid trial (FI) participants came to the shoreline at approximately 20 min intervals to consume $3\text{ml}\cdot\text{kg}\cdot\text{BM}^{-1}$ of cool (15°C) water. Each fluid consumption took roughly 15 s to complete and accounted for approximately 1 min of the 100 min trial. To control for wave quality, trials were all held in waves 1 – 1.5 m (2-4 foot) in height and 5-6 out of 10 in quality. These type of wave conditions were chosen as they were likely to be repeatable in all trials. On days when the swell was large, the surfing assessment would be held at a beach that was protected from the swell i.e. Long Reef in a northeast swell or Manly in a southeast swell (Figure 3.1).

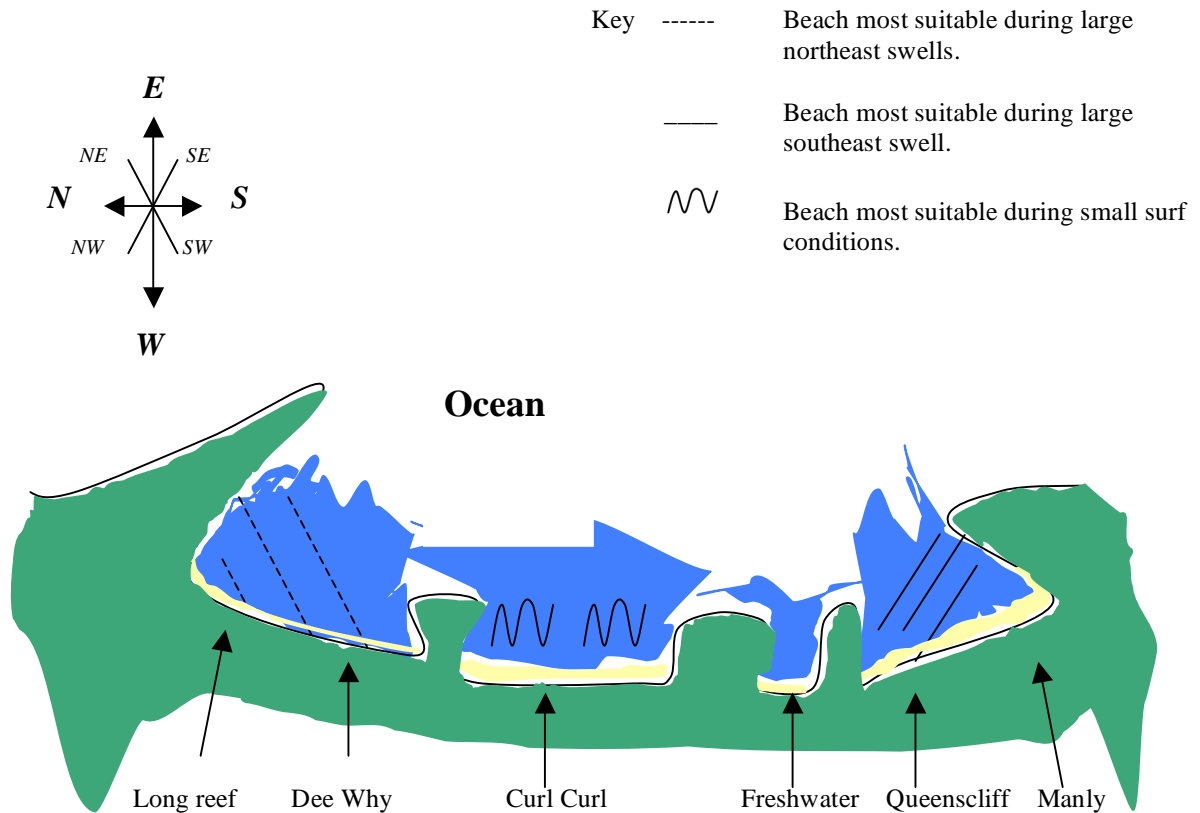


Fig. 3.1 Diagrammatic representation of beaches used for surfing protocol (not to scale).

3.4 Familiarisation session

During the preliminary session participants were briefed on the study requirements, completed a medical and exercise history questionnaire and signed an informed consent document. They were instructed on how to record food intake and, following this, participants were familiarised with an example test from each of the cognitive assessments and completed both muscular endurance tests.

3.5 Experimental design and protocol

3.5.1 Experimental environment

All experiments were conducted in Sydney, Australia during autumn and spring months where the average outdoor temperature was $18.9 \pm 2.2^\circ\text{C}$ ($12 - 28.8^\circ\text{C}$) with an average relative humidity of $69.3 \pm 9.9\%$ ($78 - 55\%$; Australian Government Bureau of Meteorology). No trial was held in the rain with most trials being conducted at beaches protected from strong winds and in partly sunny conditions. In all trials, hydration status, cognitive function and muscular endurance were assessed in the quiet controlled environment of the researcher's home. Surfing performance was assessed at one of five beaches between Manly and Collaroy where the average water temperature was $20.8 \pm 1.4^\circ\text{C}$ ($18.4 - 22.2^\circ\text{C}$; *Manly Daily* surf report and Manly Hydraulics Laboratory).

3.5.2 Experimental protocol

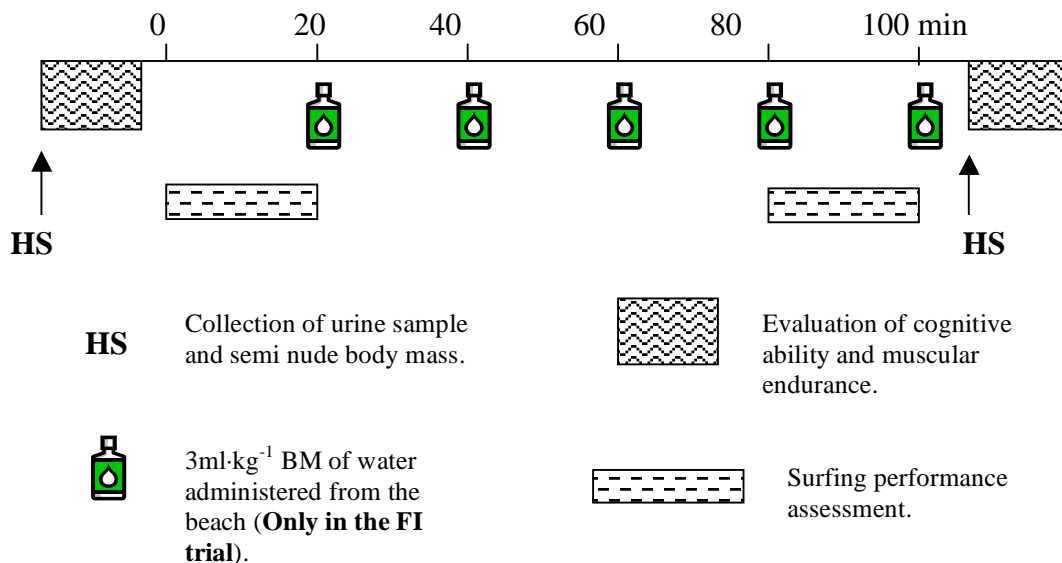


Fig. 3.2. Schematic representation of the experimental protocol used for NF and FI trials

Trials were completed in a repeated measures crossover design separated by 7 to 10 days. To achieve a euhydrated state for the first assessment, 24 hours before the trial, participants were required to record their food intake, abstain from vigorous physical activity, refrain from the consumption of alcohol and foods high in caffeine, and consume an additional 1000 ml of water before going to bed. For the subsequent trial, the process was the same, although, rather than recording food intake, they were asked to consume the same food as in the first trial.

Participants arrived for testing between 08:00 and 09:00 after a 10-hour overnight fast and were considered to be sufficiently hydrated if U_{sg} was $< 1.015 \text{ g}\cdot\text{ml}^{-1}$ (Oliver et al., 2007). Once hydration status and height were established the participant completed the following tests in the order as presented: short-term memory, paced serial addition, trail making, 1-min push-up and 1-min step-up test. Participants were then driven to the beach (which had been selected that morning) and began the surfing protocol. The journey from the researchers home to entering the water took between 20 – 40 min depending on the location and traffic conditions; however, whenever possible the same location was used. Surfing performance was assessed during the first 20 min (baseline) and last 20 min of the 100-min surfing session.

At the conclusion of the surfing session, and once surfing performance had been assessed, participants thoroughly towel dried themselves and were driven back to the researcher's home to repeat the same hydration, cognitive and muscular endurance tests (Figure 3.2). Given the time taken to drive to and from the beach, the cognitive tests and body mass measures were approximately 30 min before and after surfing practice i.e.

approximately 2.5 h apart. Note: prior to being weighed all participants were asked to emptied there bladders.

3.6 Statistical analyses

As the data analysis assessed delta change values between trials and environmental conditions, paired t-tests were used to identify statistical difference. All data analyses were undertaken using Microsoft® Excel (version 11.0). Selected relationships were also examined by Pearson product – moment correlation analysis. For clarity of presentation data are presented as means, standard deviations and range. Statistical significance was set at $P < 0.05$.

CHAPTER 4 RESULTS

4.1 Environmental conditions

The mean wave height was 1.5 ± 0.3 m (range 1.0 – 2.0 m), wave quality was rated as being 5.7 ± 0.7 out of a possible 10 (range 5 – 7) and the average water temperature was $20.8 \pm 1.4^\circ\text{C}$ (range 18.4 – 22.2). There was no statistical difference between trials for swell size ($P = 0.78$), wave conditions ($P = 1.00$), water temperature ($P = 0.94$) and environmental temperature ($P = 0.26$).

4.2 Hydration status

During the NF trial U_{sg} increased from 1.007 ± 0.004 (range 1.002 – 1.014 $\text{g}\cdot\text{ml}^{-1}$) to 1.029 ± 0.003 (range 1.025 – 1.033 $\text{g}\cdot\text{ml}^{-1}$). In the FI trial, U_{sg} increased from 1.009 ± 1.005 (range 1.003 – 1.015) to 1.014 ± 0.005 (range 1.004 – 1.024 $\text{g}\cdot\text{ml}^{-1}$).

In the NF trial, pre- to post-exercise BM was reduced from 72.7 ± 6.6 kg (range 64.0 – 85.0 kg) to 69.9 ± 6.4 kg (range 61.2 – 81.8 kg), respectively; in the FI trial, pre- to post-exercise BM was reduced from 72.2 ± 6.4 kg (63.8 – 84.0 kg) to 71.1 ± 6.3 kg (62.6 – 82.5 kg). Thus, the mean BM loss of participants in the FI and NF trials were 2.8 ± 0.6 kg and 1.1 ± 0.4 kg, respectively. When expressed as a percentage, mean BM loss at the conclusion of the NF and FI trials was $3.9 \pm 0.7\%$ (range 2.3 – 4.7%) and $1.6 \pm 0.7\%$ (range 0.7 – 2.5%), respectively. The degree of BM loss experienced when no fluid was

ingested during practice was significantly greater than that experienced when fluid was ingested ($P < 0.05$; Figure 4.1).

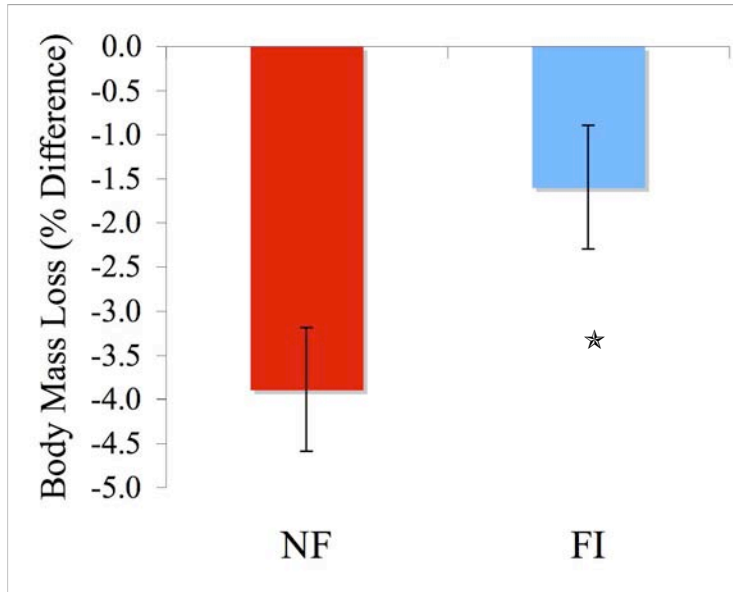


Fig. 4.1 Delta difference in body mass loss between both experimental conditions.

★ Indicates a significant difference between trials ($P < 0.05$).

The assumed degree of BM loss as a result of substrate oxidation and water metabolism in both trials was 0.415 kg. Therefore, fluid loss (FL) during the NF and FI trials was 2.4 ± 0.6 kg (range 1.2 – 3.0 kg) and 0.7 ± 0.4 kg (range 0.1 – 1.2 kg), respectively. Expressed as a percentage, this was $3.3 \pm 0.7\%$ (range 1.7 – 3.7%) and $1.0 \pm 0.5\%$ (range 0.1 – 1.6%), respectively. The amount of FL during the NF trial was greater than that experienced during the FI trial ($P < 0.05$).

4.3 Performance parameters

4.3.1. Surfing performance

The mean scores for surfing performance at the start of the NF and FI trials (baseline) were 16.0 ± 1.8 (range 12.5 – 18.8) and 15.3 ± 1.3 (range 12.8 – 17.0), respectively. The participants mean surfing scores during the final 20 min of surfing practice in the NF trial was 12.8 ± 1.6 (range 8.8 – 14.3). This was $20.3 \pm 7.1\%$ (range 8.4 – 29.6%) lower than baseline scores. During the final 20 min of the FI trial, 6 participants showed a decline in performance, 2 were unchanged and 4 improved. The mean surfing score during the last 20 min of surf practice was 15.2 ± 1.2 (range 13.8 – 18.0). This was $1.9 \pm 10.2\%$ (range -9.8 – 26.8%) greater than baseline scores. Further analysis showed a significant difference between experimental conditions ($P < 0.05$; Figure 4.2).

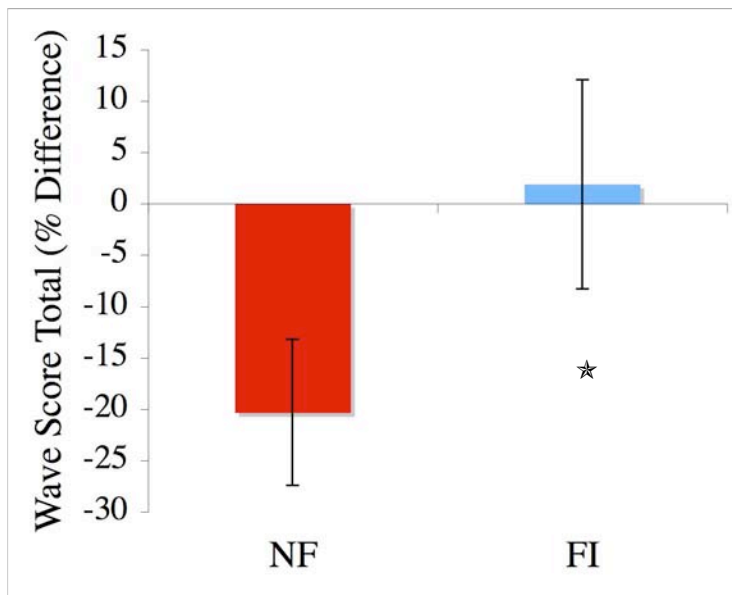


Fig. 4.2 Delta difference in wave scores under both experimental conditions.

★ Indicates a significant difference between trials ($P < 0.05$).

A good relationship was identified between dehydration and surfing performance ($r = 0.75$, $P < 0.05$; see Appendix B 102 for judging scores).

4.3.2 Short-term memory test

In the NF trial word recall was reduced from 13.9 ± 1.2 (range 12 – 16) to 10.7 ± 1.4 (range 8 – 12) from pre- to post-exercise, respectively; in the FI trial word recall increased from 13.1 ± 1.0 (range 11 – 14) to 14.3 ± 1.4 (range 12 – 17). Therefore, short term memory was reduced in the NF trial by $23.2 \pm 9.1\%$ (range 8 – 38%) and improved in FI trial by $9.7 \pm 8.1\%$ (range 8 – 21%). The reduction in STM experienced when no fluid was consumed was significantly greater than that experienced when fluid was ingested ($P < 0.05$; Figure 4.3).

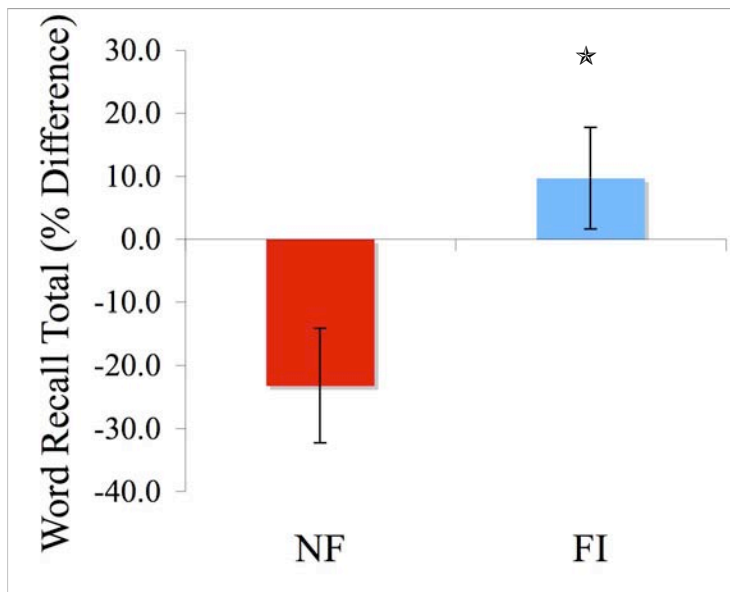


Fig. 4.3 Delta difference in short-term memory under both experimental conditions.

★ Indicates a significant difference between trials ($P < 0.05$).

There was a strong relationship between dehydration and short-term memory ($r = 0.89$, $P < 0.05$) and a moderate relationship between surfing performance and short-term memory ($r = 0.63$, $P < 0.05$).

4.3.3 Paced serial addition test

During the NF trial, baseline arithmetic ability was 4.1 ± 0.7 (range 3 – 5) whereas post-exercise values were 2.2 ± 0.4 (range 2 – 3). This resulted in a $44.0 \pm 10.4\%$ (range 25 – 60%) reduction in arithmetic ability. During the FI trial, pre- and post-exercise scores were 3.6 ± 0.7 (range 3 – 5) and 3.8 ± 0.7 (range 3 – 5), respectively. This led to a $3.8 \pm 18.5\%$ (range -25 to 33%) improvement in arithmetic ability. The reduction in arithmetic ability experienced when no fluid was consumed was significantly greater than that experienced when fluid was ingested ($P < 0.05$; Figure 4.4).

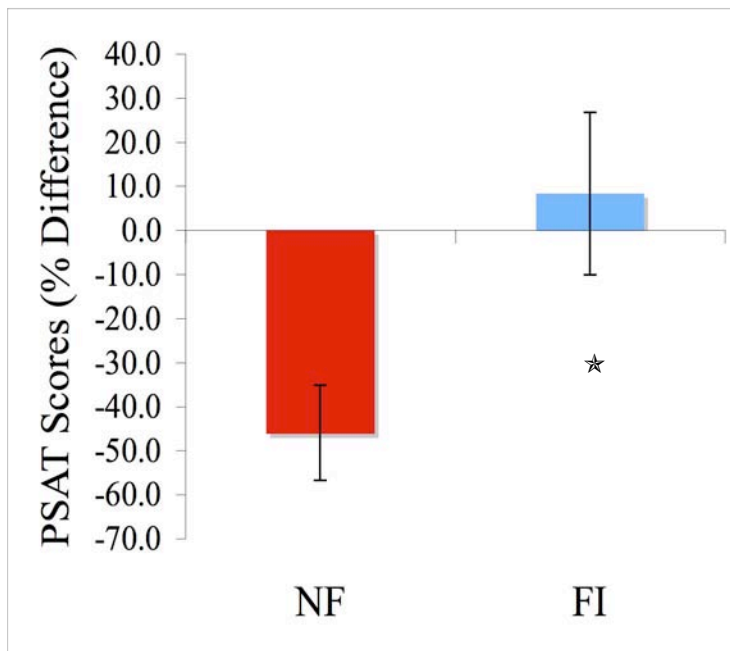


Fig. 4.4 Delta difference in arithmetic ability under both experimental conditions.

★ Indicates a significant difference between trials ($P < 0.05$).

There was a strong relationship between arithmetic ability and hydration status ($r = 0.86$, $P < 0.05$) and a good relationship between arithmetic ability and surfing performance ($r = 0.74$, $P < 0.05$).

4.3.4 Trail-making test

During the NF trial, baseline TMT score was 13.2 ± 1.4 (range 11 to 16) whereas post-exercise values were 9.9 ± 1.4 (range 7 to 12); this was a reduction of $24.3 \pm 9.8\%$ (range 15.4 to 50%). During the FI trial, pre- and post exercise scores were 13.0 ± 1.5 (10 – 16) and 14.1 ± 1.8 (range 10 to 16), respectively; this resulted in a mean improvement of $9.3 \pm 17.4\%$ (range -9.1 to 60%). The reduction in trail making ability experienced when no fluid was consumed was significantly greater than that experienced when fluid was ingested ($P < 0.05$; Figure 4.5).

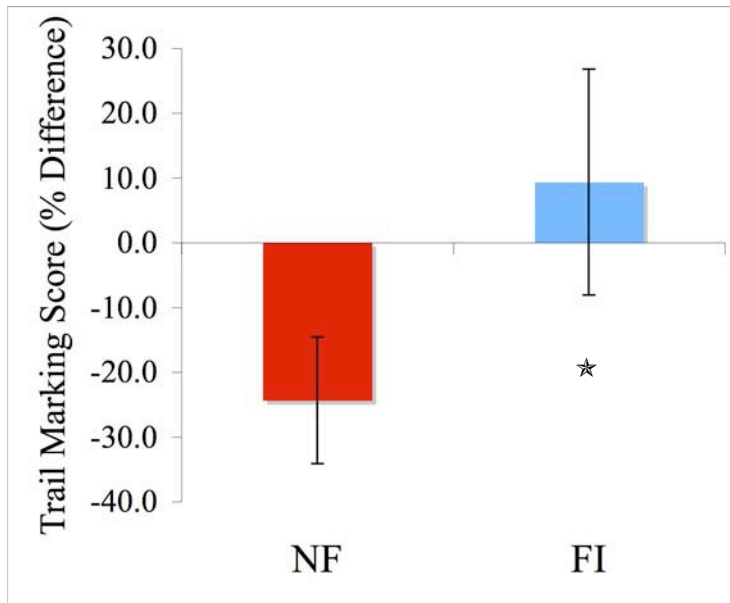


Fig. 4.5 Delta difference in trail making ability under both experimental conditions.

★ Indicates a significant difference between trials ($P < 0.05$).

A strong relationship was identified between the participants' level of dehydration and trail-making ability ($r = 0.80$; $P < 0.05$), with a moderate relationship between surfing performance and trail-making ability ($r = 0.58$; $P < 0.05$).

4.3.5 One-min push-up test

In the NF trial the mean pre- and post-exercise push-up scores were 31.8 ± 7.8 (range 22 to 48) and 25.1 ± 6.2 (range 15 to 37), respectively. This resulted in a $21.2 \pm 5.5\%$ (range 12.5 to 31%) reduction in UBE. During the FI trial pre- and post-exercise push-up score were 30.8 ± 7.7 (range 22 to 49) and 26.5 ± 7.2 (range 17 to 42), respectively. This was a $17.0 \pm 4.1\%$ (range 12.5 to 25%) decrease in UBE. The reduction in UBE experienced when no fluid was consumed was significantly greater than that experienced when fluid was ingested ($P = 0.01$; Figure 4.6).

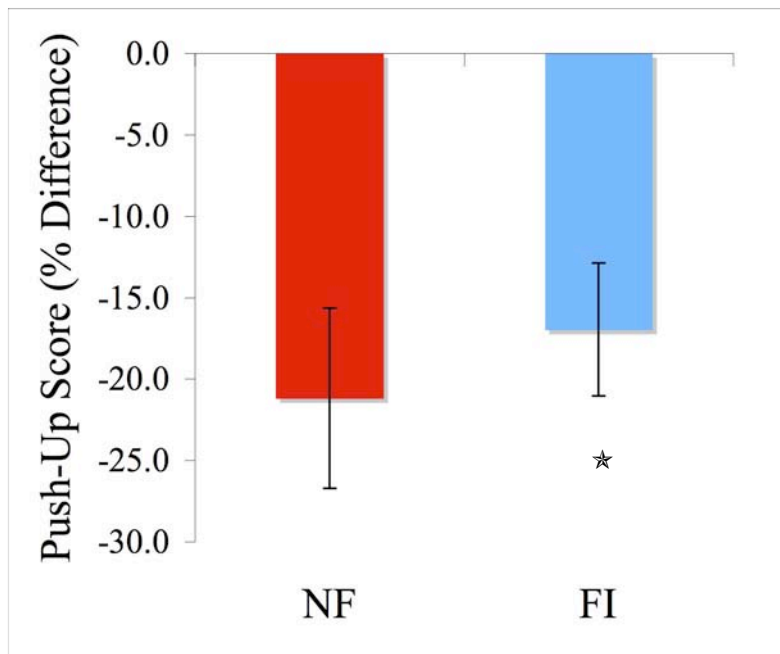


Fig. 4.6 Delta difference in push-up ability under both experimental conditions.

★ Indicates a significant difference between trials ($P < 0.05$).

There was no relationship between hydration status and UBE ($r = 0.34$; $P = 0.10$) nor surfing performance and UBE ($r = 0.31$; $P = 0.14$).

4.3.6 One-min step-up test

During the NF trial the mean pre- and post-exercise scores were 26.2 ± 0.9 (range 25 to 28) and 25.0 ± 1.5 (range 22 to 27), respectively; thus resulting in a $4.4 \pm 5.8\%$ (range -14.3 to 4.0%) decline in LBE. In the FI trial, pre- and post-exercise step-up values were 26.1 ± 1.2 (range 25 to 29) and 26.3 ± 1.1 (range 25 to 29), respectively; as a result there was a $1 \pm 3\%$ (range -3.7 – 4.0) increase in LBE. There was a significant difference between trials with regards to the mean delta change between pre- and post-exercise conditions ($P = 0.01$; Figure 4.7).

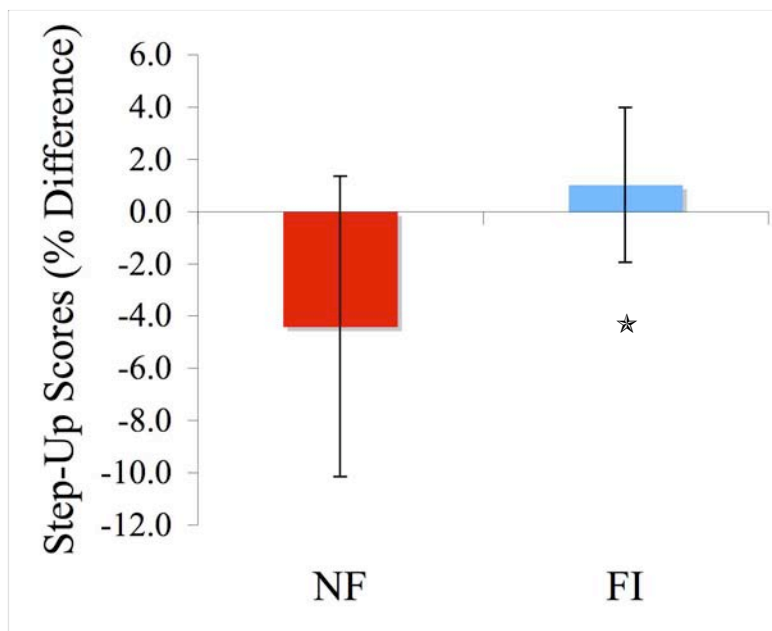


Fig. 4.7. Delta difference in step-up ability under both experimental conditions.

★ Indicates a significant difference between trials ($P < 0.05$).

A moderate relationship was observed between the level of dehydration experienced and LBE ($r = 0.54$; $P < 0.05$). There was also a weak relationship between surfing performance and LBE but not statistically significant ($r = 0.44$; $P = 0.06$).

CHAPTER 5 DISCUSSION

The main finding of the present study is that surf training without water ingestion results in a 3.9 % reduction in body mass and a 20.3% drop in surfing performance. This supports the research hypothesis that surf training for 100 min in a full-length wetsuit leads to a degree of body mass loss severe enough to adversely affect surfing performance. Furthermore, when water is not consumed both cognitive function and lower-body (but not upper-body) muscular endurance are significantly impaired with cognitive ability having the highest correlation with surfing performance.

Despite the well-known effects of dehydration on athletic performance (for further review, see Barr, 1999) surfers (even at an elite level) do not take measures to match fluid loss during practice (Felder et al, 1998). As the reported intensity of surf practice is between 70-80% HR_{peak} (Meir et al., 1991), the duration up to 5 h, (Mendez-Villanueva and Bishop, 2005) and the use of full-length wetsuits designed to trap metabolic heat common (Burrow, 2005), it is likely that surf practice is prone to causing BM loss. In the present study it was found that during the NF trial, where participants surfed for 100 min in a steamer wetsuit without fluid ingestion, there was a mean BM loss of $3.9 \pm 0.7\%$ (2.9 ± 0.6 kg). Conversely, in the FI trial where $3\text{ml}\cdot\text{kg}\cdot\text{BM}^{-1}$ of water was consumed at 20 min intervals, participants showed significantly less ($P < 0.05$) BM loss of $1.6 \pm 0.7\%$ (1.1 ± 0.4 kg). As there was still a level of BM loss at the conclusion of the FI trial, a greater amount of fluid than was used in the present study is required to match BM loss.

Yet, this might lead to other performance issues such as decreased board floatation, gastrointestinal distress (Barr et al., 1991) or possibly hyponatremia (Coyle et al., 2004).

When the findings of the present study are compared to research conducted on sports that share a similar duration, intensity and reliance on skill, surf training in a steamer wetsuit without fluid ingestion results in a considerably greater amount of BM loss (Table 5.1).

Table 5.1 Reduction in body mass experienced in intermittent sports

Study	Sport (exercise description)	Time (min)	BM loss (%)
Dawson et al., (1985) n = 8	Tennis (Simulated match vs. intermittent running)	60	2.4
Hoffman et al., (1995) n = 10	Basketball (Game)	10	1.9
Vergauwen et al., (1998) n = 10	Tennis (Training)	120	1.5
McGregor et al., (1999). n = 9	Soccer (Loughborough Intermittent Shuttle Test)	80	2.4
Davey et al., (2002). n = 18	Tennis (Loughborough Intermittent Hitting Test)	35	1.5
Shirreffs et al., (2005) n = 26	Soccer (Training)	90	1.59
Maughan et al., (2007) n = 27	Soccer (Training)	100	1.62
Present study NF trial n = 12	Surfing (Training)	100	3.9
Present study FI trial n = 12	Surfing (Training)	100	1.6

A possible explanation for the comparatively large degree of BM loss observed in the present study is that exercise conducted in a wetsuit exacerbates sweat rates and subsequently BM loss. It may also be due to the field-based nature of the study and the inherent limitations this poses on the control of confounding variables such as body mass loss from urination or evaporation loss from the lungs. Nevertheless, given the large amounts of BM loss observed in the FI trial, it would seem that the insulating qualities of a wetsuit are such that sweat rates increase to regulate core temperature.

Several studies have assessed the thermal insulation of wetsuits (Kang et al., 1983; Wolff et al., 1985; Shiraki et al., 1986; Yeon et al., 1987; Monji et al., 1989; Cotter et al., 1995; Arieli et al., 1997; Ducharme and Brooks, 1998) and all report that wetsuits reduce convective heat loss during water immersion. This is achieved by trapping a layer of water between the suit and the skin, which due to the dissipation of metabolic heat, is heated (Wolff et al., 1985). However, a few studies have found that when in cool or cold-water (14 – 27°C), wetsuits do not provide adequate thermal protection to maintain core temperature (Shiraki et al., 1986; Cotter et al., 1995; Arieli et al., 1997). This is generally attributed to flushing (water passing through the wetsuit), which moves warm water away from the body and replaces it with cool water. Flushing has been found to increase when in turbulent wave conditions (Cotter et al., 1995) and during excessive movement (Arieli et al., 1997). It is thought to be a by-product of loose fitting wetsuits and water leaking through the seams (Wolff et al., 1985; Arieli et al., 1997). Interestingly, the wetsuits used in the present study (sealed steamers) are reported to almost entirely prevent flushing and water seeping through the seams (www.ripcurl.com.au; www.oniell.com). This lack of

flushing and therefore cooling, may explain why the participants in the present study actually lost BM.

Similar levels of BM reductions have been reported in rapid weight loss (RWL) protocols employed by athletes competing in weight class sports. For instance, in the Webster (1990) study on RWL strategies employed by elite wrestlers, a 4.9% loss in BM was reported after completing a 6 hour protocol of intermittent high intensity exercise in rubberised sweat suits. Similarly, Smith et al's., (2000) assessment of the effects of RWL on boxing performance, found that 45 min of low intensity exercise, in a hot humid environment, whilst wearing thermo-restrictive clothing, led to a reduction in body mass of 3.8%. As both the Webster (1990) and Smith et al., (2000) experiments took place on dry land, the similar degree of dehydration experienced after 100-min of surf training in a full-length wetsuit, suggests that even when semi-immersed in cool water (20.8 °C), the insulating qualities of the wetsuit are such that they likely restrict water entry, trap metabolic heat and exacerbate sweating rates. However, as the temperature within the wetsuit was not measured, further research is needed to assess the actual intra-suit temperature experienced during surf practice in a steamer wetsuit.

A major finding of this study was that during the NF trial, surfing performance was reduced by $20.3 \pm 7.1\%$ (range 8.4 – 29.6%), yet in the FI trial, despite there still being a 1.6% reduction in BM, performance declines were attenuated ($1.9 \pm 10.2\%$; range -9.8 – 26.8%). A significant difference in surfing performance was detected between the two experimental conditions and a good relationship between BM loss and surfing performance was also established ($r = 0.75$; $P < 0.05$). This suggests that variations in

BM rather than other extraneous variables (e.g. wind, tide, crowds and wave quality) were likely to be responsible for the observed changes in surfing performance. The lack of effect of this 1.6% reduction in BM had on surfing performance supports the generally accepted view that BM loss, when in combination with heat stress, does not affect athletic performance when under 2% (Casa, 2000; Noakes et al., 2002). Therefore, it would seem that returning to the beach every 20 min to consume $3\text{ml}\cdot\text{kg}^{-1}$ BM of water is adequate in attenuating a BM loss mediated decline in surfing performance.

The findings of the present study are supported by declines in performance observed in other skill-based sports. For example, Smith et al., (2000) observed that 3.8% BM loss reduced boxing performance by 26.8%. Dawson et al., (1985) assessed the performance of tennis players and found that at a 2.4% reduction in BM their serve, groundstroke, volley accuracy and power were all significantly reduced. Hoffman et al., (1995) examined the effects of exercise induced BM loss on basketball game play and established that a 1.9% reduction in BM, vertical jump and shooting accuracy were significantly reduced. McGregor et al., (1999) found that 90 min of simulated football game play, without fluid ingestion, led to a 2.4% dehydrated state and a 5% reduction in soccer skills. Moreover, as was the case in the present study, McGregor et al., (1999) discovered that when fluid was consumed, performance was maintained.

Of the limited research conducted on surfing the primary focus has been on either physical or physiological attributes. Earlier studies conducted by Lowdon and Peteman (1980) and Lowdon (1980) assessed age, body mass, somatotype and the $\dot{V}O_{2\text{peak}}$ of elite surfers. More recently, Meir et al., (1991), Mendez-Villanueva and Bishop (2003) and

Mendez et al., (2005) have measured $\dot{V}O_{2peak}$, heart rate response to surfing and the different lactate thresholds of competitive surfers. Other than the present study, no research to date has assessed the cognitive aspect of surfing and its importance to superior performance. A lack of information on the role of cognitive processes in sporting performance is not unique to surfing (Hornery et al., 2007) and of the few studies that have included cognition in their research methodology, only a token effort has been made. Therefore, a secondary focus of this research was to ascertain the importance of both cognitive function and physical ability on surfing performance. The cognitive testing battery assessed 7 different cognitive domains thought likely to contribute to superior surfing performance; they were: information processing speed, working memory, short-term memory, visuomotor skill, visual tracking ability and attention.

At the conclusion of the NF trial, when participants were at a 3.9% dehydrated state, cognitive performance was reduced in all functions, i.e. short-term memory by 23%, working memory and information processing by 44% and visuomotor function involving visual acuity, motor speed and attention by 24%. At the conclusion of the FI trial cognitive function was not only maintained but also improved.

All the cognitive domains assessed showed a strong correlation to hydration status (range $r = 0.80 - 0.89$; $P < 0.05$) and a moderate relationship with surfing performance (range $r = 0.58 - 0.74$; $P < 0.05$). The cognitive domains that had the highest correlation with surfing performance were working memory (the ability to store and manipulate information) and information processing speed (the speed at which a person is able to change latent information into manifest information). This is not surprising as the ability

to quickly identify superior waves and respond to environmental cues (e.g. wave steepness, changes in water colour, variations in breaking patterns) is a focal point of surf practice (Young, 2000; Burrow, 2005).

The findings in the present study are consistent with those of Gopinathan and colleagues' (1988) that reported a significant reduction in cognitive performance at a 2% dehydrated state. Furthermore, it was discovered that as the degree of BM loss increased, so too did cognitive dysfunction. More recently, Cian et al., (2000) assessed the effects of hyperhydration, heat stress and exercise-induced dehydration on cognitive function. Similar to the results of the present study, Cian et al., (2000) found that at a 2-3% dehydrated state (be it exercise or heat induced) there was a significant impairment of cognitive function. The findings of both the Gopinathan et al., (1988) and the Cian et al., (2000) studies, as well as those of the present study, suggest that the integrity of cognitive function is maintained during the early stages of BM loss yet compromised as BM loss increases. It also suggests that the cognitive function of the participants in the present study may have been compromised at an earlier stage. Future research needs be conducted to identify the point at which dehydration compromises the mental performance of elite surfers i.e. similar to the methodology used by Gopinathan et al., (1988).

Contrary to the findings of the present study, several papers have reported cognitive function as being unaffected by mild (2 – 3%; McGregor et al., 1999; Edwards et al., 2007) to severe dehydration (< 4%; Landers et al., 2000). The incongruous findings of the aforementioned research may be a product of poor methodological approach rather

than the result of physiological and/or behavioural adaptations. For example, in the Choma et al., (1998) study, participants achieved their weight loss over a 7-day period while those partaking in the Landers et al., (2000) study had up to 10 days. No data was collected on the means to which participants lost weight and such an extended period of recovery time may have allowed for equilibrium of dehydration-induced hormonal and cellular perturbations. Furthermore, neither study established a euhydrated body mass and, as measures were obtained during the competition season where rapid weight gain between events is common (Landers et al., 2000), the participants' baseline mass may have been overestimated.

In the McGregor et al., (1999) and Edwards et al., (2007) studies, only one test was employed to ascertain the cognitive demands of football. The test was a 1-min number identification task conducted pre- and post-exercise and, although the inclusion of mental skills as a performance variable is commendable, the degree of investigation did not adequately assess the many cognitive domains associated with football. Furthermore, despite the large body of research suggesting exercise increases information processing speed and decision-making ability (Mc-Glynn et al., 1979; Paas & Adam, 1991; Chmura et al., 1994; Delignieres et al., 1994; Brisswalter et al., 1995; Adam et al., 1997; McMorris et al., 1999), neither study made adjustments to account for this. As both investigations reported slightly lower post-exercise mental concentration scores, and given that exercise actually stimulates cognitive function, the effect dehydration has on cognitive ability may have been under reported. The lack of a comprehensive cognitive testing battery like that employed by Gopinathan et al., (1988) or Cain et al., (2000) not only weakens the meaningfulness of their findings but draws attention to the lack of

significance given to the role mental skills play in superior sporting performance (Hornery et al., 2007).

A possible explanation for why cognition is affected by dehydration may relate to Baars' (1993) 'global workspace theory' on operational cognition. According to Baars (1993) cognition is of limited capacity, which creates a condition where cognitive processes are in competition for dominance of executive function. It is believed that of these competing processes some are more apt at dominating executive function than others. Yet, when activity is conducted in a dehydrated state and/or in the presence of heat stress, these stressors also begin to compete for dominance. The net result is cognitive processes of lesser importance are replaced by these stressors, which leads to a reduction in task orientation and ultimately compromised performance (Cohan, 1983; Baars 1993).

As seen in the present study, the level of dehydration experienced at the conclusion of the NF trial was severe enough to significantly reduce the 7 cognitive domains assessed and impair surfing performance. Yet in the FI trial no effect was observed. This would seem to suggest that at some stage the degree of cognitive stress associated with dehydration became greater enough to gain dominance over executive function, and thus reduce the cognitive process required for wave selection and wave riding.

From a cellular perspective, the mechanisms involved in dehydration-mediated cognitive dysfunction begin with inhibited mitochondrial function (Wilson and Morley, 2003). This begins a chain of events starting with a reduction in ATP-independent ionic segregation, which impairs the ability to regulate the normal ionic gradient and subsequently triggers inappropriate membrane depolarisation. According to Calabresi et al., (2000), membrane

depolarisation almost certainly leads to neuronal death, yet certain neuronal subtypes are more predisposed to neuronal death than others. This explains, in some way, why in the present study and other similar papers, different cognitive processes were able to withstand the deleterious effects of dehydration for longer than others. For example, at the conclusion of the NF trial, the participants in the present study showed a reduction in information processing speed and working memory of 44%, yet short-term memory was only reduced by 23%. Conversely, Choma et al., (1998) reported that at a 5% BM loss, the short-term memory of collegiate wrestlers was significantly compromised but not attention, visuomotor skills or visual acuity. Unlike wrestlers, the short-term memory of surfers seemed to be the least compromised when dehydrated. This suggests that the resilience of certain cognitive domains may vary depending on the sport. Further research is required to clarify whether certain cognitive domains are of more importance to particular sports.

The physical components thought most likely to contribute to superior surfing performance were upper and lower body muscular endurance. At the conclusion of the NF trial upper body muscular endurance (UBE) and lower body muscular endurance (LBE) were reduced by $21.2 \pm 5.5\%$ and $4.4 \pm 5.8\%$, respectively. During the FI trial when fluid was consumed, there was a substantial decline in UBE ($17 \pm 4.1\%$), yet LBE was slightly improved ($1 \pm 3\%$). A possible explanation for why water alone could not attenuate UBE declines may be due to the physical demands of paddling. Unlike LBE, which is specific to wave riding and accounts for less than 5% of a surfing session (Meir et al., 1991), UBE is required for paddling and accounts for 40-50% of surfing practice (Meir et al., 1991). Therefore, as the energy demands of the upper-body are likely to be

greater than those of the lower body (Felder et al., 1998), the declines in UBE were likely due to a peripheral fatigue that water alone could not attenuate.

Peripheral fatigue is a local, muscle specific inability to perform or maintain physical work (Hornery et al., 2007). The reduction in contractile force is generally thought to be due to the body's inability to adequately meet the energy requirements of the contracting muscle (Fitts, 1994). This suboptimal aerobic metabolism often leads to biochemical changes within the working muscle i.e. an accumulation of lactic acid and other acidic anaerobic metabolic by-products (Fitts, 1994). A more acidic cellular environment will either interfere with the release of calcium from the sarcoplasmic reticulum or result in a reduction in the sensitivity of the contractible molecules actin and myosin to calcium (Noakes, 2000); it is also known to inhibit phosphofructokinase (PFK) the rate limiting enzyme of glycolysis (Febbraio, 2001).

An unexpected result observed in the muscular endurance tests was the improvement seen in LBE at the conclusion of the FI trial. However, after further analysis it would seem that the increase in performance was due to an oversight in the research methodology rather than an actual improvement in muscular function. The oversight being that the muscular endurance tests used in the present study relied on the participants' BM to establish the resistance and in doing this failed to account for BM loss. Therefore, the muscular endurance tests were easier at the conclusion of each trial, which explains the 1% improvement in LBE and suggests that the effect of dehydration on muscular endurance may have been greater than reported. To avoid similar errors,

future research in this field should employ testing procedures with fixed weight (e.g. leg press and bench press).

Of particular note was that upper-body muscular endurance showed a poor and statistically non-significant relationship with both BM loss ($r = 0.34$; $P = 0.10$) and surfing performance ($r = 0.31$; $P = 0.14$). However, lower-body muscular endurance showed a moderate relationship with BM loss ($r = 0.54$; $P < 0.05$) and a weak, yet statistically non-significant, relationship with surfing performance ($r = 0.44$; $P = 0.06$). When compared with the results of the cognitive function assessment, it appears that cognitive prowess seems to correlate with surfing performance better than muscular endurance.

Although the findings of the present study suggests muscular endurance has little bearing on surfing performance, research conducted by Mendez-Villanueva et al., (2005) is to the contrary. In their study, the researchers investigated whether a link exists between paddling ability and surfing performance. This was achieved by comparing lactate threshold (LT) with the contest records of six European and seven regional-level surfers. The European-level surfers had superior contest results and were considered to be the better surfers. Blood lactate levels were taken while participants performed a $\dot{V}O_{2peak}$ test on a modified kayak ergometer (prone paddling) until a concentration of $4.0 \text{ mmol} \cdot \text{L}^{-1}$ (the imposed LT) was reached. The researchers concluded that aerobic peak power output, and the exercise intensity corresponding to a blood lactate concentration of $4 \text{ mmol} \cdot \text{L}^{-1}$, are higher in better performing surfers and may possibly be viewed as a performance determinate. However, the methods used to establish surfing ability and the

interpretation of the results were questionable. An oversight in the methodology used by Mendez-Villanueva et al., (2005) was the ranking of the surfers without actually observing their surfing ability. Furthermore, as the participants were either regional or national-level surfers, it is possible that they had not competed against each other, making the comparisons between ability and performance all the more tenuous.

Aside from the concern associated with the methods used by Mendez-Villanueva et al., (2005), the results seem to be far less conclusive than purported. For example, the surfer deemed to have the least ability (ranked 13th) had a LT higher than the 4th and just below the 3rd ranked surfer. What's more, the 7th and 8th ranked surfers had a LT equal to and greater than the 1st and 2nd ranked surfers. In fact, if not for the very low LT recorded for the 9th and 12th ranked surfers, the correlation between LT and surfing performance would not have been significant. Therefore, a more robust methodology that is more reflective of the findings is needed to substantiate the research of Mendez-Villanueva et al., (2005).

When designing a method to assess surfing performance, it became apparent it would be difficult to quantify whether a poor wave score was due to an error in judgement, a lack of muscular strength or a combination of both. And, despite there being methods of assessment such factor, pathway and component analysis, the participant numbers in the present study were far too small (Arrindell and Van der Ende, 1985). Therefore, the more ambiguous correlation analysis was used to gain insight into the role these factors play in surfing performance. Interestingly, it was found that significant correlations exist between cognitive performance and surfing performance while reduced correlations exist

between muscular function and surfing performance (Refer to results, chapter 4, section 4.3 performance parameters pages 56 – 62). It is important to recognise that a correlation does not imply causation. Yet, it would seem that the cognitive domains assessed in the present study might be better indicators of why surfing performance declines with dehydration. This is not to say that physical prowess does not play a role in surfing performance, as the board has to be paddled and waves ridden, but rather the importance it plays may not be as profound in surfing as it is in other sports such as running or cycling.

5.1 Conclusion

Four principle conclusions can be drawn from the present investigation. First, surf training for 100 min in a full-length wetsuit in cool water (20.8°C) results in 3.9% reduction in BM. The level of BM loss in the present study is similar to that achieved during RWL protocols, yet somewhat greater than that observed at the conclusion of other intermittent type sports (Table 5.1).

Second, during training, surfing performance is significantly reduced when a 3.9% BM loss is reached whereas, when BM is reduced by 1.6%, there seems to be no adverse effects on surfing ability or cognitive function. This is consistent with the observations reported in dehydration studies (e.g. Barr, 1999; McGregor et al., 1999; Hornery et al., 2007) and suggests current training practices where no water is consumed (Felder et al.,

1989) need to be modified to avoid the deleterious effects of dehydration on surfing performance.

Third, cognitive function is highly correlated to surfing ability and is significantly reduced when BM is reduced by 3.9%. Of the cognitive domains assessed, information processing speed and working memory have the strongest association with surfing performance. Although a correlation does not imply causality, it is possible that the ability to change latent information into manifest information, as well as the ability to store and manipulate information, may be an important aspect in superior performance. What's more, the findings of the present study support the opinion of Hornery et al., (2007), that cognitive function is intrinsically linked to performance in skill-based sports.

Lastly, muscular endurance is greatly impaired when at a 3.9% BM loss yet only lower-body muscular endurance is maintained when fluid is ingested. Declines in upper-body muscular endurance are not attenuated by water ingestion alone and likely to be due to depleted substrate availability or some other peripheral fatigue-related factor. However, of most importance is that muscular endurance capacity is not significantly correlated to surfing performance thus suggesting that, unlike many time-based sports where superior performance is often attributed to maximising muscular capabilities, surfing is a skill-based sport, and as such, places less emphasis on muscular function and greater emphasis on cognitive ability.

5.2 Limitations

The study was a field-based assessment conducted on a dynamic sport in a continuously changing environment. Although, a great deal of effort went into reducing the many confounding variables, a combination of human error and seemingly unavoidable compromises were made that may have affected the meaningfulness of the study. For example, due to the difficulty in assessing urine output during surfing, no adjustments were made for urine loss whilst surfing. Measuring evaporative loss from the lung was also not possible whilst surfing. By failing to do this, overestimation of total sweat loss or inaccuracies in post surf BM comparisons may have been made.

Despite the environmental conditions being matched as closely as possible, several variables such as climate and water temperature were out of the researcher's control. In cool water conditions this may have had little effect. Yet on occasion the water temperature was relatively warm (e.g. 22°C) and participants were required to wear steamers (which would not have been the wetsuit of choice), BM loss may have been exaggerated. This may have been avoided had all participants been assessed in cool water on the same day. Yet due to the limited availability of the participants, in conjunction with the amount of assistance that would have been required, it was not possible.

The same three surfing judges were used for each trial and even though they had professional judging experience, the variety of conditions combined with the time lapses between assessments, may have led to inconsistencies in scoring. As previously

mentioned, this may have been avoided had all participants been assessed on the same day.

Having participants come to shore every 20 min during the FI trial may have reduced the intensity of the surfing session and thus lessened the degree of BM loss. To have avoided this, participants in the NF trial could have also come to shore every 20 min or water could have been swum out to the surfers. Therefore, future research in this area should consider adopting one of these methods. Given that the participants in the present study were not accustomed to consuming water during surf practice they may have experienced GI discomfort or had difficulty adjusting to the variations in body mass. Moreover, consuming water may have had a placebo effect on performance. This is an inherent limitation in a study design that has participants acting as their own control, but allows no opportunity to administer a placebo/bogus substance.

Although matched whenever possible, the variations in traffic conditions and travel distance from the researchers home to the surfing location may have attributed to differences in mood state and recovery times. Both of which could have affected cognitive and physiological test results. Furthermore, conducting the hydration, cognitive and muscular tests at the researchers home did not provide the same level of objectivity and control as would have been achieved had this taken place in a laboratory. Yet, given the locality of the researcher's home to the wave breaks, this was a necessary compromise.

Using land-based tests to assess a dynamic sport is a difficult task, all the more so when there is limited access to equipment. Unfortunately, due to an oversight in methodology, comparisons made between pre and post upper and lower body strength endurance were flawed. This was due to the test relying on BM to set the resistance. As BM was different in each trial, so to was the intensity. Future research in this area needs to employ test that have fixed resistance such as a paddle bench ergometer or bilateral leg-press machine.

5.3 Recommendation for future research

The findings of the present study highlight a need for further investigation into the role of certain cognitive domains in relation to surfing performance. This will not only assist in establishing which cognitive functions are likely to have dominance of executive function but also provide a valuable insight into the physiological profile of elite surfers. Based on the findings of the present study, research that examines the intra-suit temperature experienced during surf practice in different types of wetsuits (e.g. steamer, spring suit and vest) would also provide valuable data on the level of heat stress likely to be experienced during surf practice. There is reasonable cause to continue along a similar research path and assess the effects of different drinks (e.g. sports drinks and water) on the cognitive, physiological and surfing performance of elite surfers. Lastly, in conducting this research it became apparent that there is a lack of recent literature on the energy expenditure and nutritional practices of elite surfers. Therefore future research in these areas would be of great benefit.

References

- Adam, J. J., Teeken, J. C., Ypelaar, P. J. C., Verstappen, F. T. J. and Paas, F. G. W. (1997). Exercised-induced arousal and information processing. *International Journal of Sport Psychology*, **28**, 217-226.
- Andersen, R.E. and Montgomery, D.L. (1988). Physiology of alpine skiing. *Sports Medicine*, **6**, 210-221.
- Arieli, R., Kerem, D., Gonen, A., Goldenberg, I., Shoshani, O., Daskalovic, Y.I. and Shupak, A. (1997). Thermal status of wetsuited divers using closed circuit O₂ apparatus in sea water of 17-18.5 degrees C. *European Journal of Applied Physiology*, **76**, 69-74.
- Armstrong, L.E., Costill, D.L. & Fink, W.J. (1985). Influence of diuretic-induced dehydration on competitive running performance. *Medicine in Science and Sports Exercise*, **17**, 456-461.
- Arrindell, W.A. and van der Ende, J. (1985). An empirical test of the utility of the observations-to-variables ratio in factor and components analysis. *Applied Psychological Measurement*, **9**, 165 - 178.
- Association of Surfing Professionals (ASP) [online]. Available from URL: <http://www.aspworldtour.com>. [Accessed 2007 May 5].
- Association of Surfing Professionals: World Championship Tour 2003 personal profiles. (ASP) [online]. Available from URL: <http://www.aspworldtour/profiles.com>. [Accessed 2007 May 5].

- Astrand, P.O. and Rodahl, K. (1986). *Textbook of Work Physiology*. New York: McGraw Hill, 523-576.
- Baddeley, A.D. (1986). *Working Memory*. Oxford: Claridon Press.
- Baars, B.J. (1993). How does a serial, integrated and very limited stream of consciousness emerge from a nervous system that is mostly unconscious, distributed parallel and of enormous capacity? Ciba Foundation symposium. **174**, 282–290.
- Barr, S.I. (1999). Effects of dehydration on exercise performance. *Canadian Journal of Applied Physiology*, **24**, 164-172.
- Barr, S.I., Costill, D.I. and Fink, W.J. (1991). Fluid replacement during prolonged exercise: effects of water, saline, or no fluid. *Medicine in Science and Sports Exercise*, **23**, 811-817.
- Baumgartner, T., Oh, S., Chung, H. and Hales, D. (2002). Objectivity, reliability and validity for a revised push-up test protocol. *Measurement in Physical Education and Exercise Science*, **6**, 225-242.
- Below, P., Mora-Rodriguez, R., Gonzalez-Alonso, J. and Coyle, E.F. (1995). Fluid and carbohydrate ingestion independently improve performance during 1 h of intense exercise. *Medicine and Science in Sports and Exercise*, **27**, 200-210.
- Bernard, T., Gavary, O., Bermon, S., Giacomoni, M., Marconnet, P. and Falgairette G. (1997). Relationships between oxygen consumption and heart rate in transitory and steady states of exercise and during recovery: influence of type of exercise. *European Journal of Applied Physiology*, **75**, 170-176.
- Bhambhani, Y., Maikala, R. and Buckley, S. (1998). Muscle oxygenation during incremental arm and leg exercise in men and women. *European Journal of Applied Physiology*, **78**, 422-431.

- Billat, V., Lepretre P., Heugas, A., Laurence, M., Salim, D. and Koralsztein, J. (2002). Training and bioenergetic characteristics in elite male and female Kenyan runners. *Medicine and Science in Sports and Exercise*, **35**, 297-304.
- Bosco, J.S. and Terjung, R.L. (1968). Effects of progressive hypohydration on maximal isometric strength. *Journal of Sports Medicine and Physical Fitness*, **8**, 81-86.
- Brisswalter, J., Durand, M., Delignieres, D., and Legros, P. (1995). Optimal and non-optimal demand in a dual-task of pedaling and simple reaction time: Effects on energy expenditure and cognitive performance. *Journal of Human Movement Studies*, **29**, 15-34.
- Burke, L.M., Broad, E.M., Haukka, J., Modulon, S. and Slater, G. (1996). Dietary survey of 1996 Olympic team. Unpublished date, 1996.
- Burrow, T. (2005). *Tag Burrow's book of hot surfing*. Sydney: Rollingyouth Press Publishers.
- Calabresi, P., Centonze, D. and Bernardi, G. (2000). Cellular factors controlling neuronal vulnerability in the brain. *Neurology*, **55**, 1249-1255.
- Campbell, M. (1982). *Surfing down under*. Sydney: Golden Press.
- Carroll, N. (1991). *The next wave*. Sydney: Harper Collins Publishers.
- Carter, J.E.L. and Marfell-Jones, M.J. (1994). Somatotypes. In: Carter, J.E.L., Auckland TR, editors. (1994). *Kinanthropometry in aquatic sports: a restudy of world-class athletes*. Champaign (IL): Human Kinetics, 55-82.
- Campbell, M. (1982), *Surfing down under*. Sydney: Golden Press.
- Casa, D.J. (2000). National athletic trainer's association position statement: fluid replacement for athletes. *Journal of Athletic Training*, **35**, 212-224.

- Cazorla, G. and Montpetit, R.R. (1988). Metabolic and cardiac responses of swimmers, modern pentathletes, and water polo players during freestyle swimming to a maximum. In: Ungerechts, B., Wilke, K. and Reischle, K. editors (1988). *Swimming science V*. Champaign (IL): Human Kinetics, 251-257
- Chevront, S., Carter, R. and Sawka, M.N. (2003). Fluid balance and endurance exercise performance. *Current Sports Medicine Reports*, **2**, 202-208.
- Chmura, J., Nazar, K., and Kaciuba-Ulscilko, H. (1994). Choice reaction time during exercise in relation to blood lactate and plasma catecholamine threshold. *International Journal of Sports Medicine*, **15**, 172–176.
- Choma, C.W., Sforzo, G.A. and Keller, B.A. (1998). Impact of rapid weight loss on cognitive function in collegiate wrestlers. *Medicine and Science in Sports and Exercise*, **30**, 746-749.
- Cian, C., Koulmann, N., Barraud, P.A., Raphel, C., Jimenez, C. and Melin, B. (2000). Influence of variation of body hydration on cognitive function: effect of hyperhydration, heat stress and exercise induced dehydration. *Journal of Psychophysiology*, **14**, 29–36.
- Cohen, S. (1983). After effects of stress on human performance during a heat acclimatization regimen. *Aviation, space, and environmental medicine*. **54**, 709-713.
- Cotter, J.D. and Taylor, N.A.S. (1995). Physiological assessment of the RNZAF constant wear immersion suit: laboratory and field trials. *Aviation, Space, and Environmental Medicine*, **66**, 528-536.
- Coyle, E.F. and Montain, S.J. (1992). Benefits of fluid replacement with carbohydrate during exercise. *Medicine and Science in Sports and Exercise*, **24**, 324-330.

- Coyle, E.F. (2004). Fluid and fuel intake during exercise. *Journal of Sports Sciences*, **22**, 39–55.
- Cox, G.R., Broad, E.M., Riley, M.D. and Durke, L.M. (2002). Body mass changes and voluntary fluid intakes of elite level water polo players and swimmers. *Journal of Science and Medicine in Sport*, **5**, 183-193.
- Dawson, B., Elliott, B., Pyke, F. and Rogers, R. (1985). Physiological and performance responses to playing tennis in a cool environment and similar intervalized treadmill running in a hot climate. *Journal of Human Movement Studies*, **11**, 21-34.
- Davey, P.R., Thorpe, R.D. and Williams, C. (2002). Fatigue decreases skilled tennis performance. *Journal of Sports Science*, **20**, 311-318.
- Davis, J.M. and Bailey, S.P. (1997). Possible mechanisms of central nervous system fatigue during exercise. *Medicine and Science in Sports and Exercise*, **29**, 45-57.
- Delignieres, D., Brisswalter, J. and Legros, P. (1994). Influence of physical exercise on choice reaction time in sports experts: the mediating role of resource allocation. *Journal of Human Movement Studies*, **27**, 173-188.
- Ducharme, M.B. and Brooks, C.J. (1998). The effect of wave motion on dry suit insulation and the responses to cold water immersion. *Aviation, Space, and Environmental Medicine*, **69**, 957-964.
- Edwards, A.M., Mann, M.E., Marfell-Jones, M.J., Rankin, D.M., Noakes, T.D. and Shillington, D.P. (2007). Influence of moderate dehydration on soccer performance: physiological responses to 45 min of outdoor match-play and the immediate subsequent performance of sport-specific and mental concentration tests. *British Journal of Sports Medicine*, **41**, 385-391.

- Felder, J.M., Burke, L.M., Lowdon, B.J., Cameron-Smith, D. and Collier, G.R. (1998). Nutritional practices of elite female surfers during training and competition. *International Journal of Sports Nutrition*, **8**, 36-48.
- Finney, B.R. and Houston, J.D. (1996). *Surfing history of the ancient Hawaiian sport*. San Francisco: Pomegranate Art books.
- Fitts, R.H. (1994). Cellular mechanisms of muscle fatigue. *Physiology Review*, **74**, 49–94.
- Febbraio, M.A. (2001). Alterations in energy metabolism during exercise and Heat Stress. *Sports Medicine*, **31**, 47-59.
- Frentsos, J.A. and Baer, J.T. (1997). Increased energy and nutrient intake during training and competition improves elite triathletes' endurance performance. *International Journal of Sports Nutrition*, **7**, 61-71.
- Galloway, S. and Maughan, R., (1997). Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man. *Medicine in Science and Sports Exercise*, **29**, 1240–1249.
- Garciaacutea-Rovés, P.M., Fernández, S., Rodriacute, M., Pérez-Landaluce, J. and Patterson, A.M. (2000). Eating Pattern and Nutritional Status of International Flatwater Paddlers. *International Journal of Sports Nutrition & Exercise Metabolism*, **10**, 182-186.
- St Clair Gibson, A., Baden, D.A., Lambert, M.I, Lambert, E.V., Harley, Y,X., Hampson, D., Russell, V,A. and Noakes, T.D. (2003). The conscious perception of the sensation of fatigue. *Sports Medicine*, **33**, 167-76.
- Givoni, B., and Goldman, R.F. (1972). Predicting rectal temperature response to work, environment, and clothing. *Journal of Applied Physiology*, **32**, 812-822.

- Gopinathan, P., Pichan, G. and Sharma, V. (1988). Role of dehydration in heat stress-induced variations in mental performance. *Archives of Environmental Health*, **43**, 15-17.
- González-Alonso, J. (1998). Separate and combined influences of dehydration and hyperthermia on cardiovascular responses to exercise. *International Journal of Sports Medicine*, **19** (suppl.), 111-114.
- González-Alonso, J., Mora-Rodríguez, R. and Coyle, E.F. (2000). Stroke volume during exercise: interaction of environment and hydration. *American Journal of Physiology*, **278**, 321-330.
- Gandevia, S.C., Allen, G.M. and McKenzie, D.K. (1995). Central fatigue. Critical issues, quantification and practical implications. *Advances in Experimental Medicine and Biology*, **38**, 281-94.
- Greenleaf J.E., Brock, P.J., Keil, L.C. and Morse, J.T. (1983). Drinking and water balance during exercise and heat acclimation. *Journal of Applied Physiology*, **54**, 414-419.
- Greiwe, J.S., Staffey, K.S., Melrose, D.R., Narve, M.D. and Knowlton, R.G. (1998). Effects of dehydration on isometric muscular strength and endurance. *Medicine in Science and Sports Exercise*, **30**, 284-288.
- Hagerman, F.C. and Tritt, A. (1970). A comparison of selected physiological variables and competitive performance in modern pentathlon athletes. *Australian Journal of Sports Medicine*, **3**, 15-29.
- Hertig, B.A., Riedesel, M.L. and Belding, H.S. (1962). Time course of sweating in warm baths. *Advances in Biological Skin*, **3**, 213-229.

- Hinghofer-Szalkay, H., Harrison, M.H. and Greenleaf, J.E. (1987). Early fluid and protein shifts in men during water immersion. *European Journal of Applied Physiology and Occupational Physiology*, **56**, 673-678.
- Hirano, Y. and Tada, N. (1994). Mechanics of a turning snow ski. *International Journal of Mechanical Sciences*, **36**, 421-429.
- Hoffman, J.R., Stavsky, H. and Falk, B. (1995). The effect of water restriction on anaerobic power and vertical jumping height in basketball players. *International Journal of Sports Medicine*, **16**, 214-218.
- Hope, A., Aanderud, L. and Aakvaag, A. (2001). Dehydration and body fluid-regulating hormones during sweating in warm (38°C) fresh-and seawater immersion. *Journal of Applied Physiology*, **91**, 1529-1534.
- Hornery, D., Farrow, D., Mujika, I. and Young, W. (2007). Fatigue in tennis mechanisms of fatigue and effect on performance. *Sports Medicine*, **37**, 199-212.
- Jacobs, I. (1980). The effects of thermal dehydration on performance of the Wingate anaerobic test. *International Journal of Sports Medicine*, **1**, 21-24.
- Kang, D.H., Park, Y.S., Park, Y.D., Lee, I.S., Yeon, D.S., Lee, S.H., Hong, S.Y., Rennie, D.W. and Hong, S.K. (1983). Energetics of wet-suit diving in Korean women breath-hold divers. *Journal of Applied Physiology*, **54**, 1702-1707.
- Kang, J., Robertson, R.J., Goss, F.L., Dasilva, S.G., Suminski, R.R., Utter, A.C., Zoeller, R.F. and Metz KF. (1997). Metabolic efficiency during arm and leg exercise at the same relative intensities. *Medicine in Science and Sports Exercise*, **29**, 377-382.
- Kleiner, S.M. (1999) Water: an essential but overlooked nutrient. *Journal of American Dietitians Association*, **99**, 200-206.

- Konstantaki, M. and Swaine, I.L. (1999). Lactate and cardiopulmonary responses to simulated arm-pulling and leg-kicking in collegiate and recreational swimmers. *International Journal of Sports Medicine*, **20**, 118-121.
- Koppo, K., Bouckaert, J. and Jones, A.M. (2002). Oxygen uptake kinetics during high-intensity arm and leg exercise. *Respiratory Physiology and Neurobiology*, **133**, 241-250.
- Kristal-Boneh, E., Glusman, J.G., Chaemovitz, C. and Cassuto, Y. (1988). Improved thermoregulation caused by forced water intake in human desert dwellers. *European Journal of Applied physiology and Occupational Physiology*, **57**, 220-224.
- Landers, D.M., Arent, S.M. and Lutz, R.S. (2001). Affect and cognitive performance in high school wrestlers undergoing rapid weight loss. *Journal of Sport and Exercise Psychology*, **23**, 307-316.
- Lehrl, S. and Fischer, B. (1988). The basic parameters of human information processing: their role in the determination of intelligence. *Personality and individual Differences*, **9**, 883-896.
- Leveque, J. M., Brisswalter, W., Bernard, O. and Goubault, C. (2002). Effect of paddling cadence on time to exhaustion and V_{O2} kinetics at the intensity associated with V_{O2}max in elite white-water kayakers. *Canadian Journal of Applied Physiology*, **27**, 602-611.
- Lollgen, H., Nieding, G.V., Kopenhagen, K., Kersting, F. and Just, H. (1981). Hemodynamic response to graded water immersion. *Klinische Wochenschrift*, **59**, 623-628.

- Lowdon, B.J. and Peteman, N. A. (1980). Physiological parameters of international surfers. *Australian Journal of Sports Medicine*, **12**, 30-33.
- Lowdon, B.J. (1980). The somatotypes of international surfboard riders. *Australian Journal of Sports Medicine*, **12**, 34-39.
- Lowdon, B.J. (1994). *Competitive surfing - a dedicated approach* (2nd ed.). Victoria: Movement Publications.
- Manly Hydraulics Laboratory* [online]. Water temperature. Available from URL: <http://www.mhl.nsw.gov.au>. [Accessed 2006-2007].
- The Manly Daily* [online]. Surf report. Available from URL: <http://www.manlydaily.com.au/> [Accessed 2006-2007].
- Margan, F. and Finney, B.R. (1970). *A pictorial history of surfing*. Sydney: Paul Hamlyn Pty Ltd.
- Maughan, R.J., Shirreffs, S.M., Merson, S.J. and Horswill, C.A. (2004). Fluid and electrolyte balance in elite male football (soccer) players training in a cool environment. *Journal of Sports Sciences*, **23**, 73-79.
- Maughan, R.J., and Shirreffs, S.M. (2007). Nutrition for soccer players. *Current Sports Medicine Reports*, **6**, 279-280.
- McArdle, W.D., Katch, F.I. and Katch, V.L. (1996). *Exercise physiology, energy, nutrition, and human performance (4th edition)*. Williams and Wilkins: USA.
- McGlynn, G. H., Laughlin, N. T., and Rowe, V. (1979). The effects of increasing levels of exercise on mental performance. *Ergonomics*, **22**, 407-414.
- McGregor, S.J., Nicholas, C.W., Lakomy, H.K. and Williams, C. (1999). The influence of intermittent high intensity shuttle running and fluid ingestion on the performance of a soccer skill. *Journal of Sports Sciences*, **17**, 895-903.

- McMorris, T., Meyers, S., Macgillivray, W. W., Sexsmith, J. R., Fallowfield, J., Graydon, J., & Forster, D. (1999). Exercise, plasma catecholamine concentrations and performance of soccer players on a soccer-specific test of decision making. *Journal of Sports Sciences*, **17**, 667-676.
- Meir, R.A., Lowdon, B.J. and Davie, A.J. (1991). Heart rates and estimated energy expenditure during recreational surfing. *Australian Journal of Science and Medicine in Sport*, **23**, 70-74.
- Mendez-Villanueva, J.A., Bishop, D. and Hamer, P. (2003). Activity patterns of elite surfing competition [abstract]. *Journal of Science and Medicine in Sport*, **6**(suppl.), 11.
- Mendez-Villanueva, A. and Bishop, D. (2005). Physiological aspects of surfboard riding performance. *Sports Medicine*, **35**, 55-70.
- Mendez-Villanueva, A., Perez-Landaluce, J., Bishop, D., Fernandez-García, B., Ortolano, R., Leibar, X. and Terrados, N. (2005). Upper-body aerobic fitness comparison between two groups of competitive surfboard riders. *Journal of Science and Medicine in Sport*, **8**, 43-51.
- Meeusen R.D. and Meirleir, K. (1995). Exercise and brain neurotransmission. *Sports Medicine*, **20**, 160-188.
- Monji, K., Nakashima, K., Sogabe, Y., Miki, K., Tajima, F. and Shiraki, K. (1989). Changes in insulation of wetsuits during repetitive exposure to pressure. *Undersea Biomedical Research*, **16**, 313-319.
- Montain, S.J., Smith, S.A., Mattot, R.P., Zientara, G.P., Jolesz, F.A. and Sawka, M.N. (1998). Hypohydration effects on skeletal muscle performance and metabolism: a ³¹P-MRS study. *Journal of Applied Physiology*, **84**, 1889-1894.

- Morton, D.P. and Gastin, P.B. (1997). Effect of high intensity board training on upper body anaerobic capacity and short lasting exercise performance. *Australian Journal of Science and Medicine in Sport*, **29**, 17-21.
- Nielsen, B., Savard, G., Richter, E.A., Hargreaves, M. and Saltin, B. (1990). Muscle blood flow and muscle metabolism during exercise and heat stress. *Journal of Applied Physiology*, **69**, 1040-1046.
- Noakes, T.D. (1993). Fluid replacement during exercise. *Exercise and Sports Science Review*, **21**, 297-330.
- Noakes, T.D. (2000). Physiological models to understand exercise fatigue and the adaptations that predict or enhance athletic performance. *Scandinavian Journal of Medical Science in Sports*, **10**, 123-145.
- Noakes, T. and Martin, D. (2002). IMMUDA-AIMS advisory statement on guidelines for fluid replacement during marathon running. *New Studies in Athletics*, **17**, 15-24.
- Norsk, P., Drummer, P., Johansen, L. and Gerzer, R. (1993) Effect of water immersion on renal natriuretic peptide (urodilatin) excretion in humans. *Journal of Applied Physiology*, **74**, 2881-2885.
- Oliver, S.J., Laing, S.J., Wilson, S., Bilzon, J.L. and Walsh, N. (2007). Endurance running performance after 48 hours of restricted fluid and/or energy intake. *Medicine and Science in Sports and Exercise*, **39**, 316-322.
- O'Neill [online]. Steamer Wetsuits. Available from URL: <http://www.oneill.com> [Accessed 2007-2008].
- Oppliger, R.A., Magnes, S.A., Poppwiski, L.A. and Gisolfi, C.A. (2005). Accuracy of urine specific gravity and osmolality as indicators of hydration status. *International Journal of Sport Nutrition and Exercise Metabolism*, **15**, 236-251.

- Paas, F. G. W. C., and Adam, J. J. (1991). Human information processing during physical exercise. *Ergonomics*, **34**, 1385-1397.
- Paschoal, V.C. and Amancio, O. (2004). Nutritional status of Brazilian elite swimmers. *International Journal of Nutrition and Exercise Metabolism*, **14**, 81-94.
- Ratel, S., Lazaar, N., Williams, C.A., Bedu, M. and Duché, P. (2003). Age differences in human skeletal muscle fatigue during high-intensity intermittent exercise *Acta Paediatrica*, **92**, 1248–1254.
- Reitan, R.M. (1958). *Halstead-Reitan Neuropsychology Test Battery*. Tucson, AZ: Reitan Neuropsychology Laboratory.
- Rip Curl Australia [online]. Steamer Wetsuits. Available from URL: <http://www.ripcurl.com.au> [Accessed 2007-2008].
- Rogers, G., Goodman, C. and Rosen, C. (1997). Water budget during ultra-endurance exercise. *Medicine and Science in Sports and Exercise*, **29**, 1477-1481.
- Sawka, M.N. (1986) Physiology of upper body exercise. *Exercise and Sport Science Reviews*. **14**, 175-211.
- Sawka, M.N. and Pandolf, K.B. (1990). Effects of body water loss on physiological function and exercise performance. *Perspectives in Exercise Science and Sports Medicine*, **3**, 1–38.
- Sawka, M. and Montain, S.J. (2000). Fluid and electrolyte supplementation for exercise heat stress. *American Journal of Clinical Nutrition*, **72**(suppl.), 564-572.
- Schneider, D.A., Sedlock, D.A., Gass, E. and Gass, G. (1999). $VO_{2\text{peak}}$ and the gas-exchange anaerobic threshold during incremental arm cranking in able-bodied and

paraplegic men. *European Journal of Applied Physiology and Occupational Physiology*, **80**, 292-297.

Schneider, D.A., Wing, A.N. and Morris, N.R. (2002). Oxygen uptake and heart rate kinetics during heavy exercise: a comparison between arm cranking and leg cycling. *European Journal of Applied Physiology Occupational Physiology*, **88**, 100-106.

Schultes, B., Peters, A., Kern, W., Gais, S., Oltmanns, K.M., Fehm, H.L. and Born, J. (2005). Processing of food stimuli is selectively enhanced during insulin-induced hypoglycemia in healthy men. *Psychoneuroendocrinology*, **30**, 496-504.

Shiraki, K., Sagawa, S., Konda, N., Park, Y.S., Komatsu, T. and Hong, S.K. (1986). Energetics of wet-suit diving in Japanese male breath-hold divers. *Journal of Applied Physiology*, **61**, 1475-1480.

Shirreffs, S.M., Aragon-Vargas, L.F., Chamorro, M., Serratosa, L. and Zachwieja, J.J. (2005). The sweating response of elite professional soccer players to training in the heat. *International Journal of Medicine*, **26**, 90-95.

Smith, H.K. (1998). Applied physiology of water polo. *Sports Medicine*, **26**, 317-334.

Smith, M.S., Dyson, R., Hale, T., Harrison, J.H. and McManus, P. (2000). The effects in humans of rapid loss of body mass on a boxing-related task. *European Journal of Applied Physiology*, **83**, 34-39.

Speedy, D.B., Noakes, T.D., Kimber, N.E., Rogers, I.R., Thompson, J.M., Boswell, D.R., Ross, J.J., Campbell, R.G., Gallagher, P.G. and Kuttner, J.A. (2001). Fluid balance during and after an ironman triathlon. *Clinical Journal of Sport Medicine*, **11**, 44-50.

Stapelberg, G. (1996) *Pro surfing*. USA: faircount International.

- Stocks, J.M., Patterson, M.J., Hyde, D.E., Jenkins, A.B., Mittleman, K.D. and Taylor, N.A. (2004). Effects of immersion water temperature on whole-body fluid distribution in humans. *Acta physiologica Scandinavica*, **182**, 3-10.
- Swaine, I.L. and Winter, E.M. (1990). Comparison of cardiopulmonary responses to two types of dry-land upper-body exercise testing modes in competitive swimmers. *European Journal of Applied Physiology*, **80**, 588-590.
- Taylor, S.A. and Batterham, A.M. (2002). The reproducibility of estimates of critical power and anaerobic work capacity in upper-body exercise. *European Journal of Applied Physiology*, **87**, 43-49.
- Vergauwen, L., Brouns, F. and Hespel, P. (1998). Carbohydrate supplementation improves stroke performance in tennis. *Medicine and Science in Sports and Exercise*, **30**, 1289-1295.
- Veronique, B., Lepretre, P., Heugas, A., Laurence, M. (2003). Training and bienergetic characteristics in elite male and female Kenyan runners. *Medicine in Sports and Exercise*, **35**, 297-304.
- Wakabayashi, H., Hanai, A., Yokoyama, S. and Nomura, T. (2006). Thermal insulation and body temperature wearing a thermal swimsuit during water immersion. *Journal of Physiological anthropology*, **25**, 331-338.
- Webster, S., Rutt, R. and Weltman, A. (1990). Physiological effects of a weight loss regimen practiced by college wrestlers. *Medicine in Science and Sports Exercise*, **22**, 229-234.
- Wilcock I.M., Cronin, J.B. and Hing, W.A. (2006). Physiological response to water immersion: a method for sport recovery? *Sports Medicine*, **36**, 747-765.

- Wilson, M., and Morley, J. (2003). Impaired cognitive function and mental performance in mild dehydration. *European Journal of Clinical Nutrition*, **57**, 2 (suppl.), 24-29.
- Wolff, A.H., Coleshaw, S.R., Newstead, C.G. and Keatinge, W.R. (1985). Heat exchanges in wet suits. *Journal of Applied Physiology*, **58**, 770-777.
- Yankanich, J., Kenny, L., Fleck, S. and Kraemer, R. (1998) Pre-competition weight loss and changes in vascular fluid volume in NCAA division I college wrestlers. *Journal of Strength and Conditioning Research*, **12**, 138-145.
- Yeon, D.S., Park, Y.S., Choi, J.K., Kim, J.S., Lee, I.S., Kang, D.H., Lee, S.H., Hong, S.Y., Rennie, D.W. and Hong, S.K. (1987). Changes in thermal insulation during underwater exercise in Korean female wet-suit divers. *Journal of Applied Physiology* **62**, 1014-1019.
- Young. (2000). *Surfing Fundamentals*. Sydney: Palm Beach Press.

Appendix A: Questionnaires and consent documents

Participant information:	Page
Invitation to participate	98
Health screen questionnaire	100
Statement of informed consent	101

Effects of exercise-induced dehydration on cognitive ability, muscular endurance and surfing Performance.

INVITATION TO PARTICIPATE IN STUDY

My name is Alex Carrasco and I am currently in the process of completing a Masters of Sports Science with the Institute of Food Nutrition and Human Health (IFNHH), at Massey University (New Zealand). Previously I have completed a Bachelor of Human Movement Studies and a Graduate Diploma of Education, majoring in Sports Nutrition and Exercise Physiology at ACU and UTS. This year I am researching the effects of hypohydration (low body water volume) on cognitive, neuromuscular and surfing performance of elite surfers. To achieve this, 16 elite surfers will be recruited to participate in this study. The Study will examine hydration status before and after a typical training session and investigate the affect hypohydration has on cognitive, neuromuscular and surfing performance. If the findings of this study suggest that hypohydration adversely affects surfing performance, it may initiate the introduction of hydration regimes to not only improve the quality of training but also reduce the health-related risks associated with hypohydration.

Participant Recruitment

All participants will be selected on the criteria that they have sponsorship, are male, over 18 years of age, have a minimum of 5 years competitive surfing experience and have no medical conditions that may be exacerbated by participating in the study. Approximately 16 participants will be recruited for this study, as this will provide an adequate representation of this specific surfing population. There will be no foreseeable risks to you as the participant taking part in this study.

Procedures

Preliminary Session (approximately 20 min)

During the preliminary session you will be given an overview of the study, asked to complete a health check and exercise history questionnaire and shown how to accurately complete a food diary.

Pre-Study Protocol

Three days prior to the assessment you will be asked to consume additional water before going to sleep, refrain from vigours physical activity and keep a food diary.

Test Protocol

1. Provide a small urine sample and have your body mass measured (5 min).
2. Complete strength, cognitive and surfing performance tests (20 min).
3. Surf for 2 hours in a 'Steamer' with or without fluid ingestion.
4. Recovery (30 min).
5. Repeat steps 1 and 2 (25 min).

Measurements Taken

Hydration status will be monitored through urine and body weight analysis.

Participant's Rights

As a participant you have the right to:

Withdraw at any time up to one week after the data collection is complete. Ask the investigator any questions about the study at any time during participation.

Provide information on the understanding that your name will not be used at any time by the researcher in any publications, and your individual data will only be used as a part of the group's data.

Be given access to a summary of the project findings when it is concluded

Know that participation or non-participation will have no affect on future judgments or access to coaching.

Confidentiality

The data collected will be used as part of a Masters Thesis and for research papers resulting from this study. The data collected may be presented in various forms (journal articles, papers or conference presentations). However, personal information will be treated in confidence, i.e. neither name nor initials will be used to describe the data in any presentations. All data will be dealt with confidentially and will be stored in a secure location for 5 years. After this time it will be disposed of by an appropriate staff member from IFNHH. Upon completion of the data analysis you will be given a personal feedback sheet and can ask further questions regarding your results. A coded number will identify you on the questionnaires and diet record sheets. Only the researcher will have access to the codes and identity of the participants. The results will be given back to you personally and it is up to you whether or not you choose to share the results with anyone else.

Further information

Any questions about this study are welcome. Please do not hesitate in contacting Alex Carrasco (primary researcher) via email at carrascos@excite.com or by phone on (H) 02 99386630 (M) 0424890991 with any queries. If you would like further information about the study the research supervisor Dr Ajmol Ali can be contacted by email at a.ali@massey.ac.nz or by phone on +64 (0) 9 414 0800 extension 41184.

Committee Approval Statement

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 06/56. If you have any concerns about the conduct of this research, please contact Professor John O'Neill, Chair, Massey University Human Ethics Committee: Southern A, telephone 06 350 5799 x 8635, email humanethicsoutha@massey.ac.nz.

Effects of exercise-induced dehydration on cognitive ability, muscular endurance and surfing Performance.

HEALTH SCREEN QUESTIONNAIRE FOR STUDY VOLUNTEERS

This Health Screen Questionnaire is designed to ensure that the participants of this research study are currently in good health and have had no significant medical problems. It is also designed to ensure the participants' own continuing wellbeing and to avoid the possibility of individual health issues confounding the studies outcome.

Please complete the brief questionnaire to confirm fitness to participate (circle the correct response)

At present, do you have any health problems for which you are:

- a. On medication, prescribed or otherwise Yes No
- b. Attending you general practitioner (GP) Yes No
- c. On a hospital waiting list Yes No

In the past two (2) years have you had illness that required you to:

- a. Consult your GP Yes No
- b. Attend a hospital outpatient department Yes No
- c. Be admitted to a hospital Yes No

Have you ever had any of the following:

- a. Convulsions/epilepsy Yes No
- b. Asthma Yes No
- c. Eczema Yes No
- d. Diabetes Yes No
- e. A blood disorder Yes No
- f. Head injury Yes No
- g. Digestive problems Yes No
- h. Heart problems Yes No
- i. Problems with bones or joints Yes No
- j. Disturbance of balance/co-ordination Yes No
- k. Numbness in hands or feet Yes No
- l. Disturbance of vision Yes No
- m. Ear/hearing problems Yes No
- n. Thyroid problems Yes No
- o. Kidney or liver problems Yes No
- p. An allergic reaction Yes No

Has any, otherwise healthy, member of your family under the age of 35 died suddenly during or soon after exercise? Yes No

If yes to any question, please describe briefly if you wish (e.g to confirm problem was/is short lived, insignificant or well controlled). _____

Thank you for your cooperation!

Effects of exercise-induced dehydration on cognitive ability, muscular endurance and surfing Performance.

STATEMENT OF INFORMED CONSENT

This consent form will be held for a period of five (5) years.

I have read the information sheet, and have had the details of the study explained to me. My questions have been answered to my satisfaction and I understand that I may ask further questions at any time.

I understand I have the right to withdraw from the study at any time and to decline to answer any particular questions.

I agree to provide information to the researcher on the understanding that my name will not be used without my permission. *(The information will be used only for this research and publications arising from this research project.)*

Name: _____ Contact Number: _____

Age: _____ Date of Birth: _____

Address: _____

Participant's Signature: _____ Witnessed By: _____

Appendix B: Test and surfing performance results

Cognitive testing battery:	Page
Short term memory word list	103
Short-term memory task	104
Paced serial addition test strings	106
Trail marking tests	107
Surfing performance results	111

Short-Term Memory Word List

Surfing related words

1. Floater
2. Re-entry
3. Aerial
4. Cutback
5. Bottom turn
6. Natural
7. Goofy
8. Wax
9. Leg rope
10. Grip
11. Surfboard
12. Barrel
13. Tube
14. Rip
15. Malibu
16. Snap
17. Tail slid
18. Closeout
19. Left-hander
20. Right-hander
21. Local
22. Drop-in
23. Hassle
24. Take-off
25. Nose-dive

Neutral words

1. Stick
2. Tree
3. Bush
4. Rock
5. Person
6. Boy
7. Girl
8. Paper
9. Pen
10. Torch
11. Bag
12. Computer
13. Telephone
14. Watch
15. Bed
16. Television
17. Couch
18. Knife
19. Window
20. Car
21. Fence
22. Plant
23. Shoe
24. House
25. Pillow

Emotional words

1. Father
2. Disappointment
3. Friend
4. Lover
5. Passion
6. Child
7. Sister
8. Student
9. Partner
10. Boss
11. Enemy
12. Mother
13. Rival
14. Disgusting
15. Annoyed
16. Anger
17. Kindness
18. Fairness
19. Husband
20. Joyful
21. Fear
22. Excitement
23. Envy
24. Wife
25. Admiration

Short-Term Memory Task

Trial A	List 1 Pre	List 2 Pre
1.	Re-entry	1. Husband
2.	Disappointment	2. Snap
3.	Tree	3. Car
4.	Bottom turn	4. Tail slid
5.	Bush	5. Window
6.	Father	6. Anger
7.	Floater	7. Closeout
8.	Person	8. Kindness
9.	Friend	9. Knife
10.	Stick	10. Fairness
11.	Aerial	11. Left-hander
12.	Lover	12. Couch
13.	Rock	13. Joyful
14.	Cutback	14. Television
15.	Passion	15. Grip

Trial A	List 1 Post	List 2 Post
1.	Bag	1. Nose-dive
2.	Disgusting	2. Fear
3.	Surfboard	3. Fence
4.	Watch	4. Local
5.	Barrel	5. Plant
6.	Bed	6. Excitement
7.	Enemy	7. Drop-in
8.	Natural	8. Shoe
9.	Mother	9. Envy
10.	Telephone	10. Hassle
11.	Rival	11. House
12.	Rip	12. Wife
13.	Computer	13. Take-off
14.	Annoyed	14. Admiration
15.	Malibu	15. Pillow

Short-Term Memory Task

Trial B

List 1
Pre

1. Billabong
2. Carpet
3. Snake
4. Chic
5. Stool
6. Panic
7. Clubby
8. Door
9. Smashed
10. Kettle
11. Beach
12. Upset
13. Grass
14. Justice
15. Shorey

List 2
Pre

1. Emergency
2. Wipe-out
3. Radio
4. Uncle
5. Rip curl
6. Sky
7. Spider
8. Snaking
9. Wire
10. Desire
11. Wheel
12. Nosedive
13. List
14. Joy
15. Boardies

Trial B

List 1
Post

1. Leg rope
2. Boy
3. Right-hander
4. Partner
5. Paper
6. Wax
7. Boss
8. Tube
9. Pen
10. Child
11. Goofy
12. Sister
13. Torch
14. Student
15. Girl

List 2
Post

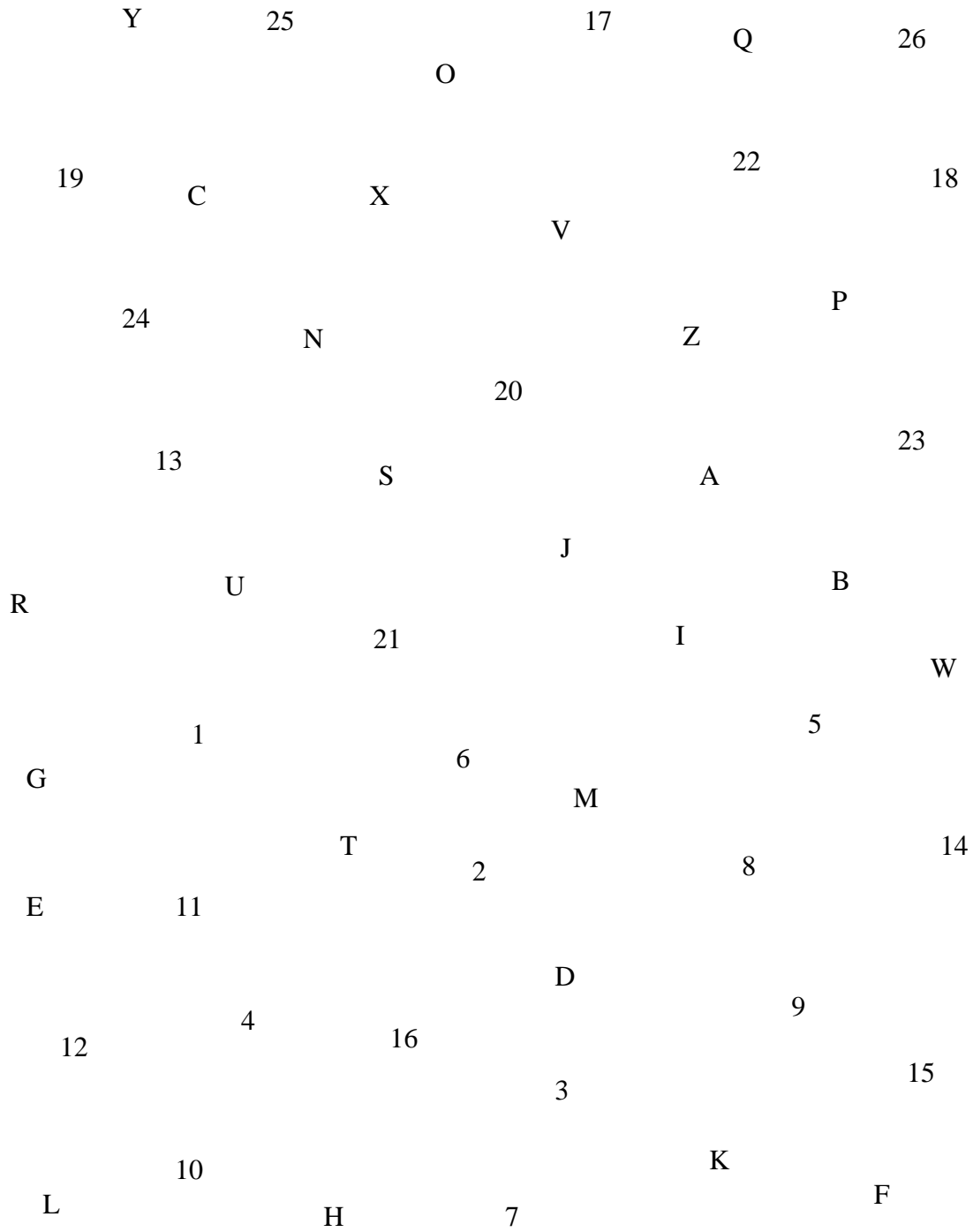
1. Humble
2. River
3. Drown
4. Bully
5. Building
6. Fins
7. Hand
8. Grateful
9. Painting
10. Thruster
11. Dancing
12. Mountain
13. Bodyboard
14. Fighter
15. Quicksilver

Paced serial addition test strings

	Trial A before Practice string		Trial A after Practice string		Trial B before Practice string		Trial B after Practice string
1		11		3		17	
4		8		2		8	
6		3		11		7	
4		6		7		1	
15	Answer = 30	5	Answer = 33	3	Answer = 26	2	Answer = 35
	String one		String one		String one		String one
8		5		9		3	
1		7		2		6	
4		4		5		1	
7		8		3		8	
8	Answer = 28	9	Answer = 33	1	Answer = 20	2	Answer = 20
	String two		String two		String two		String two
2		3		7		6	
5		8		2		3	
18		15		15		16	
3		4		6		3	
2	Answer = 30	7	Answer = 37	9	Answer = 39	2	Answer = 30
	String three		String three		String three		String three
12		17		2		7	
8		8		13		13	
17		13		4		9	
9		7		5		6	
4	Answer = 50	4	Answer = 49	6	Answer = 30	5	Answer =
	String four		String four		String four		String four
6		9		2		8	
5		5		3		3	
12		18		18		12	
7		9		6		7	
8	Answer = 38	3	Answer = 44	3	Answer = 32	4	Answer = 34
	String five		String five		String five		String five
16		16		18		14	
3		1		1		7	
18		17		16		18	
1		3		3		1	
3	Answer = 41	9	Answer = 46	7	Answer = 45	6	Answer = 46
	String six		String six		String six		String six
7		9		7		4	
18		18		12		18	
14		14		11		15	
6		9		8		4	
9	Answer = 54	2	Answer = 52	8	Answer = 46	3	Answer = 44

Trail making tests

Trial A – pre test



Trial A – post test

G J 5
I 11 Z
20 A 21 D
H P
7 S 8 Q 12
K Y 9 C
24 19
B 1 T 10 F
16 22
E 15 6 17
25 U
13 R L 23
V 4 M 14
M 2 O 18
W 3 N

Trial B – pre test

S 25 19
C O A E
24 X 20
26 T Y D
Z
13 2 18 Q
G 4 W B
L F 16 14
I 6
M 1 5
K
V N 22 8
10 15 P
23 21 9
17 3 12
U 11 J 7 H R

Trial B – post test

7 P 21 12
I Z 3
20 G D 26 A
H 5 J
8 C 16
F 13 Q
1 K 2 M 19
N 24 Y S
15 17 V 10
E 6 25 22
R 23 L U
9 X 14 M 4
T W O 11 18 B

Surfing performance judge's scores

NF trial

Part	Pre tally Judge 1	Pre tally Judge 2	Pre tally Judge 3	Pre Mean	Post tally Judge 1	Post tally Judge 2	Post tally Judge 3	Post Mean
001	15.5	15	15.5	15.3	13	13	13	13.0
002	17	16.5	17	16.8	15	13.5	14.5	14.3
003	17	17	17	17.0	12	13.5	12.5	12.7
004	19	18.5	19	18.8	13.5	14	14	13.8
005	15.5	15.5	15.5	15.5	14	15	13.5	14.2
006	12.5	12.5	12.5	12.5	8.5	9.5	8.5	8.8
007	13	13	13	13.0	11	11	11	11.0
008	16	15.5	16	15.8	13.5	14.5	13.5	13.8
009	17	17	17	17.0	12	13	12	12.3
010	16.5	17	16.5	16.7	11.5	13	11.5	12.0
011	17	17.5	17	17.2	13.5	15	14	14.2
012	16.5	17	16.5	16.7	12.5	13.5	13	13.0

FI trial

Part	Pre tally Judge 1	Pre tally Judge 2	Pre tally Judge 3	Pre Mean	Post tally Judge 1	Post tally Judge 2	Post tally Judge 3	Post Mean
001	16	17	16.5	16.5	15	15.5	15.5	15.3
002	14.5	15.5	15	15.0	16	15.5	16	15.8
003	16.5	16.5	16.5	16.5	15	15.5	16	15.5
004	17	17	17	17.0	16.5	16	17	16.5
005	12.5	13	13	12.8	14	14.5	15	14.5
006	15.5	15.5	15	15.3	14.5	15.5	16	15.3
007	14	14.5	14	14.2	18	18	18	18.0
008	15.5	15.5	15	15.3	14	13.5	14	13.8
009	16.5	15.8	16	16.1	17	17.5	17.5	17.3
010	14	15	14.5	14.5	14.5	14.5	14.5	14.5
011	14.5	15	15	14.8	14.5	14.5	15	14.7
012	16	15.5	16	15.8	15.5	14.5	16	15.3