

**Competitive Surfing: A Physiological Profile of Athletes and Determinants of
Performance**

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

A handwritten signature in blue ink, appearing to read 'O. Farley', is positioned above the printed name.

Signed

Oliver Farley

Date 27/10/2011

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ETHICAL APPROVAL

Ethics approval (10/104) from the AUT University Ethics Committee was gained prior to commencement of the study and written informed consent was obtained from each subject prior to commencing data collection.

ABSTRACT

Despite a huge growth in competitive surfing there is still a paucity of research available to underpin assessment and conditioning practice. Limited research investigating surfers' aerobic and anaerobic fitness provides an initial insight into the physiological demands of surfing; however it is limited in terms of competitive surfing and is characterized by methodological discrepancies. Likewise performance analysis has not been utilized extensively in surfing. Information available to-date suggests that competitive surfing is characterized by repeat high intensity intermittent bouts of paddling interspersed with moderate and high heart rates. Additionally, research evidence indicates that surfers possess moderately high aerobic fitness levels, comparable to other athletic groups such as competitive swimmers and surf life savers. To understand more about the sport of surfing, fundamental research into competitive surfing is needed. Therefore, the objectives of this study were to use methods of performance analysis to measure the physical outputs, workloads and activity patterns of elite surfers during competitions, and to specifically measure their anaerobic power output and peak oxygen uptake ($\text{VO}_{2\text{peak}}$) on a modified kayak ergometer, and the relationship between these outputs and surfing performance.

The study investigated the performance of surfing athletes during competitive surfing events. Twelve national ranked surfers were fitted with heart rate monitors and Global Positioning System (GPS) units and videoed during two sanctioned competitions. From the 32 videos analysed the greatest amount of time spent during surfing was paddling $54 \pm 6.3\%$. Remaining stationary represented $28 \pm 6.9\%$ of the total time, wave riding and paddling for a wave represented only $8 \pm 2\%$, and $4 \pm 1.5\%$ respectively. Surfers spent $61 \pm 7\%$ of the total paddling bouts and $64 \pm 6.8\%$ of total stationary bouts between 1 - 10 seconds. The average speed recorded via GPS for all subjects was 3.7 ± 0.6 km/h, with an average maximum speed of 33.4 ± 6.5 km/h (45 km/h was the peak). Surfers spent $58 \pm 9.9\%$ of the total speed zones between 1 – 4 km/h. The average distance covered from the two events combined was 1605 ± 313.5 meters. During the heats, surfers spent 60% of the total time between 56% and 74% of age predicted heart rate maximum (HRmax), 19% above 46% HRmax and approximately 3% above 83% HRmax. The mean HR during the

surf competitions was 139.7 ± 11 b.min⁻¹ (64.4% HRmax), with a (mean) peak of 190 ± 12 b.min⁻¹ (87.5% HRmax).

The aerobic $\text{VO}_{2\text{peak}}$ uptake and anaerobic peak power of nationally ranked surf athletes was determined over multiple testing occasions using a customized surf-paddle specific, kayak ergometer. Eight national level surfers participated in the incremental $\text{VO}_{2\text{peak}}$ test and 20 participated in the anaerobic power test. A kayak ergometer was modified with a surfboard and hand paddles, in an attempt to simulate a surfing-specific paddling action. The subjects' peak power (W) output calculated via the kayak ergometer computer was 205 ± 54.3 W, during a 10 second maximal intensity simulated paddle. A key finding from the current study was the significant relationship between surfers season ranking and anaerobic peak power output ($r = -0.55$, $P = 0.02$). Although correlations do not imply cause and effect, such a finding provides theoretical support for the importance of anaerobic paddling power in assessment batteries and conditioning practice for surf athletes. During the incremental $\text{VO}_{2\text{peak}}$ uptake test, subjects recorded a $\text{VO}_{2\text{peak}}$ of 44.0 ± 8.26 mL/kg/min, a result similar to previous studies. We found that there was no significant correlation between the surfers' season ranking and aerobic $\text{VO}_{2\text{peak}}$ values, or aerobic peak power outputs. Thus suggesting that peak oxygen uptake and peak aerobic power are not defining measures of surfing ability.

In conclusion, competitive surfing involves repeated measures of low intensity paddling, followed by intermittent high intensity bouts of all out paddling intercalated with relatively short recovery periods, combined with intermittent breath holding. Paddle power is conceivably important for competitive surfing athletes due to the significant relationship between surfers' season rank and peak anaerobic power. The ability to produce maximal power might improve surfing performance by allowing more powerful surf athletes to paddle and catch waves that lower ranked competitors miss.

THESIS OUTLINE AND STRUCTURE

This thesis is presented in six chapters. Chapter One presents an introduction, history and overview of surfing literature. Chapters Two and Four are literature reviews relating to the experimental chapters (Three and Five). Chapter Three (physiological demands of competitions) quantifies the physical demands of elite men's surfing using data obtained from surfing competitions. Chapter Five (anaerobic and aerobic fitness profiling) investigates the elite surfers anaerobic power output and their aerobic $\text{VO}_{2\text{peak}}$ on a modified ergometer and relationships to surfing performance. Finally, Chapter Six provides an overall summary and conclusion of the thesis, as well as discussion of limitations, practical applications and directions for future research.

PUBLICATIONS ARISING FROM THIS THESIS

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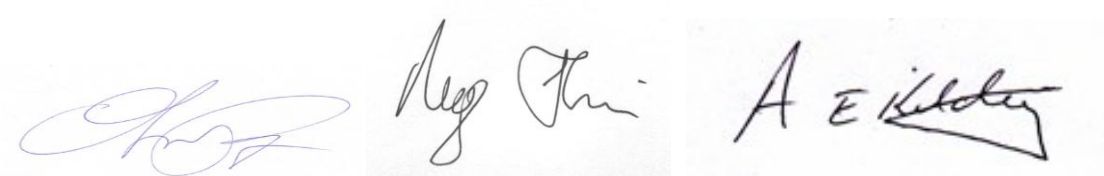
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CHAPTER 1: INTRODUCTION

A substantial growth in professional surfing since the first World Championship held in Australia in 1964 (Kampion, 2003) has seen an increase in the attention given to the physical preparation of surfers worldwide. However, research specifically on the physiology of competitive surfing athletes remains very limited. Surfing is an activity characterised by intermittent exercise bouts of varying intensities and durations involving various muscles and numerous recovery periods (Mendez-Villanueva & Bishop, 2005a). Lowdon (1983) found that surfers must implement a short powerful burst of paddling to gain enough momentum for the wave take-off, as well as prolonged periods of prone endurance paddling. It has also been proposed that surfers require muscular endurance and anaerobic power of the upper torso, and excellent cardio-respiratory endurance and recovery to withstand periods of breath holding (Lowdon, 1983; Lowdon, Bedi, & Horvath, 1989).

To understand more about the sport of surfing, fundamental research into competitive surfing is needed. Performance analysis is a technique for analysing physical demands, movement, technical and tactical aspects of match performance, and is increasingly becoming an integral part of the coaching process in elite sport (Hughes, 2004; Lythe, 2008). Monitoring of athletes has changed considerably since the early pioneered analysis methods in the 1950's and 60's (Pollard, 2002). The advances in technology have enhanced performance analysis by incorporating a variety of modern, commercially available devices, as well as a variety of software programmes. Coaches and sport scientists can now collect objective data on athletes work rates via heart rate (HR) monitors; evaluate training loads, movement patterns and activity profiles of athletes via Global Positioning System (GPS) units; and track athletes via video cameras and software (Time-motion analysis). The developments in modern technology have seen portable GPS receivers becoming increasingly applied in sporting applications (Cunniffe, Proctor, & Baker, 2009; Lythe, 2008; Schutz & Chambaz, 1997). As yet however, there is no scientific literature published that has applied GPS units to sport surfing.

To date, Meir, Lowdon and Davie (1991), and Mendez-Villanueva, Bishop and Hamer (2006), are the only studies that have analysed activity patterns of surfing via time-motion analysis using video recordings. Additionally, Meir et al., (1991) and Mendez-Villanueva and Bishop (2005a) have investigated physiological demands of surfing by investigating surfer's heart rates. Moreover, current research, using $\text{VO}_{2\text{peak}}$ testing, reveals that surfers possess a high level of aerobic fitness (Loveless & Minahan, 2010a, 2010b; Lowdon, 1983; Lowdon et al., 1989; Lowdon & Pateman, 1980; Meir et al., 1991; Mendez-Villanueva & Bishop, 2005a; Mendez-Villanueva et al., 2006; Mendez-Villanueva et al., 2005b).

The literature on surfing physiology (aerobic and anaerobic) is also limited. Developments in technology have seen ergometers used as an alternative to pool testing in the assessment of arm power, anaerobic and aerobic ($\text{VO}_{2\text{Peak}}$) fitness levels. Previous studies have used tethered board paddling (Lowdon et al., 1989), arm cranking (Lowdon et al., 1989), swim-bench ergometers (Meir et al., 1991), and modified kayak ergometers (Mendez-Villanueva et al., 2005b) to investigate peak aerobic output during surfboard paddling. Despite previous interest in the aerobic energy demands of surfboard riding, only one study (Loveless & Minahan, 2010a) assessed the test-retest reliability of peak power output during maximal-intensity paddling on a swim-bench ergometer.

Despite its increasing global audience, little is known about physiological factors related to surfing performance (Mendez-Villanueva & Bishop, 2005a). Therefore, the objective of this project is to increase understanding of the physical demands of elite men's surfing.

CHAPTER 1: LITERATURE REVIEW

BACKGROUND HISTORY OF SURFING

Surfing is an ancient sport with scant written or recorded varied history prior to Captain James Cook's observations of Tahitian canoe surfing in 1777. The beginnings of the sport in the form of canoe surfing appear to date back to almost 2000 B.C., when the ancestors of the Polynesians and the other Pacific Islanders started moving eastward from Southeast Asia (Finney & Houston, 1996). Surfing as it exists today is a Polynesian invention, with Hawaii's population mastering the art of standing on and shaping surfboards around 1000 years ago with both royalty and commoner practicing the sport ("Surfing history," ; Warshaw, 2003).

Indigenous surfing in the Pacific was most highly developed on the islands within the Polynesian triangle, bounded by Hawaii, Rapa Nui (Easter Island), and Aotearoa (New Zealand) (Finney & Houston, 1996). Early reports of surfing along the shores of islands from Papua New Guinea to Polynesia indicate that surfing, in its rudimentary form, was part of the common heritage of those who spread across the Pacific thousands of years ago (Finney & Houston, 1996). The Polynesians referred to it as *he'e nalu* (*he'e*: to ride; *nalu*: the surf) (Nendel, 2009). Surfing was noble and commoners would take their rightful place on smaller boards, but never at the same time as their chiefly leaders who sometimes surfed wearing their massive feathered headdresses and ceremonial cloaks (Harvey, 2009). Surfing was not merely a pastime for the leaders of old. This sport served as a training exercise meant to keep chiefs in top physical condition. Furthermore, surfing served as a system of conflict resolution.

British explorer Captain James Cook was one of the first to describe the act of surfing following a visit to the Tahitian Islands in 1777 (Axford, 1969). After witnessing a canoe surfer Cook commented: "*I could not help concluding that this man felt the most supreme pleasure while he was driven on so fast and smoothly by the sea*" (Captain James Cook, logbook entry, Polynesia, 1777, cited in ("Surfing history," ; Warshaw, 2003). On a

subsequent visit to Hawaii in 1778 (Axford, 1969), Cook saw a man standing on a board and riding a wave (Kampion, 2003). The following year after Cook's death, Lieutenant James King wrote an entry in Volume III of the *Voyage* series in 1779 about the "great art" of stand-up surfing, seen in Hawaii ("Surfing history," ; Warshaw, 2003).

The turn of the twentieth century saw the annexation of Hawaii to the United States of America as a territory. The meaning of surfing changed drastically from a sport steeped in cultural and religious significance to one resembling the same competitive and commercial values of other American sports, such as baseball, football and basketball (Nendel, 2009). The transformation over this period altered the sport of prowess, leading to the development of modern surfing (Nendel, 2009).

When the Europeans arrived in New Zealand they found that coastal Maori tribes were 'surfing' (whakaheke ngaru) using relatively uncrafted boards (kopapa), logs (paparewa), canoes (waka) and even kelp bags (poha) as a regular summertime activity (Williamson, 2000). In the mid - 1800s, the arrival of the missionaries and the subsequent advent of Christianity meant that many aquatic activities practiced by the Maori were no longer deemed to be appropriate. The practice of 'surfing' waned (Williamson, 2000). The sport of surfing underwent numerous changes over this period, with these changes came reduced links with its traditional values. With the rebirth of surfing in Hawaii taking place in the early twentieth century, an extraordinary man by the name of Duke Paoa Kahanamoku embarked on a world tour. The three time world record holder and multiple Olympic gold medal champion in free style swimming was invited to Australia to demonstrate the sport to amazed onlookers in Sydney. In 1915, Duke was invited by the New South Wales Swimming Association to give a swimming exhibition in Sydney. Australians were vaguely aware of surfing at the time, and were thrilled when Duke fashioned an 8ft' 6inch alaia board out of native Australian sugar pine (Marcus).

Duke Kahanamoku visited Wellington, New Zealand in 1915 for a swimming demonstration at Lyall Bay, furthermore he also demonstrated surfing. Duke Kahanamoku devoted a lot of his time traveling all over Europe, Australia and the USA performing surfing and swimming demonstrations. Since then, the popularity of surfing has been

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gradually growing, becoming a thriving culture in the 21st Century (Mendez-Villanueva & Bishop, 2005a).

Surfing – Overview of the Activity

Surfing or surfboard riding is the term given for the act of riding various types of surf boards along the unbroken section or wall of a wave before it breaks. Surfing is performed in an upright position with the rider standing erect on his or her feet. Learners accustom their skills by riding the broken part (white wash) of the wave on a large board called a long-board (9'1 - 16ft or 2.7m – 4.8m) or mini-Malibu (7'8 - 9ft or 2.1m – 2.7m). The larger boards have a wider area to stand up on, thus creating a far greater balancing area than that of a small short board (5'5 - 6'6 ft. or 1.6m – 2m) that experienced surfers use. By using these bigger boards it is far easier to learn on and develop the basic balance, control and movements required for surfing. Once these skills are gradually mastered, surfers will then choose smaller boards for faster, better manoeuvrability to try and ride the wall of the wave that experienced surfers would.

The ancient Hawaiian surfboards were large (16ft) and were difficult to manoeuvre due to being made out of heavy wood. They were substituted with lighter balsa wood surfboards in 1940's that were relatively easy for the surfer to manoeuvre. Advances in technology saw the developments in boards being made out of polyurethane foam, polyester resin and fiberglass cloth with multiple layers of wooden strips (Richardson). The modern surfboards come in various shapes and form, height, length, style and manoeuvrability. Generally a sharp pointed or rounded nose is made of a plastic, wood or fiberglass (Frisby & Mckenzie, 2003). The latest technology in surfboards has seen boards made from epoxy or carbon fibre composition.

Before any of the actual surfing can begin, the most physically demanding aspects of surfing occur. Lowdon, (1983) described the process of having to paddle through or around the breakers in the prone position, or sometimes kneeling (typically with a larger board) in order to reach the take-off area. During the prone surf paddling action, isometric

contractions of the trunk and neck hyperextensors fixate the shoulder girdle for effective paddling and allow for head rotation to read the wave and time the take-off (Lowdon, 1983). When a suitable wave approaches powerful paddling is required to give the board enough momentum to catch the forming wave. When the wave has been caught, it is necessary to quickly stand up, the surfer then chooses how they want to perform variations of manoeuvres on the wave's wall until it breaks. This same process is repeated many times throughout a surfing session.



Figure 1: Photo showing a take-off zone; (marked by { }) the area from paddling to the pop up stance and riding.

The skill of surfing requires the ability to stand on the surfboard while being pushed along by the wave. This requires immense balance executed over long durations. Once this skill is mastered, other aspects such as performing manoeuvres in the fastest, vertical or barrelling section of the unbroken wave require a combination of fast reaction time, velocity of body movements, dynamic balance, agility, mobility of body joints and the ability to anticipate and adapt to the continuously changing wave formation (Lowdon, 1983; Lowdon & Pateman, 1980). The combination of the above and the surfers speed of reflexes are vital in performing the turns, snaps, cutbacks and aerials of modern day surfing.

Surfing has dramatically expanded over the last decade at both the recreational and the competitive level. Professional surfers are international stars with the winner of a surf event on the ASP (Association of Surfing Professionals) World Tour collecting prize money

valued at approximately US\$75,000 ("ASP World Tour Schedule,"). The ASP World Title Race consists initially of 45 males and 17 female surfers fighting it out for points to decide the undisputed ASP World Champion. In 2010 the World Championship Tour of professional surfing was completed over ten events for men and nine events for women. These surfers are competing for a total prize pool of approximately USD\$4,000,000 (men) / USD\$910,000 (women).

However, despite its increasing global audience and international marketing and sponsorship deals, there is limited specific research on the factors that contribute to surfing performance. Previous authors have noted that surfing is a sports modality in which the environmental factors closely influence the physical fitness of athletes (Lowdon & Lowdon, 1988), especially the energy supply systems (Lowdon et al., 1989; Meir et al., 1991). Lowdon et al., (1989) stated that surfing is a somewhat unique sport in that participants practice their skills as often as their time and the surfing conditioning will permit, without conscious attention to training. The amount of time spent in the water is similar to the training times of elite athletes of other sports, yet surfers are more likely to consider this time as recreational rather than as training (Lowdon et al., 1989). Lowdon, Mourad, and Warne, (1990) reported that the majority of the competitors prior during the 1980's did not have a specific or suitable training routine. They believe that the sport's practice itself is sufficient for reaching the physical fitness level demanded in a competition. A decade later saw most elite surfers undergoing rigorous training programs, however, most recreational surfers do not train or condition, the fitness levels they attain are purely from the activity of surfing (Lowdon et al., 1990). Within the professional environment training modalities appear to be based largely on anecdotal opinion.

CHAPTER 2: LITERATURE REVIEW

PERFORMANCE ANALYSIS OF SURFING

Introduction

Despite huge growth in surfing worldwide, the paucity of research into the physical demands of competitive surfing confounds our ability to underpin training practice with empirical data. To date, only three studies have analysed the physiological demands of surfing by investigating surfers' heart rates (Meir et al., 1991; Mendez-Villanueva et al., 2005b), and activity through time-motion analysis (Meir et al., 1991; Mendez-Villanueva et al., 2006) during competition (39, 40) and recreational surfing (37). Performance analysis is a technique for analysing physical, technical and tactical aspects of competitive performance and is increasingly becoming an integral part of the coaching process in elite sport (Lythe, 2008). Performance analysis incorporates tactical and technical evaluation, analysis of movement and physical demands, and the development of predictive models (Hughes, 2004). Advances in technology have recently enhanced performance analysis by incorporating a variety of devices with associated software programs. A commercial piece of technology that is becoming increasingly applied to a range of sporting applications is the portable Global Positioning System (GPS). Satellite tracking GPS units can now be worn during competition and training to provide detailed information about movement patterns and physical activities of athletes (Lythe, 2008). Furthermore, advances in video cameras and software now allow us to capture high definition videos with small portable cameras. These videos are then able to be downloaded to computers for easy analysis through video player software. When used in combination, these technologies provide an opportunity to provide detailed and meaningful insights into sport and athlete performances that may be useful for the strength and conditioning coach.

The monitoring of athletes during competitions to develop an understanding of physical and technical demands has existed in American baseball as early as 1912 (Pollard, 2002). It

was not until the 1950's and 60's that the current performance analysis methods of comprehensive notational analysis system were first used, created and developed by Charles Reep for football, and subsequently evolved (Pollard, 2002). Although performance analysis has been established for a considerable period of time and utilized in a range of sporting codes (Lythe, 2008), it has not been utilised extensively in surfing. Therefore, with such an ancient sport that is 'booming' in terms of sponsorship, prize money, participants and media attention (Mendez-Villanueva & Bishop, 2005a) performance analysis is significantly needed to expand on the current research. The review provides an insight to methodological protocol, and delimitations of research into athlete analysis via video analysis, heart rate monitoring and GPS tracking. Literature addressed within this review was established via searching under Google Scholar, SPORTdiscus, PubMed, INFOtrieve and Scopus under the terms of surfing, surfing performance, physiological aspects of surfing, heart rate monitoring, GPS, athlete analysis, time-motion analysis; content was limited from 1980 to present, in English.

TIME-MOTION ANALYSIS

Time-motion analysis refers to the frame-by-frame examination of video footage of individual athletes during match-play and the recording of time-and-distance data (King, Jenkins, & Gabbett, 2009), movement patterns, frequency, mean duration and total time spent in activities (Duthie, Pyne, & Hooper, 2005). Time-motion analysis has been used to assess the activity profiles of soccer (Bangsbo, Norregaard, & Thorsoe, 1991; Mayhew & Wenger, 1985), soccer refereeing (Krustrup, Mohr, & Bangsbo, 2002), rugby (Deutsch, Maw, Jenkins, & Reaburn, 1998; Docherty, Wenger, & Neary, 1985; Duthie et al., 2005), rugby league (King et al., 2009), badminton (Cabello-Manrique & Gonzalez-Badillo, 2003), basketball (Matthew & Delextrat, 2009; McInnes, Carlson, Jones, & McKenna, 1995), field hockey (Spencer et al., 2004), and wrestling (Nilsson, Csargo, Gullstrand, Tveit, & Refsnes, 2002) amongst others. Time-motion analyses is a reliable method (Hopkins, 2000; Mendez-Villanueva et al., 2006), and can be used as the basis to design testing protocols and training programs according to the characteristics of the sport (Kovacs, 2004; Taylor, 2003).

Surfing is characterized by intermittent bouts of exercise varying in intensity and duration, which requires high muscular endurance, moderate-high cardio-respiratory endurance and recovery, and anaerobic power of the upper torso required during the short powerful bursts of paddling to repeatedly catch waves (Lowdon, 1983; Lowdon et al., 1989; Lowdon et al., 1990; Lowdon & Pateman, 1980; Mendez-Villanueva & Bishop, 2005a). The four main activities during surfing have been described as paddling, stationary, wave riding and miscellaneous (Meir et al., 1991) with many factors that will affect durations spent in each activity (Meir et al., 1991; Mendez-Villanueva et al., 2006), and resulting intensity. These factors include wave formation, type of wave break, wave size, weather, currents, rips, frequency of waves, tides and geographic location. However, despite these broad observations, there is limited information on the physiological aspects and intensity of effort expended during surfing. A summary of the classifications for data analysis may be observed in Table 1.

Motion Category	Definition as defined by (Meir et al., 1991)	Definition as defined by (Mendez-Villanueva et al., 2006)
Paddling	All forward board propulsion using alternate-arm paddling action	Defined as forward board propulsion using alternate-arm paddling action
Stationary	Subjects sitting or lying on their boards, including a slow one arm paddling action to maintain position in the take-off zone Recorded from the time of a subject's last arm stroke to the moment the subject's feet lost contact with the board or the subject effectively finished riding the wave	All situations in which surfers were sitting or lying on their boards, with no locomotion activity (Slow 1-arm paddling action aiming to maintain position in the take-off area was included in this category) Recorded from the time of a subject's last arm stroke to the moment the subject's feet lost contact with the board or the subject effectively finished riding the wave
Wave riding	Walking or running up the beach, wading, duck diving under white water and recovering and getting back on the surfboard after falling	All situations not previously defined which mainly included duck diving under broken waves and recovering and getting back on the surfboard after falling
Miscellaneous		

Table 1: Surfers movement classifications based on observation.

To date there have only been two previous studies investigating the time-motion analysis of surfers during competition (Mendez-Villanueva et al., 2006) and recreation (Meir et al., 1991). Specifically, Meir et al., (1991) used time-motion analysis when investigating heart rates and estimated energy expenditure of six male recreational surfers, who had competed at state surfing level. Each subject was videoed individually for approximately one hour, from a location considered advantageous for the particular surfing conditions. Surf

conditions, swell size, wind direction, tide and number of other participants in the water varied for each subject (Meir et al., 1991). Mendez-Villanueva et al., (2006) examined the activity profiles of 42 world-class professional surfers during an international contest (World Qualifying Series, WQS). Time-motion analysis was used to characterize changes in the activity patterns of elite male professional surfers during competitive heats. Each subject was videoed (four surfers competed against each other) individually for the entire duration of the heat. The duration of heats were 25 minutes long, with 42 heats (surfers) filmed during the seven days of competitive surfing. The video camera was mounted on a tripod and positioned at an approximate height of 30 meters and a distance of approximately 50 meters from the surfing venue. Because the surf conditions varied for each subject, the location of the camera was changed to ensure the most advantageous position for the particular surfing conditions (Mendez-Villanueva et al., 2006). In both previous studies (Meir et al., 1991; Mendez-Villanueva et al., 2006), the analysis was performed by a single observer who calculated the time (average and total) spent in each activity, the frequency (n) of occurrence of each activity, and the percentage of the total time spent on each activity. Mendez-Villanueva et al., (2006) and Meir et al., (1991) additionally recorded the number of paddling bouts and rest periods at given time intervals and the activity patterns between the waves (Meir et al., 1991) and two waves (Mendez-Villanueva et al., 2006). The actual time intervals for paddling, stationary and length of ride for each subject were then matched at 15 second heart rate intervals, as recorded by the Sports Tester memory (Meir et al., 1991). The results can be observed in Table 2.

Study	Total Time Paddling (min:sec)	Total Time Stationary (min:sec)	Total Time Riding Waves (min:sec)	Total Time Miscellaneous (min:sec)	Total Number of Waves Ridden
<i>Meir et al. (1991)</i>					
Mean	27:10	21:18	3:04		21
Range	18:55 – 31:50	15:22 – 31:35	2:15 – 4:11		16 – 28
Ave bout	0:20.1				
Total time %	44%	35%	5%	16%	
<i>Mendez-Villanueva et al. (2006)</i>					
Mean	12.53	10:37	0:57	0:32	5
Total Range	6:19-17:3	5:46-18:2	0:30-1:52	0:1-1:31	2-8
Ave bout	0:30.1	0:37.7	0:11.6	0:5.1	
Range	0:1-4:46	0:1-5:53	0:1-:44	0:1-:31	
Total time %	51%	42%	4%	2.5%	

Table 2: Time-motion analysis results.

The time-motion analysis data reported by Meir et al., (1991) and Mendez-Villanueva et al., (2006) are for the most part in agreement (Table 2), though some small differences do exist (Meir et al., 1991). The data from Meir et al., (1991) time-motion analysis established that the average time for paddling was 25.9 seconds for the group, with all subjects having intervals exceeding one minute, and three subjects recording periods exceeding two minutes. Meir et al., (1991) suggested that there appeared to be no set pattern for paddling activity. Typically, subjects produced the shortest intervals while paddling to catch the wave or while trying to improve their position in the take-off area (Meir et al., 1991). The percentages of time established could vary greatly due to a number of factors, including inconsistent surf, the number of individuals competing for waves and/or level of motivation of the participant (Meir et al., 1991). Furthermore, it may be reasonably conjectured that the percentage time spent effectively riding waves would vary greatly depending on the surfing conditions (Meir et al., 1991).

In the study by Mendez-Villanueva et al., (2006), there was on average, a change in movement category every 28 seconds. Mendez-Villanueva et al., (2006) also recorded the mean frequency of paddling bouts at different time intervals during a surfing heat. Most of the paddling bouts (60%) were performed for time intervals of between 1 and 20 seconds. The paddling duration zone of 11 to 20 seconds had the highest number of bouts recorded. Furthermore, combining the first two paddling intervals zones (1-20 sec) and (21- 90 sec), represented more than 90% of the total paddling bouts documented during all the heats.

Mendez-Villanueva et al., (2006) reported that approximately (mean) 51% of the rest intervals were between 1 and 20 seconds, with 1-10 seconds the highest number of rest periods in the heats. It was also noted that 66% of the total time between consecutive waves was spent paddling, with the greatest amount of that time devoted to paddling back to the take-off zone. Additionally, stationary and miscellaneous time represented 30% and 4% of the total time between consecutive waves, respectively.

The average values were assumed by Mendez-Villanueva et al., (2006) to not represent all the patterns of physical activity in surfing competitions. Furthermore, the unpredictable nature of the surfing environment, as well as length and frequency of the different activities performed during a competition heat would be highly variable (Mendez-Villanueva et al., 2006). The differences found between recreational surfing (Meir et al., 1991) and competitive surfing (Mendez-Villanueva et al., 2006) (Table 2) would be due to a wide range of variations associated with the sport of surfing, and the differences between competitive and recreational surfing. Mendez-Villanueva et al., (2005a) commented that the specific demands imposed during competitive surfing might impact on surfers' activity patterns, such as tactical decisions, opponent's heat scores or wave selection. Additionally, the percentages may also reflect the influence the multiple environmental factors such as swell size, inconsistent surf, currents, and wave frequency or length. Mendez-Villanueva et al., (2006) videoed competitive heats lasting 25 minutes during which competition performance pressures and wave selection pressures (such as maximal number of waves caught that the conditions allowed, and competition for waves) would have been encountered. In contrast, Meir et al. (Meir et al., 1991) used recreational surfers that were simply catching waves over a 60 minute period with no pressure on performance nor

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competition for the waves and number of waves they caught. Nonetheless, the data from these two studies (Meir et al., 1991; Mendez-Villanueva et al., 2006) provides a valuable insight to the percentages and durations of activities associated with surfing. Clearly, more research is needed to describe the activity patterns associated with competitive surfing. A potential tool to further progress time-motion analysis data and understand activity patterns of surfing in future studies is the use of GPS. The implementation of GPS units has been used successfully in other sports.

HEART RATE RESPONSE

Heart rate monitoring is considered an important component of cardiovascular fitness assessment and training prescription (Laukkanen & Virtanen, 1998). Vast improvements in technology have seen heart rate monitors (HRMs) evolve rapidly (Achten & Jeukendrup, 2003), and become a widely used training and monitoring device for a vast range of sports codes. The validity of these devices has been previously described (Achten & Jeukendrup, 2003; Gilman, 1996; Laukkanen & Virtanen, 1998), with predominant use of the Polar (Polar Electro Oy, Finland) with use of HRMs implemented in exercise-based fitness research (Goodie, Larkin, & Schauss, 2000; Kinnunen & Heikkila, 1998; Laukkanen & Virtanen, 1998; Vuori, 1998; Wajciechowski, Gayle, Andrews, & Dintiman, 1991), and have featured in surfing research conducted to date (Meir et al., 1991; Mendez-Villanueva et al., 2005b).

Lightweight telemetric heart rate monitors equipped with conventional electrodes have been available since 1983 and have been shown to be accurate, valid tools for heart rate monitoring and registering in the field (Laukkanen & Virtanen, 1998). The validity of these devices has been previously described (Achten & Jeukendrup, 2003; Gilman, 1996; Laukkanen & Virtanen, 1998). Scandinavian company Polar (Polar Electro Oy, Finland) have been recognized as the most accurate, reliable, non-obtrusive tools for heart rate monitoring and registering in the field (Achten & Jeukendrup, 2003; Gilman, 1996; Goodie et al., 2000).

The use of HR as a measure of exercise intensity relies on a consistent relationship between HR and oxygen consumption (Lythe, 2008). This is based on the understanding that there are linear relationships between heart rate, work rate and oxygen consumption (Arts & Kuipers, 1994). Arts and Kuipers, (1994) stated that there was such a strong linear relationship between power output, HR and oxygen consumption that one could easily be predicted from the other (Arts & Kuipers, 1994).

Previous studies have reported heart rates and estimated energy expenditure during recreational surfing (Meir et al., 1991), and during simulated competitive surfing; (Mendez-Villanueva & Bishop, 2005a). During recreational surfing, Meir et al., (1991) monitored heart rate responses in six surfers during one hour of recreational surfing. The heart rates were recorded using Polar Electro Sport Tester PE 3000 Receiver and PE 3000S (swimming model) Transmitter. Difficulties were experienced when using the system in saltwater, as it caused the signals to be severely attenuated and diverted from the receiver. Modifications were made to increase the efficiency of the system by using a twin coaxial cable, and readjustments of the transmitters recommended position to reduce discomfort on the surfer. To allow quantification of relative exercise intensity, subjects also carried out a maximal arm-paddling test on a swim-bench ergometer. Relative to the peak heart rate (HR_{peak}) attained during the swim-bench test ($180 \text{ b}\cdot\text{min}^{-1}$), the peak heart rate attained during recreational surfing was $171 \pm 7 \text{ b}\cdot\text{min}^{-1}$ or $95\% \pm 3.6\% HR_{peak}$. The mean heart rate value for the total time surfing (1 hour) was $135 \pm 6 \text{ b}\cdot\text{min}^{-1}$ representing $75 \pm 4.2\% HR_{peak}$ for total surfing time. Additionally, during other activities, paddling resulted in a mean heart rate of $143 \pm 10 \text{ b}\cdot\text{min}^{-1}$ ($80 \pm 4.8\% HR_{peak}$) and stationary time represented $127 \pm 7 \text{ b}\cdot\text{min}^{-1}$ ($71 \pm 5.5\% HR_{peak}$). Meir et al., (1991) commented that the heart rates produced during 60 minutes of recreational surfing provide some insight into the intensity of effort, but are not necessarily typical of all responses expected by all participants of this sport in all conditions. As one would expect, individuals will participate with varying degrees of voluntary effort (Meir et al., 1991). The heart rates and activity were synchronized, however heart rates were recorded at 15 second intervals, meaning the heart rate will fluctuate over any given 15 second interval. The intermittent nature of surfing means that the exercise intensity is constantly changing. The use of a five second heart rate sample

have featured in the following sports studies, soccer (Capranica, Tessitore, Guidetti, & Figura, 2001; Krstrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Tessitore, Meeusen, Piacentini, Demarie, & Capranica, 2006), hockey (Boyle, Mahoney, & Wallace, 1994; Johnston, Sproule, McMorris, & Maile, 2004), basketball (Abdelkrim, El Fazaa, & El Ati, 2007; Rodriguez-Alonso, Fernandez-Garcia, Perez-Landaluce, & Terrados, 2003) and rugby (Deutsch et al., 1998). According to McCarthy and Ringwood (McCarthy & Ringwood, 2006) this sample rate has been mathematically demonstrated to be adequate for analytical purposes. Therefore, the reported heart rate values of Meir et al., (1991) should be interpreted with this in mind.

Mendez-Villanueva and Bishop (2005a) investigated heart rates (recorded continuously at five second intervals) on five competitive male surfers during a simulated 20-minute surfing heat. Using a similar approach to Meir et al., (1991), subjects performed a laboratory maximal arm paddling test on a modified kayak ergometer to determine HR_{peak}. The heart rate response during surfing was classified based on percentage time spent in six heart rate zones: 1) <75% HR_{peak}; 2) 75-80% HR peak 3) 80-85% HR peak; 4) 85-90% HR_{peak}; 5) 90-95% HR_{peak} and 6) >95% HR_{peak}.

The group's mean heart rate peak for the laboratory arm paddling test was $174 \pm 9 \text{ b}\cdot\text{min}^{-1}$. Mean heart rate for the simulated surfing heat was $146 \pm 20 \text{ b}\cdot\text{min}^{-1}$, representing 84% of the laboratory HR_{peak}. Surfers spent 25% of the total time above 90%HR_{peak}. According to Mendez-Villanueva and Bishop (2005a), the heart rate responses suggested that periods of moderate intensity activity, soliciting mainly the aerobic system, are intercalated with bouts of high-intensity activity (>90%HR_{peak}) demanding both aerobic and anaerobic metabolism.

Mendez-Villanueva and Bishop (2005a) commented that due to the different types of muscular work (i.e. upper- vs. lower-body, isometric vs. dynamic contractions), the intermittent nature of surfing activity and the many external factors that might influence physiological responses to surfing, average heart rate values are not likely to represent all patterns of physical activity in surfing. Furthermore, the heart rate could conceivably be elevated due to any one of a number of factors. Mendez-Villanueva and Bishop (2005a) suggested that certain characteristics of surfing (e.g. isometric contractions during wave

riding, high levels of concentration or great emotional stress may induce an elevation of heart rate.

In summary, there is limited data with which to establish definitive parameters for a heart rate profile of surfing. Data suggests that there is no difference between the heart rates recorded during dry-land paddling tests, 180 ± 6 b.min⁻¹ (swim-bench test) (Meir et al., 1991), and 174 ± 9 b.min⁻¹ (arm paddling test) (Mendez-Villanueva & Bishop, 2005a). However, there is a difference between the heart rates attained during recreational surfing (1 hour) 135 ± 6 b.min⁻¹ (Meir et al., 1991), and the simulated surfing heat 146 ± 20 b.min⁻¹ (Mendez-Villanueva & Bishop, 2005a). The differences between the two studies are likely due to methodological differences in heart rate testing protocol, the relatively small number of subjects tested and heart rate sample intervals.

GLOBAL POSITIONING SYSTEM ATHLETE ANALYSIS

Recently, the Global Positioning System (GPS) has been proposed as a means to monitor physical activity such as position and speed of participants (Larsson, 2003), movement patterns and physical activities of athletes (See Appendix One). GPS technology has been applied to a range of sporting applications (Cunniffe et al., 2009; Lythe, 2008; Schutz & Chambaz, 1997) and is considered an accurate and reliable tool to determine outdoor speed of displacement in athletes (Schutz & Herren, 2000) that can be applied to a range of sporting contexts (Cunniffe et al., 2009; Edgecomb & Norton, 2006; Larsson, 2003; Lythe, 2008; Petersen, Pyne, Portus, & Dawson, 2009; Schutz & Chambaz, 1997; Schutz & Herren, 2000; Townshend, Worringham, & Stewart, 2007). Recently improved miniaturization and enhanced battery life have made athlete-tracking GPS units a more convenient, less time-consuming, and increasingly popular method to quantify movement patterns and physical demands in sport (Petersen et al., 2009). To our knowledge however, there is no scientific literature published that has applied GPS units while surfing. This is due to surfing research on a whole being in its infancy.

Reliability and Validity of GPS Measurement

The reliability and validity of the portable GPS unit relies on the accuracy and reliability of the GPS software to establish distances and velocities. Six important previous studies investigating the validity, reliability and accuracy in the use of portable GPS units in linear and nonlinear tracking are addressed.

Two prior studies using similar methods established the validity of GPS for speed recording. Shultz and Chambaz (1997) and Shultz and Herren (2000) implemented similar studies and recorded significant relationships between the actual speed and the speed assessed by GPS. Shultz and Chambaz (1997) recorded significant relationships ($r = 0.99$, $p < 0.0001$) while walking and running (2-20 km/h) and cycling (20-40km/h) with one subject. The overall error of prediction (s.d. of difference) averaged 0.8 km/h, with little bias in the prediction of velocity (Schutz & Chambaz, 1997). In addition, Edgecomb and Norton (2006) and Petersen, Pyne, Portus, Dawson, (2009) investigated a commercially available GPS (SPI-10 GPSports Pty) unit. Edgecomb and Norton (2006) reported that triplicate repeat measures of the distance a subject travelling over a range of circuits reported a TEM of 5.5% (intratester reliability), with correlation between the triplicate measures as highly significant ($r = 0.98$). During Pertersen et al., (2009), distances and movement patterns were quantified with the standard error of the estimate using typical error expressed as a coefficient of variation (Petersen et al., 2009). The validity of the SPI-10 unit during walking to striding patterns ranged from 0.5% to 2.1%. Pertersen et al., (2009) also suggested that the reliability of GPS estimation of locomotion patterns was better for longer distances. The SPI-10 had good reliability with a TE <2% over the different distances walking to striding. The SPI-10 unit underestimated the criterion distance of walking through to striding by 1% to 3%.

The studies by Edgecomb and Norton (2006) and Pertersen et al., (2009) implemented sports specific locomotion activities. Edgecomb and Norton (2006) implemented 28 trials at various speeds around circuits ranging from 125m to 1386m, based around Australian football, and Pertersen et al., (2009) implemented walking 8800 m, jogging 2400 m, running 1200 m and striding 600 m based on cricket-specific locomotion. Edgecomb and

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Norton (2006) used paired T-tests to determine differences between GPS distances and actual distances and found they were highly correlated ($r=0.99$). However, the GPS system overestimated the actual values by about $4.8\% \pm 7.2\%$ with an absolute error of $6.3 \pm 6.0\%$ (Edgecomb & Norton, 2006). During Shultz and Herren (2000), the accuracy of speed prediction resulted in standard deviations of 0.08km/h (walking, from 2.9km/h) and 0.11 km/h (running, up to 25.2 km/h) with a coefficient of variation (SD/mean) of 1.38% and 0.82%, respectively.

Portas, Rush, Barnes and Batterham (2007), compared linear distance and velocity measurements with three GPS units and timing gates. For the GPS-estimated distance, mean % error was calculated. For velocity, a log-transformed linear regression was conducted with the standard error of the estimate for each unit expressed as a coefficient of variation. The error for GPS distance measurements varied by the velocity of the trial. The mean % error was highest during running at 22.5km/h (5.64%; 2.82m) and the lowest at 6.45km/h (0.71%; 0.36m). The % CV for the GPS-estimated velocity was 1% for each of the three units (95% CI 0.8% to 1.2%) (Portas et al., 2007). The GPS data recording at 1 Hz seemed appropriate for calculating distance at lower velocities but that greater error in estimation may occur at higher velocities. More recently Gray, Jenkins, Andrews, Taaffe and Glover (2010) collected data from seven 1-Hz GPS receivers on one participant while walking, jogging, running, and sprinting over linear and non-linear 200 m courses. The results from all non-linear movements were significantly lower than corresponding values from the linear course ($p < 0.05$). Results of linear course walking and jogging produced (205.8 ± 2.4 m, 2.8%) and (201.8 ± 2.8 m, 0.8%) respectively, whereas, the non-linear values produced (198.9 ± 3.5 m, -0.5%) and (188.3 ± 2 m, -5.8%), respectively. The percentage bias across all movement intensities on the linear course was 2.0%, (5.2% and -1.2%, upper and lower limits). The percentage bias across all movement intensities on the non-linear course was -6.0%, (2.0% and -13.4%, upper and lower limits). The overall coefficient of variation within and between receivers was 2.6% and 2.8% respectively.

It should be noted that several studies (Gray et al., 2010; Petersen et al., 2009; Witte & Wilson, 2004) have reported that GPS units have good accuracy during basic linear movements but that accuracy, errors in speeds and reliability decrease as speed and

movement intensity increase and with activity over circular paths. Furthermore, path and movement intensity appear to affect GPS distance accuracy via inherent positioning errors, update rate, and conditions of use (Gray et al., 2010). It is an important point to consider when it comes to limitations of GPS applications to surfing research.

Performance analysis research continues to use methods that involve human observation and involve a degree of subjectivity (Lythe, 2008). Indeed, the reliability of measures in studies adopting this technique could be influenced if key events are overlooked and/or the analyst codes events incorrectly (Lythe, 2008). Therefore, the need to train system operators is required to have clear procedures to avoid data being entered inaccurately, to reduce inter-observer variability, and different interpretations of performance being made (Bloomfield, Polman, & O'Donoghue, 2007). By implementing a single analyst to perform the classifications, these potential problems can be avoided, or at least reduced. The analyst needs to ensure the operational definitions are well thought out and understood, and to check all analysts' codes for a match against a gold standard (James, Taylor, & Stanley, 2007). Such a method should be incorporated in all performance analysis studies; such as when dealing with video recordings, heart rates and GPS data.

Summary

There is a paucity of studies detailing the physiological and performance analysis profile of competitive surfers during competition. However, information available to-date suggests that competitive surfing is characterized by repeat high intensity intermittent bouts of paddling interspersed with moderate and high heart rates which requires a well-developed aerobic and anaerobic energy system. From strength and conditioning perspective, literature suggests elite surf athletes should perform very high and moderate workload intensities to enhance both aerobic and anaerobic metabolism combined with muscular endurance and power. Recent developments in technology have made it possible for coaches and sport scientists alike to utilize heart rate monitors, GPS units and video analysis to record valid, reliable, objective data on athletes in actual competitive situations. Future use of such technology is required to help further develop our understanding of the physical demands

and characteristics of competitive surfing. Consequently, such information would support the development of surf specific on and off-water training programs that aim to enhance surf performance. A novel approach would be to position GPS, HRM's onto elite surfers and synchronize video footage of competitive surfing heats with the GPS and heart rates, and to analysis the effects of conditions on the performance variables.

Initial investigation determined limited research on the physiological and performance analysis profile of competitive surfers during competition. To date, time-motion analysis suggests that competitive surfing is characterized by repeat high intensity intermittent bouts of paddling interspersed with moderate and high heart rates. There is no current literature to date implementing GPS technology in surfing. It was considered that fundamental research on surfing performance is required to better understand what fitness aspects are required during competitive surfing before prescribing training routines. Therefore, the following investigation will provide further insight into the physiological demands during surfing.

CHAPTER 3: PHYSIOLOGICAL DEMANDS OF COMPETITIVE SURFING

Introduction

Despite huge growth in surfing worldwide, a paucity of research into the physical demands of competitive surfing confounds our ability to underpin training practice with empirical data. Performance analysis incorporates a number of applications including tactical and technical evaluation, analysis of movement and physical demands, and the development of predictive models (Hughes, 2004; Lythe, 2008). Coaches and sport scientists can now collect objective data on athletes' work rates via HR monitors (Achten & Jeukendrup, 2003; Goodie et al., 2000; Lambert, Mbambo, & St Clair-Gibson, 1998; Laukkanen & Virtanen, 1998), evaluate training loads, movement patterns and activity profiles of athletes via GPS units (Cunniffe et al., 2009; Larsson, 2003; Lythe, 2008; Townshend et al., 2007) and track athletes via time-motion analysis (Abdelkrim et al., 2007; Duthie et al., 2005; King et al., 2009; Matthew & Delextrat, 2009). Developments in technology have made it possible to utilize such devices to record valid, reliable data but limited studies on surfing have been conducted to-date. Only two studies have analysed surfers' heart rates (Meir et al., 1991; Mendez-Villanueva & Bishop, 2005a) and activity through time-motion analysis using video recordings (Meir et al., 1991; Mendez-Villanueva et al., 2006). The mean heart rates of recreational ($n=6$) (Meir et al., 1991), and ($n=5$) competitive surfers (Mendez-Villanueva & Bishop, 2005a) were 135 ± 6 b.min⁻¹, and 146 ± 20 b.min⁻¹ of total duration, respectively. Meir et al. (1991) also examined the activity patterns of one hour recreational surfing, reporting that 44% of the total time was spent paddling, 35% stationary, 5% wave riding and 16% miscellaneous activity. More recently, world-class professional surfers were investigated during competitive heats (Mendez-Villanueva et al., 2006) in which surfers spent 51% of total time paddling, 42% stationary, 3.8% wave riding and 2.5% performing miscellaneous activities. Currently no research has used GPS units during any form of surfing. Use of such technology would provide us with more detailed performance analysis data. Therefore, this study incorporates the use of HR and GPS monitors, and video analysis to conduct a unique profile of surfing athletes during a competitive surfing event in order to provide descriptive data to underpin future research and practice.

METHODS

Experimental Approach to the Problem

This descriptive study was conducted to determine the physiological demands of surfing competition, heart rate (HR) monitor, Global Positioning System (GPS) and video footage data were obtained from nationally ranked surfers during competition. Descriptive data was subsequently produced on the surfers' heart rates, durations of activities, velocities and distances covered while competing.

Subjects

Twelve national level male surfers (23.6 ± 5.7 yrs, 73 ± 10.3 kg, 179.2 ± 6.8 cm) volunteered to participate in this study. The subjects who had a history of surfing at least three times per week and have competed for at least three years were tested during the final two events of the competitive season. All subjects were from the current top 30 ranked surfers in New Zealand and competing in the sanctioned New Zealand Surf Association competition. Subjects were tested following their normal routine of sleep, nutritional and hydration levels prior to competitions. Ethics approval from the AUT University Ethics committee was gained prior to commencement of the study and written informed consent was obtained from each subject prior to commencing data collection.

Equipment

Subjects wore a Global Positioning System (GPS) recording device (SPI10 Sports Performance Indicator, GPSports Systems Ltd, Australia) and a Polar T31 (Polar Electro Oy, Kempele, Finland) heart rate monitor transmitter belt fastened around the sternum. The SPI10 GPS unit integrates heart rate measurement technology with the GPS system. A single GPS unit (91mm x 45mm x 21mm, weighing 75g) was worn by the subject during his heat. The GPS devices recorded the position coordinates of the subjects at a frequency of 1Hz (1 sample per second). During the competition heats, surfers were filmed using a

nine megapixel, 60 times optical zoom, Sony camera (Sony, DCR-SR67, Japan) mounted on a tripod for time-motion analysis. The video footage was recorded onto the camera's hard disk drive, and later videos were downloaded for analysis through Windows Media Player 11(© 2010 Microsoft Corporation).

Procedures

Prior to the beginning of a heat each subject was fitted with the HR monitor and GPS unit. Data collection was synchronized with heat start (and end) times. Additionally, the subjects' actions were recorded on video once the heat had started and ended. When the subject had returned to the beach (after conclusion of heat), position recording by the GPS unit was manually stopped. The data from the GPS unit was downloaded to a computer for subsequent analysis.

The first data collection was conducted during Event one, an event where the beach break swell ranged between 1 – 1.5 meters (3-4ft faces), with an onshore wind causing the waves to be choppy. Event two, the second data collection, was conducted at a point break beach where wave conditions were consistently 1.5 meters (4 ft), approximately. The point break provided a longer, quality wave that enabled subjects to ride for longer periods.

Global Position System

GPS units were turned on to locate satellites approximately five minutes before use. The GPS unit was placed into a water tight sealed bag, turned on to record, then positioned under the wetsuit of the subject around the upper Thoracic Vertebra and Scapula. The subjects' wetsuits held the units in place. This procedure was implemented approximately five minutes before the subjects entered the water. Data was downloaded using the manufacturer-supplied software (GPSports Team AMS v1.6.3.0, Australia). Raw data was then exported into Microsoft Excel 2010 (© 2010 Microsoft Corporation) for analysis.

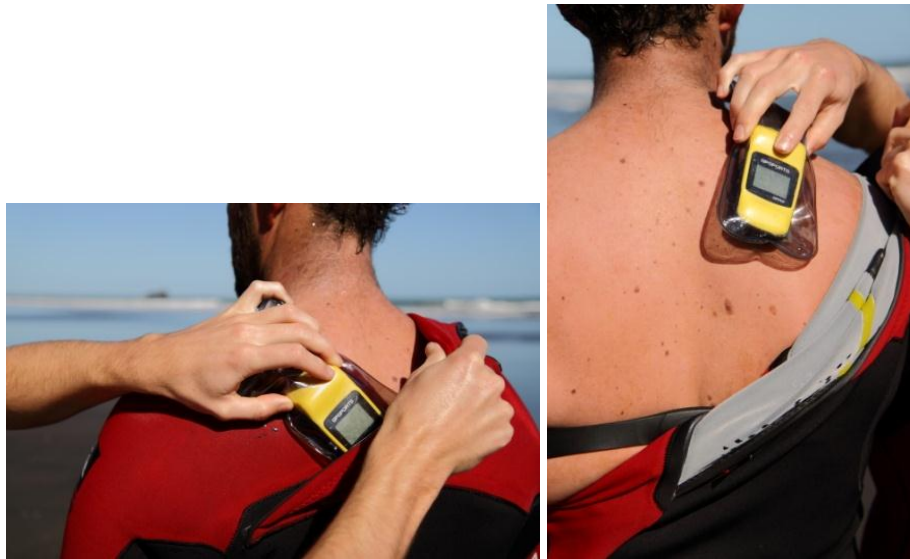


Figure 2: Placement positions of GPS units.

Heart Rate

During the heats, subjects wore a HR monitor chest strap (Polar T31) fastened around the Sternum and T7-T9 Thoracic Vertebra, using an elastic strap to keep it in place. The HR sensor electrode was positioned on the Thoracic Vertebra for comfort. The subjects' wet suit was then pulled up and over the HR monitor. The HR data recorded to the GPS unit was downloaded to the manufacturer-supplied software (GPSports Team AMS v1.6.3.0, Australia). Raw data was then exported into Microsoft Excel 2010 (© 2010 Microsoft Corporation) for analysis.



Figure 3: Heart rate monitor placement.

Video Analysis

Each heat recorded during the two events was 20 minutes in duration. Ten heats of the Event one competition were videoed with only one subject videoed per heat. During Event two, 26 individually videoed heats (surfers) were recorded during the three days of competition with two subjects recorded during each heat. Different subjects were videoed each time. The video camera at Event one was positioned on a sand dune approximately two meters high with the camera set one meter high overlooking the surf and approximately 50 meters away from the surf (depending on the tide). The location was as side-on as geography allowed. At Event two, two Sony cameras were positioned on a hill approximately 10 meters high overlooking the bay. Both cameras were set at one meter high, and approximately 5-10 (depending on the tide) meters away from the sea, with the subject another 10-30 meters away in the surf. The location of the camera was side on, looking along the waves as they broke (See Figure 4). This position ensured that the subject was not lost when going behind the wave, as when filming from front on.



Figure 4: Camera positions (C) for surf competition video recording Event two.



Figure 5: Still from actual video footage of Event two

The videos were started and paused every time the activity changed, with the times recorded for each activity in a Microsoft Excel spread sheet. Videos were rewound back and played up to five times for analysis of exact durations and to exclude any uncertainty in time allocated. One investigator only was responsible for all coding of activity from video replay.

Data Analysis

GPS data was edited to only include the total heat time (20 mins) spent in the surf and then separated into nine speed zones as presented in Table 3. Speed zones were established from the GPS data recorded. This was established by an emerging pattern of speeds the surfers travelled at during the different activities. No previous study has established speed zones before in surfing.

Zone	Speed Range	Category Label
1	1 – 4 km/h ⁻¹	Slow – Mod Slow Paddling
2	4.1 - 8 km/h ⁻¹	Moderate – High Intensity Paddling/ Slow Wave Riding
3	8.1 - 12 km/h ⁻¹	
4	12.1 - 16 km/h ⁻¹	Moderate Wave Riding
5	16.1 - 20 km/h ⁻¹	
6	20.1 - 25 km/h ⁻¹	High Speed Wave Riding
7	25.1 - 30 km/h ⁻¹	
8	30.1 - 40 km/h ⁻¹	Extremely High Speed Wave Riding
9	40.1 - 46 km/h ⁻¹	

Table 3: GPS Speed Zones and Category of Intensity.

Similarly, HR data was edited to only include the 20 minute surfing heats. The surfing HR data was then divided into seven zones as displayed in Table 4. The mean and peak HR's were recorded. Mendez-Villanueva and Bishop (2005a), categorized heart rates into exercise intensity as a percentage of peak into six zones. Higher HR's were obtained in the current study; therefore, seven categories (HR zones) were established.

Zone	HR Zone	Approximate %HR maximum*	Category Label
1	1 – 100 b.min ⁻¹	< 45%	Low Intensity
2	101 – 120 b.min ⁻¹	> 45 – < 55%	Moderate Intensity
3	121 – 140 b.min ⁻¹	> 55 – < 65%	
4	141 – 160 b.min ⁻¹	> 65 – < 75%	High Intensity
5	161 – 180 b.min ⁻¹	> 75 – < 85%	
6	181 – 200 b.min ⁻¹	> 85 – < 95%	Very High Intensity
7	201 – 220 b.min ⁻¹	> 95%	Maximal Intensity

* Heart rate zones are measure by the age predicted method (Tanaka, Monahan, & Seals, 2001).

Table 4: Heart Rate Zones and Category of Intensity.

Time-Motion Activity Criteria

A surfer's actions were classified based on Meir et al., (1991) with the new addition of 'paddling for wave' added, with slight modifications also made to the classifications.

Motion Category	Definition as defined by (Meir et al., 1991)	Current study definitions
Paddling	All forward board propulsion using alternate-arm paddling action.	Defined as forward board propulsion using alternate-arm paddling action.
	Subjects sitting or lying on their boards, including a slow one arm paddling action to maintain position in the take-off zone.	Defined as all situations in which subjects were sitting or lying on their boards, with no locomotion activity.
Stationary		Recorded from the time the subject started to implement the pop up stance immediately after the last stroke, to the moment the subject's feet lost contact with the board or the subject effectively finished riding the wave.
Wave riding	Recorded from the time of a subject's last arm stroke to the moment the subject's feet lost contact with the board or the subject effectively finished riding the wave.	Defined as duck diving under broken/unbroken waves, recovering and getting back on the surfboard after falling, slow one-arm paddling action aiming to maintain position in the take-off zone and sitting on the board moving the arms in water to move around but not paddling forward
Miscellaneous	Walking or running up the beach, wading, duck diving under white water and recovering and getting back on the surfboard after falling.	

**Paddling for
wave**

Recorded from the time the subject turned towards the shore and began to paddle forward with the wave forming, to right before they either implement the pop up stance to ride the wave or turned off the wave.

Table 5: Time-motion activity analysis criteria

The time (average and total) spent in each activity, the frequency (n) of occurrence of each activity, and the percentage of the total time spent on each activity were calculated. The activity bouts of paddling and stationary and the given time intervals were also recorded.

Statistics

Descriptive statistics are used throughout and presented as means and standard deviations to represent centrality and spread of data.

RESULTS

Activity Durations

The mean ($\pm$ SD) per cent values of the time spent on each activity are presented in Figure 6. From the 32 videos analysed the greatest amount of time spent during surfing was paddling ($54 \pm 6.3\%$). Remaining stationary represented ($28 \pm 6.9\%$) of the total time, wave riding and paddling for a wave represented only $8 \pm 2\%$, and $4 \pm 1.5\%$ respectively. Miscellaneous periods typically included 3 ± 1.4 sec of continuous breath holds directly after wave riding.

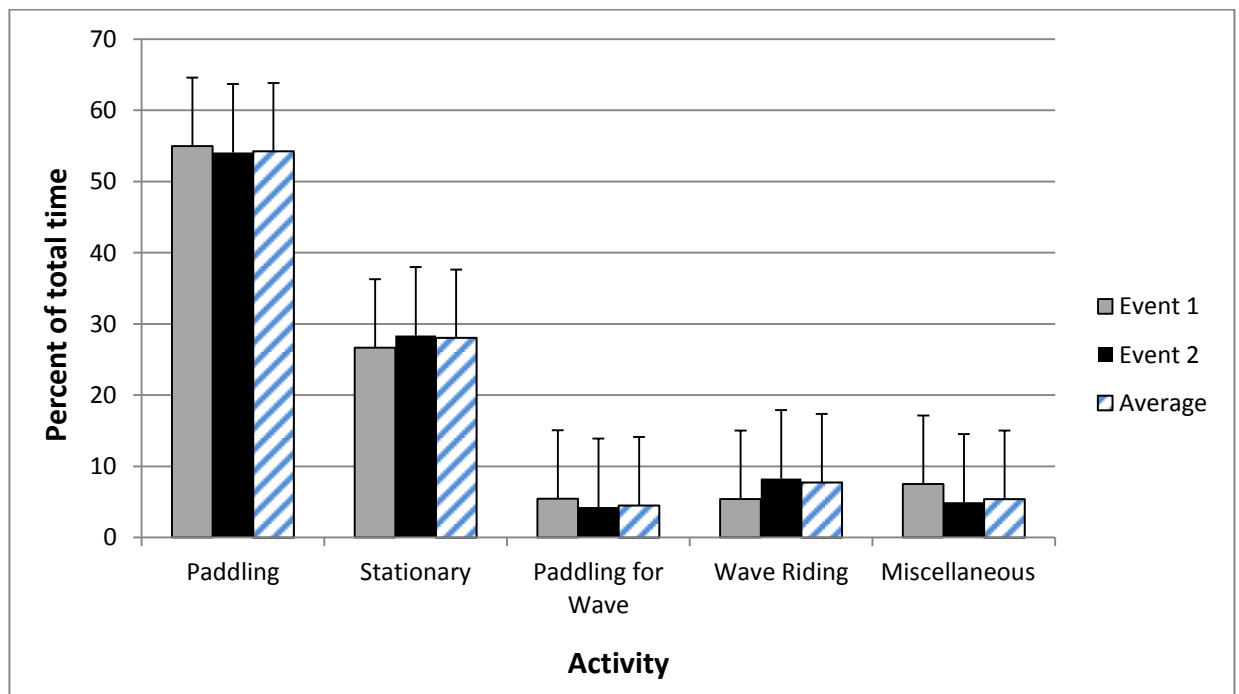


Figure 6: Mean proportion of total time spent performed during the 20-minute competitive surfing heats.

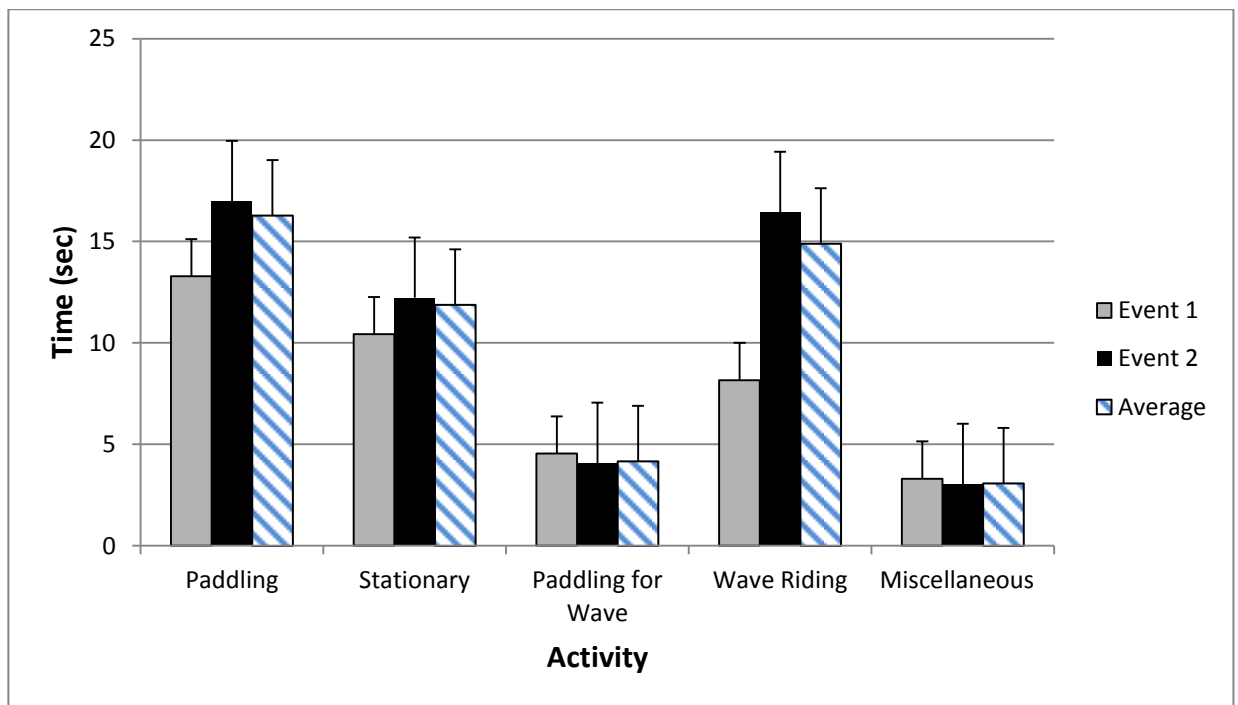


Figure 7: Mean time spent performing the activity during the 20-minute competitive surfing heats.

Figure 7 shows the average continuous time spent performing activities, before changing to another activity. Paddling was the biggest consumption of time (16 ± 4.5 sec) often due to paddling back to the take-off area. Comparable to paddling time, wave riding was the second biggest consumption of time once it is performed with (15 ± 5.6 sec).

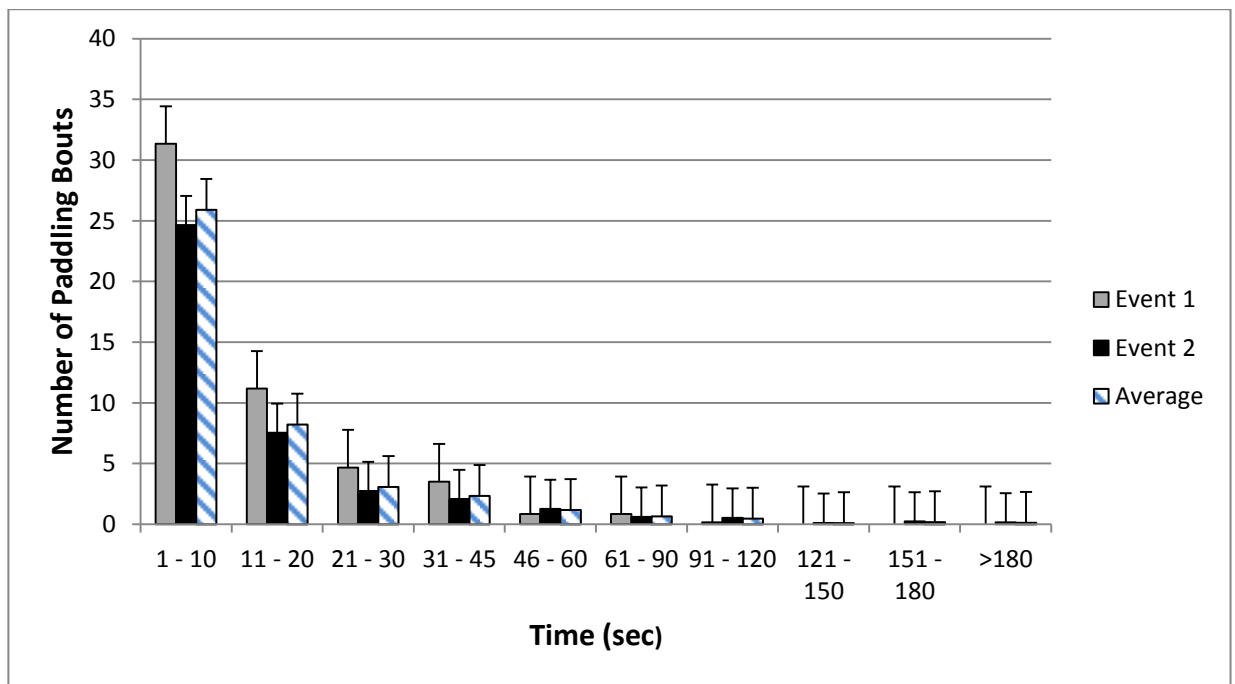


Figure 8: Number of paddling bouts (not including paddling for wave criteria) of various durations performed during a competitive surfing heat (mean $\pm$ SD).

In Figure 8, the mean frequency of paddling bouts at different time intervals during a surfing heat is shown. Most of the paddling bouts ($61 \pm 7\%$) were performed at time intervals of between 1 and 10 seconds. When combined with paddling intervals between 11 and 20 seconds ($19 \pm 3.8\%$), this represented 80% of the total paddling bouts documented during the heats.

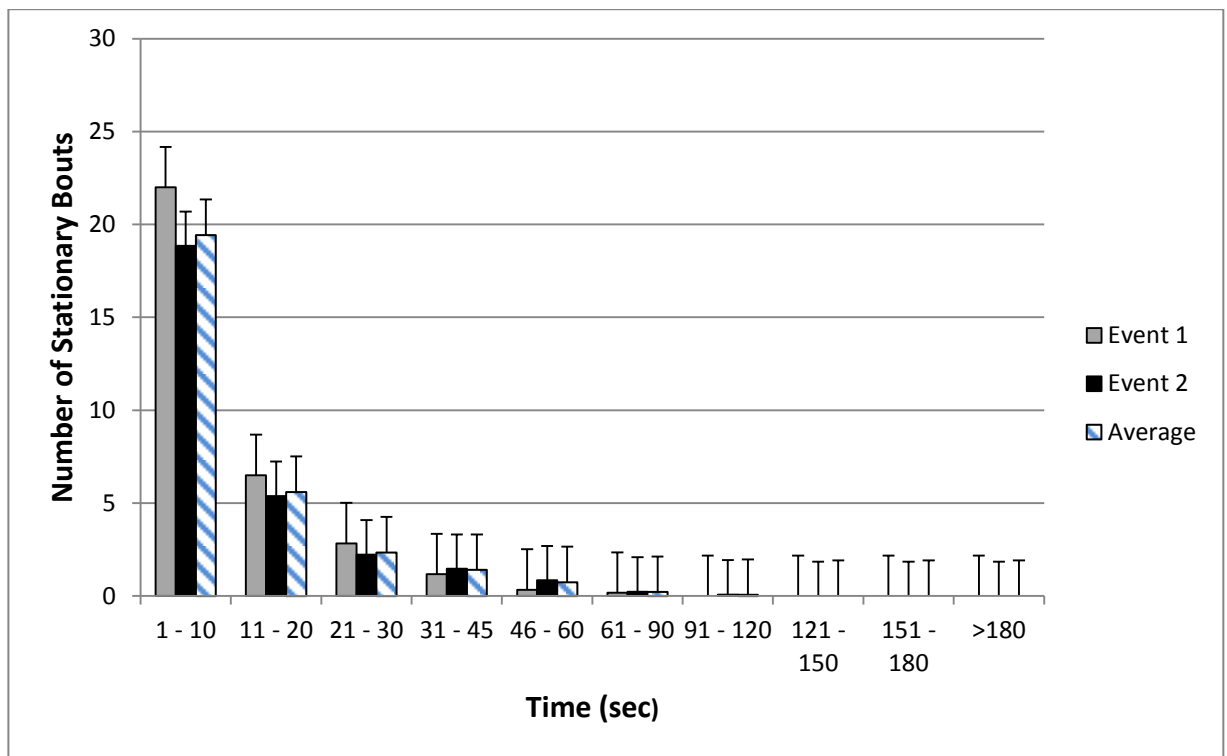


Figure 9: Number of stationary periods of various durations performed during a competitive surfing heat (mean $\pm$ SD).

Figure 9 displays the mean distribution of stationary periods at given time intervals during the heats. The longest period of the surfer being stationary was ($64 \pm 6.8\%$) between the duration of 1 and 10 seconds. When combined together with the second largest stationary period of 11 and 20 seconds ($19.3 \pm 2.7\%$), the total accounts for 83% of the total stationary periods recorded.

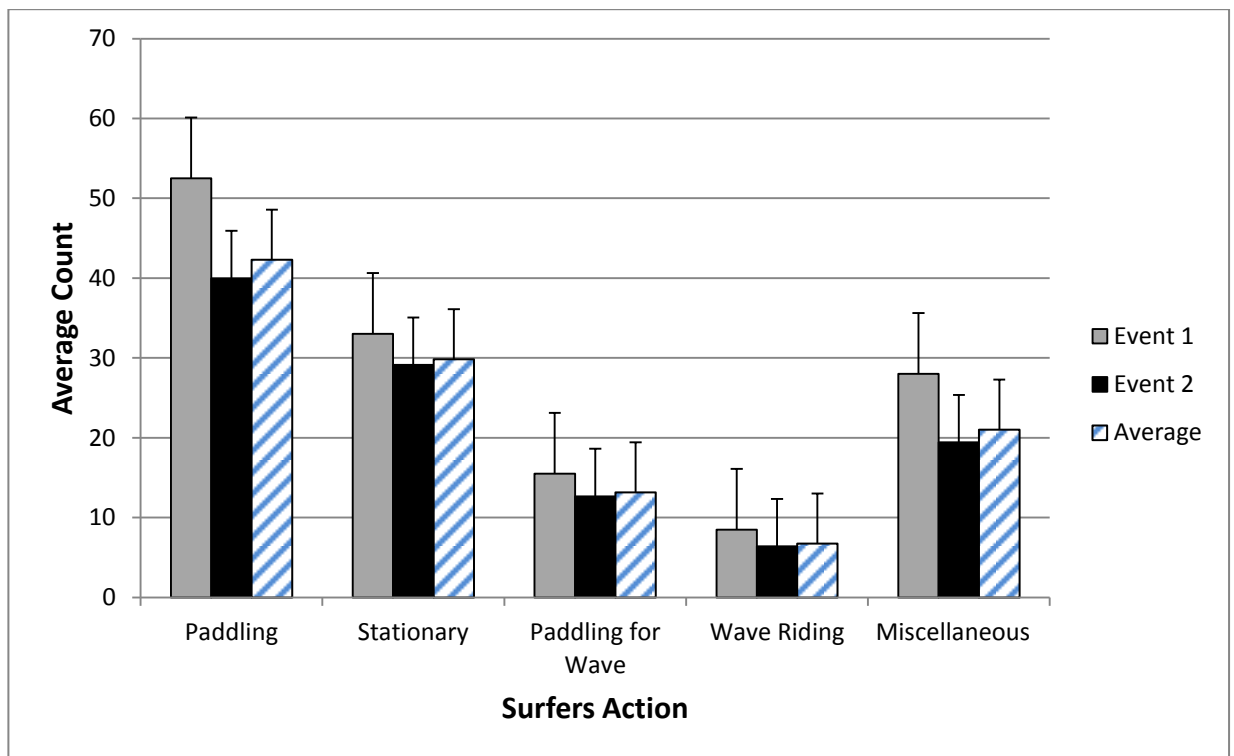


Figure 10: Mean number of times the action is performed during the 20-minute competitive surfing heat.

In Figure 10, the mean counts of the surfers' actions per heat are presented. Paddling is the largest count of the actions with it performed during a heat (n) (42 ± 9.4) times. Stationary is relatively close with an average of (n) (30 ± 6.7) counts per heat. Paddling for the wave is almost double of the actual waves caught in wave riding with (n) (13 ± 4.1) and (n) (7 ± 1.9) counts respectively.

Global Positioning System Speeds

In Figure 11, an example of the data recorded from a heat and compiled in the manufacturer-supplied software (GPSports Team AMS v1.6.3.0) is presented. The GPSports graph presents the heart rates, speeds and time recorded from a competition. The six peaks in the graph represent waves caught, while the lower secondary line represents the HR. The speeds recorded are the absolute speed, therefore including the speed of the ground swell.

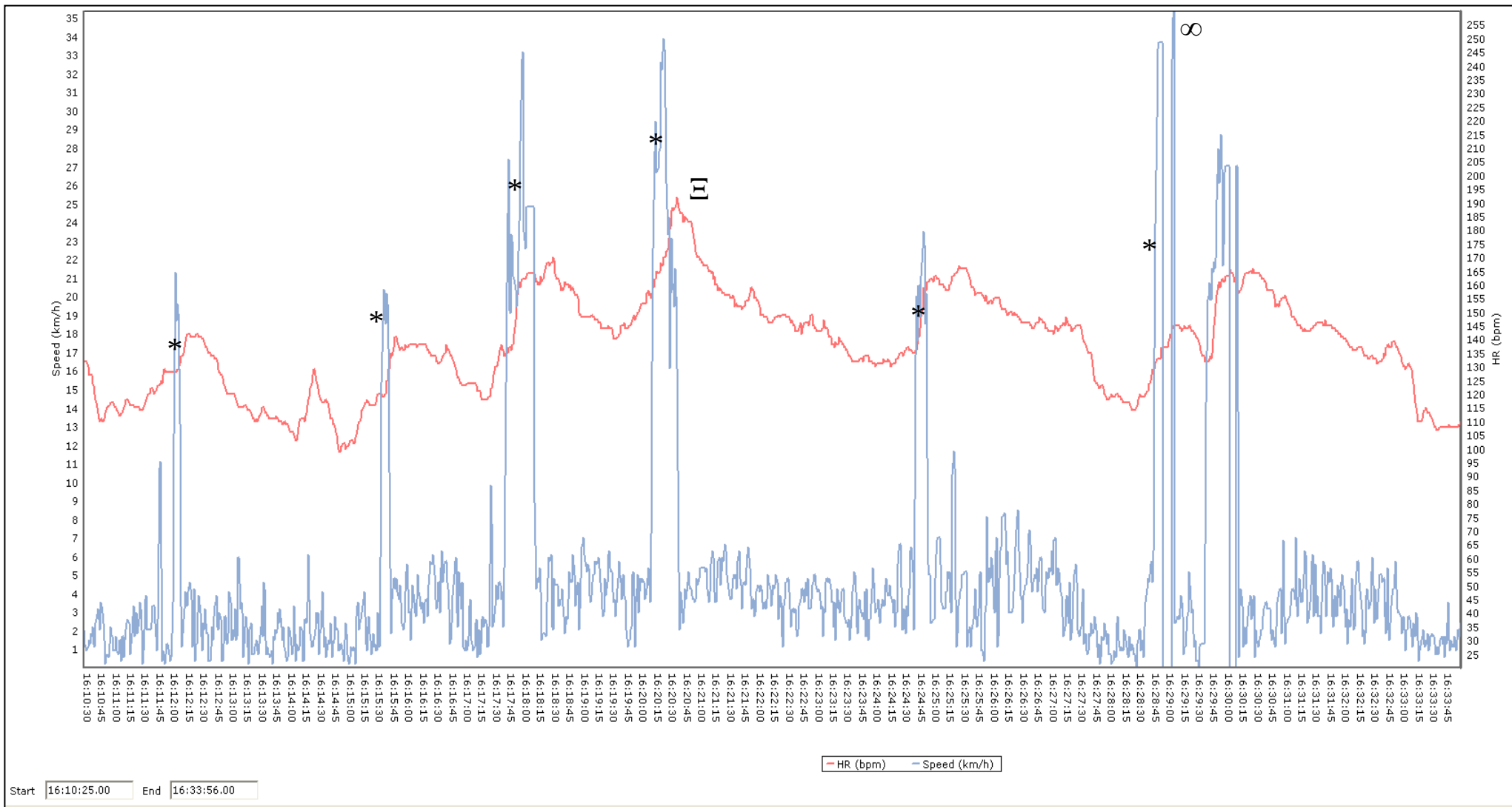


Figure 11: Example GPSports graph of GPS and HR recording from a competition.

Key: * = Waves caught (n=6)

Ξ = Peak HR (192 b.min^{-1})

∞ = Peak speed (35.4 km/h^{-1})

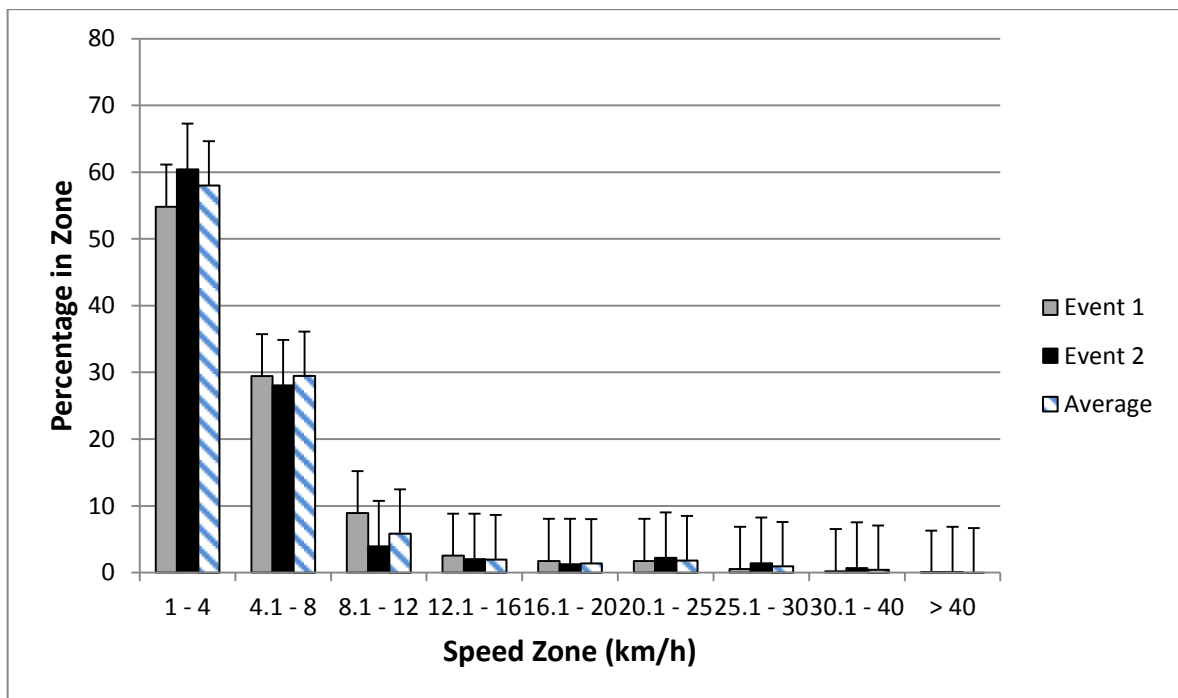


Figure 12: Percentages of time spend within the respective speed zone.

In Figure 12, the average percentage a surfer spends in each speed zone is displayed. The highest percentage ($58 \pm 9.9\%$) was in the slowest zone, between 1 and 4 km/h. The percentage of time spent within each speed zone decreased to less than 5%, for all zones greater than 8-12km/h. The average speed for all of the subjects combined was (3.7 ± 0.6 km/h), with an average maximum speed of (33.4 ± 6.5 km/h).

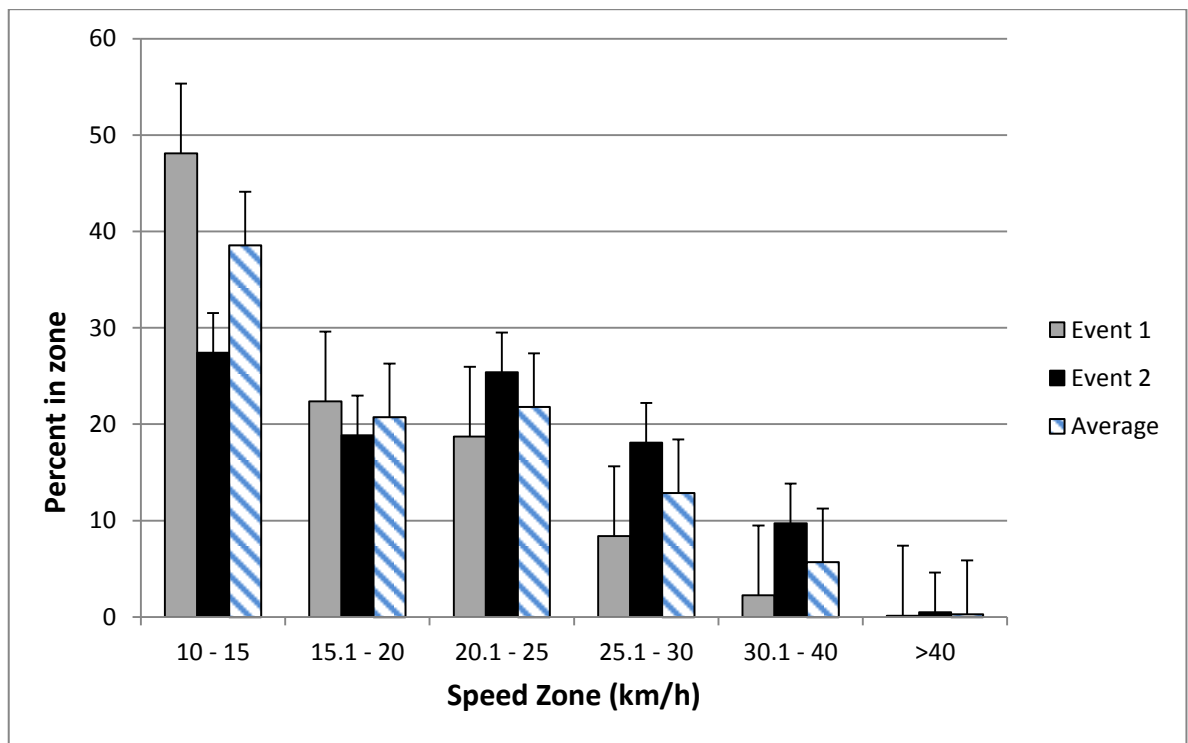


Figure 13: Per cent time spent within the respective wave riding speed zones.

Figure 13, displays the averages within the wave speed zones. The top percentage accumulated was ($38.6 \pm 18.8\%$) within the speed zone of 10 – 15 km/h. The third speed zone of 20.1 – 25 km/h has the second highest percentage surfers reach while wave riding, representing ($21.8 \pm 8.6\%$). The average speed for all of the surfers combined was (22.5 ± 3.8 km/h).

Distances

The average total distance covered per heat in event one was 1433 ± 249.8 meters. The total mean distance covered per heat in event two was significantly higher, representing 1806 ± 266.8 meters. The average from the two events combined is 1605 ± 313.5 meters.

Heart Rates

Surfers spent 60% of total time from 56% to 74% of age predicted HR maximum (HRmax), 19% above 46% HRmax and approximately 3% above 83% HRmax. Only three surfers from the competitions reached heart rates over 200 b.min⁻¹ (99%, 103%, 106% HRmax).

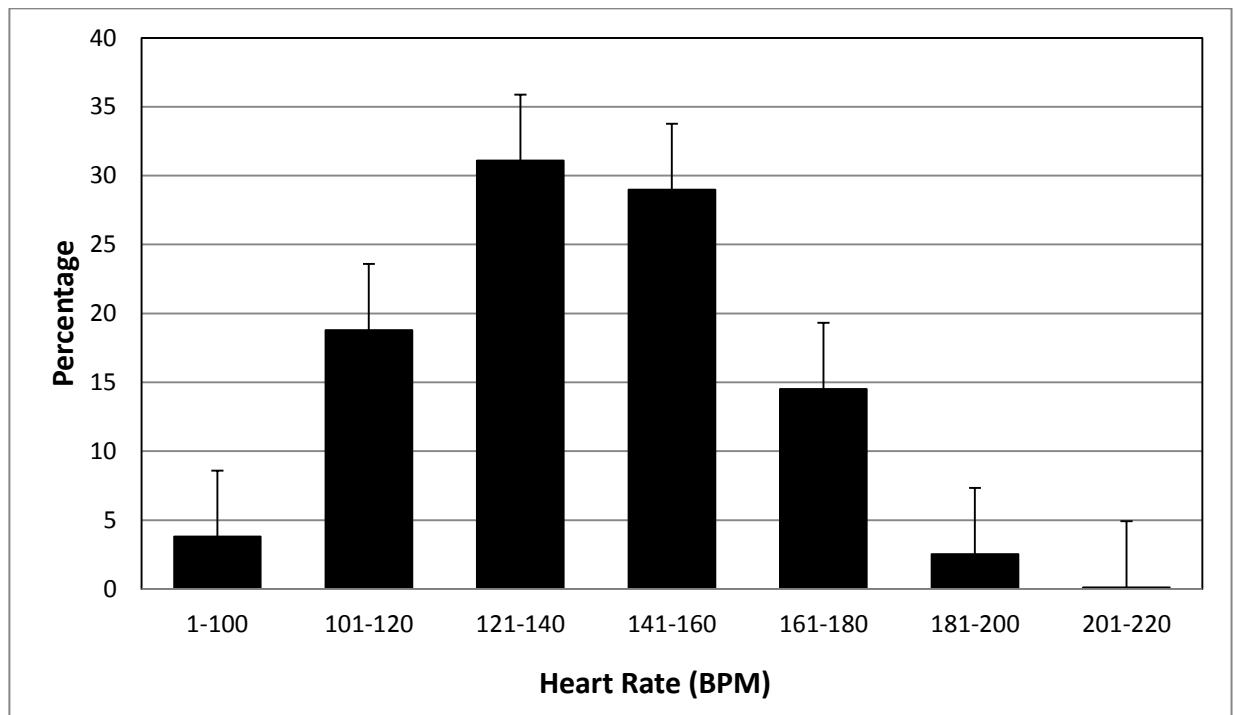


Figure 14: Mean percentage of the heart rates during the competitions.

In the Figure 14, the average heart rates of subjects during competition are shown. The HR zones of 121-140 and 141-160 b.min⁻¹ are very similar, ranging between (31 ± 12.7%) and (29 ± 11.3%) respectively, representing 60% of the total HR zones. The maximal HR zones of 181-220 b.min⁻¹ represented just 3% of total time. At the end of each wave ride peaks in HR were observed.

The mean HR during the surf competitions was 139.7 ± 11. b.min⁻¹ which equated to 64.4% HRmax. The peak HR reached during the events was 190 ± 12. b.min⁻¹ or 87.5% HRmax.

DISCUSSION

The surf conditions and type of wave breaks influenced the durations of time and per cent of time the surfers spent performing each respective activity. This was to be expected as previous authors (Meir et al., 1991; Mendez-Villanueva & Bishop, 2005a; Mendez-Villanueva, Mujika, & Bishop, 2010; Mendez-Villanueva et al., 2005b) have noted that the variables associated with surfing are profoundly affected by the surfing environments and conditions. It was suggested that time spent engaged in various activities may reflect variations due to the influence of the multiple environmental factors (swell size, inconsistent surf, currents, wave length or wave frequency, beach-break or reef-break, competing for waves) and/or level of motivation of the participant (Meir et al., 1991; Mendez-Villanueva & Bishop, 2005a; Mendez-Villanueva et al., 2006). Moreover, during competition, tactical decisions due to different factors (e.g. heat opponent's scores or wave selection) might have also have had an impact on the total time surfers' spent in these activities (Mendez-Villanueva & Bishop, 2005a; Mendez-Villanueva et al., 2006). Ultimately, the environmental conditions are a substantial factor which greatly influences the degree of total time spent paddling, stationary or riding waves and therefore the physiological costs associated with this activity (Meir et al., 1991). The reader should be cognizant of this limitation when interpreting these findings. Nonetheless, the results and data collected from the two sanctioned surfing events still provide an insight to the physiological aspects, time and activity patterns associated with surfing.

Time-Motion Analysis

Paddling was performed for 54% of total time, which was noticeably higher than previously reported (Meir et al., 1991), but comparable to some other time-motion studies (Mendez-Villanueva et al., 2006). Stationary, representing 28% of total time was lower than the previous studies (Meir et al., 1991; Mendez-Villanueva et al., 2006). Meir et al., (1991) reported that 44% and 35% of the total time was spent paddling and remaining stationary, respectively. Mendez-Villanueva et al., (2006) reported that paddling and stationary represented 51% and 42% of the total time respectively. The durations of time spent wave riding, performing miscellaneous activities and paddling for a wave represented 8%, 5% and 4% of the total time respectively in the present study. In comparison, Meir et al., (1991) reported 5% for wave riding, and 16% for miscellaneous activities for the total time, respectively. Moreover, Mendez-Villanueva et al., (2006) reported that wave riding accounted for 3.8% of the total time, whereas miscellaneous activity accounted for the remaining 2.5% of the total time.

Based on the video analysis, 80% of the total paddling time was performed for between 1 and 20 seconds. The second largest period of activity duration was the surfer being stationary with 64% of total stationary time between 1 and 10 seconds. The reasons for such a high percentage of time within the lower timed segments was due to the paddling between the sets of broken waves, waiting for the waves or resting, then having to paddle to reposition in the take-off area. It is also during these short stationary intervals that the surfers need to recover quickly. Heart rate data supports this typical activity pattern with HR dropping by 10 - 21 beats (approximately 5 – 13% HRmax) in 20 seconds.

An interesting observation from the analysis was the time it took the surfer to get back out beyond the breakers once he finished riding a longer ride of around 30 seconds. The surfers had to paddle and duck dive for around three minutes to get back out beyond the breaking waves. Once beyond the waves, the surfer still had to paddle across to the wave sets. Paddling would then continue for another 40-50 seconds to get to the take-off zone. Hence almost half of total heat time was spent paddling back from riding longer waves. Points from riding the wave to its full potential (15 ± 5.6 seconds in the current study) are likely to

be higher; however judging is based on the two best waves ridden. Therefore, the physical capacity to catch as many waves as possible during a heat is an important factor, and could be the difference between winning and losing. Arguably then, general aerobic conditioning may be an important component of fitness for surf athletes.

The present study has recorded higher activities in some movement categories and lower in others in comparison to those previously reported (Meir et al., 1991; Mendez-Villanueva et al., 2006). By combining the current and the two previous studies (Meir et al., 1991; Mendez-Villanueva et al., 2006) together, it appears that surfers spend ~50% of their total time paddling, ~35% of their total time stationary, ~6% wave riding and ~8% performing miscellaneous activities. (See Appendix Two)

Speeds and Distance Covered During Competitive Surfing

In the present study, GPS units were used to measure physical outputs of surfers during competitions. No previous study to date has incorporated such technology to investigate the speeds and distances surfers' attain while competing. It should be noted with current GPS technology, satellite reception could vary with location. Therefore, practitioners should check indicators of signal quality and number of satellites being used when interpreting GPS data (Petersen et al., 2009). We determined that surfers spent most of their time ($58 \pm 10\%$) within the slowest speed zone (1 - 4 km/h), mainly owing to all of the paddling bouts performed during each heat. The zone surfers spent the second largest amount of time ($29 \pm 5.5\%$) was between 4.1 and 8 km/h. This speed zone percentage is mainly made up of periods when the surfer paddled harder to catch a wave, quickly got into the take-off zone or paddled harder to get over a wave before it broke. The average speed for all of the surfers combined was 3.7 ± 0.6 km/h, with an average max of 33.4 ± 6.5 km/h.

The distances covered provide an insight to how far surfers travel, and may be useful in designing training routines. The average from the two events combined was 1605 ± 313.5 meters in 20 minutes. Approximately 947 ± 185.6 meters was spent paddling ranging from slow to high intensity bursts for the waves, and approximately 128.4 ± 25 meters was spent wave riding. The larger distances travelled at Event two (1806m) were most likely due to

waves wrapping around the point producing longer rides and conditions. Once the surfer was up and riding a wave at Event two, they were riding the wave for longer distances. This in turn meant that the paddle back to the take-off zone was by far a longer paddle when compared to the beach break of Event one. It has been asserted that the surfing environments and conditions profoundly affect the performance variables associated with surfing (Meir et al., 1991; Mendez-Villanueva & Bishop, 2005a; Mendez-Villanueva et al., 2010; Mendez-Villanueva et al., 2005b). The reader should be cognizant of this when interpreting these findings.

Heart Rate

We hypothesized that the HR would peak when paddling to catch the wave due to the intense paddling nature requiring large muscle groups utilized in an explosive motion, however this was not observed; in fact the HR peaked right after the subject had finished riding the wave. One reason for such a result could be the physical demands of riding the wave, coupled with the adrenaline release ensuing from the wave ride and fall. Additionally, once the surfer had finished riding the wave, or had fallen off, breath holding and intense paddling would commence as the surfer struggled to paddle through the breaking waves. The delay in peak HR may also be attributable to so-called HR lag (Achten & Jeukendrup, 2003).

The surf athletes spent 60% of the all surf heats ranging from 56% to 74% of HRmax. The two HR zones the surfers encountered the most during competitions are a useful insight to the physiological workloads surfers encounter. By using the age predicted maximal heart rate principle, the optimal cardiorespiratory training occurs in a zone lying between 70% ($137.9 \text{ b}\cdot\text{min}^{-1}$) and 85% ($167.5 \text{ b}\cdot\text{min}^{-1}$) of the maximal heart rate. The present study recorded a similar mean HR and a higher peak HR to the two previous studies of Meir et al., (1991) and Mendez-Villanueva and Bishop (2005a). The mean HR during the surf competitions was $140 \pm 11.6 \text{ b}\cdot\text{min}^{-1}$, whereas, Meir et al., (1991) recorded $135 \pm 6.9 \text{ b}\cdot\text{min}^{-1}$ during recreational surfing, and Mendez-Villanueva and Bishop (2005a) recorded $146 \pm 20 \text{ b}\cdot\text{min}^{-1}$ during simulated heat surfing. The peak HR reached during the events was

(mean) 190 ± 12 b.min⁻¹, whereas, Meir et al., (1991) recorded a peak HR of 171 ± 7 b.min⁻¹.

It should be noted that there were differences in the methodological procedures of testing the HR and number of subjects tested, therefore explaining differences in HR zones. Meir et al., (1991) recorded heart rates during recreational surfing over a 60 minute period, therefore the physiological and psychological demands would have been less due to no pressure on performance nor competition for the waves and number of waves they caught. The subjects used were recreational surfers that were simply catching waves without the competitive element of the current study, hints to the lower HR intensities. In addition, the heart rates were recorded at 15 second intervals on six subjects, hence should be considered as approximations only, since heart rate will fluctuate over any given 15 second interval. Mendez-Villanueva et al., (2005a) recorded HR continuously at five second intervals on only five subjects during simulated surfing heats. Simulated surfing heats are not the same as competitive surfing heats; therefore variations in performance pressures are highly likely to affect HR intensities. Differences in HR's from previous studies and the current one are also likely attributed to the intermittent nature of surfing and the variations of external factors such as wave height, conditions, environment and the fact that the present study recorded HR's at one second intervals.

The HR values from these studies suggest that periods of moderate intensity activity, soliciting mainly the aerobic system, are intercalated with bouts of high-intensity exercise demanding both aerobic and anaerobic metabolism. Furthermore, the HR values recorded met the American College of Sports Medicine training intensity criteria (55/65% to 90% of the maximum HR) for developing and maintaining cardio respiratory fitness in healthy adults (Pollock et al., 1998).

Conclusion

The results of this study show that surfing is an intermittent activity, during which surfers' workloads vary considerably. The majority of time, however, is spent performing moderate to high intensity activity which lies within optimal cardiorespiratory training zones

(Mendez-Villanueva & Bishop, 2005a; Wilmore & Costill, 2004). Surfers also cover considerable distances, approximately 1600 meters in a 20 minute heat, and can reach speeds up to 45 km/h, although approximately 80% of total time is spent at low speeds. The physiological demands imposed on each surfer and activity durations are subject to conditions.

Practical Applications

Our data provides practitioners with insights into the physiological profile of competitive surfing. We found competitive surfing to involve repeated measures of low intensity paddling, followed by intermittent high intensity bouts of all out paddling intercalated with relatively short recovery periods, combined with intermittent breath holding. Consequently, Figure ten presents a schematic of a proposed competition specific conditioning session for a surfing athlete. Such sessions should be underpinned by an ‘aerobic’ base, particularly given that we found at least 80% of HR intensities to be above 120 b.min⁻¹.

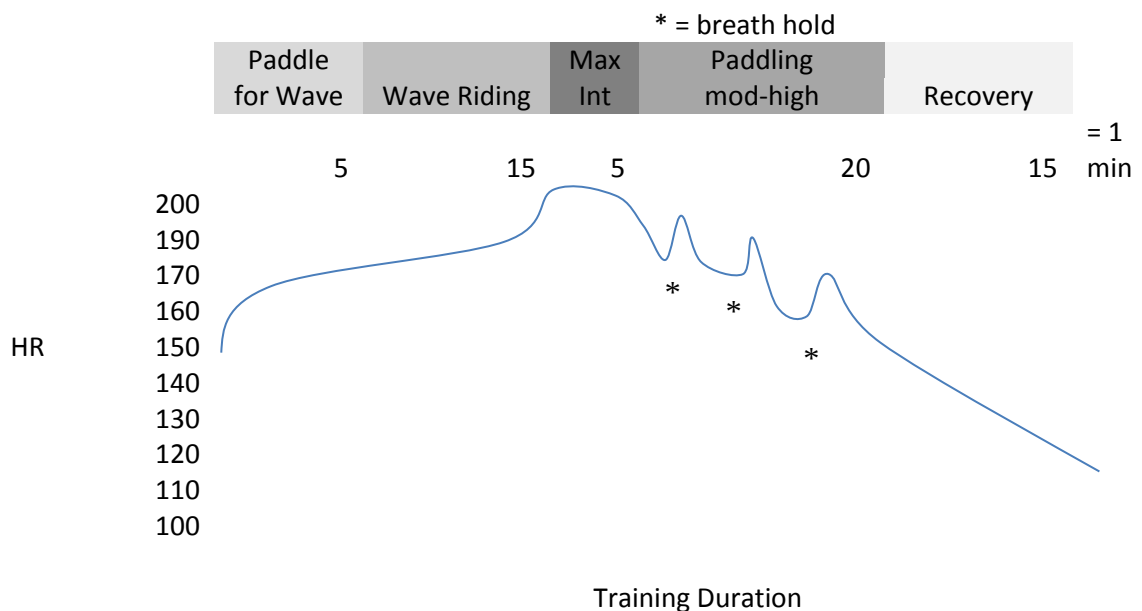


Figure 15: Intermittent training example.

The development of aerobic endurance could include paddling on the modified ergometer, and simulating surfing heats with repeated measures of low intensity paddling, short rest periods, followed by intermittent high intensity bouts of all out paddling. Recovery periods are short according to current data; therefore, development of energy systems is vital. Overload training should mimic the maximal paddling burst and short recovery periods. Training distances should also mimic the intermittent nature of surfing, therefore based around 1500 – 2500m as observed from distances covered in the competitions from the GPS tracking. Training should also include forms of cross training, such as cycling, running and swimming for periods of 20-40 minutes. The cross training should also include bouts of high intensity HR workloads (180-200BPM), to simulate sport specific aspects of surfing observed in the current data. Athletes should mimic base training distances, then periodise down with an increase in intensity.

The prescription for anaerobic power should detail the loading parameters specific to surfing competitions such as four second bursts, observed during paddling for waves. Power training should emphasize maximal power force production for greater propulsion in water as well as anaerobic endurance to withstand long durations of constant paddling.

Recommendations for future research should include further performance analysis of competitive surfing through GPS, HR and video analysis with the synchronization of video footage and GPS data, with an analysis of the effects of conditions on the performance variables. To enhance surf athletes training regimes and exercise prescription, longitudinal studies investigating the physiological responses and adaptations of surfing specific water based training, surfing specific gym based training, controlled with just surfing need to be implemented. Further recommendations would be to investigate the kinematics of surfboard paddling both in the laboratory via ergometry testing and in water testing, and investigating the physiological attributes of elite surfers with a surfing specific assessment battery.

CHAPTER 4: LITERATURE REVIEW

PHYSIOLOGICAL PROFILE OF SURFERS

Introduction

With the substantial growth in professional surfing worldwide there has been an increase in the attention given to the physical preparation of surfing athletes. Surfing is an activity characterized by intermittent exercise bouts of varying intensities, durations, and recovery periods, using both the upper and lower body (Lowdon & Pateman, 1980; Mendez-Villanueva & Bishop, 2005a). During a surfing session, surfers will experience various durations where they are paddling, remaining stationary, recovering, or waiting for a suitable wave to arrive. It has been purported that surfing requires a high aerobic fitness level, as the paddle out through the breaking waves to the take-off zone (where the ocean swell forms into a wave for the surfer to catch and ride) can require up to 10 minutes of strenuous work. In addition to this, repeated duck-diving requiring breath holding under advancing broken waves adds to the intensity of surfing (Loveless & Minahan, 2010a, 2010b; Lowdon, 1983; Lowdon et al., 1989; Lowdon & Pateman, 1980; Meir et al., 1991; Mendez-Villanueva & Bishop, 2005a; Mendez-Villanueva et al., 2006; Mendez-Villanueva et al., 2005b). Once the surfer has reached the take-off zone, durations of continuous paddling to the waves, against currents, and moving to different locations will ensue. These activities stress the aerobic and anaerobic energy systems, especially when repeatedly paddling to gain enough momentum to catch the forming/breaking wave. Physiological demands are of course subject to considerable variation in environmental conditions (Meir et al., 1991; Mendez-Villanueva et al., 2006). Figure 16 (based on Mendez-Villanueva and Bishop (2005a) presents a broad overview of the multi-factorial nature of surfing performance.

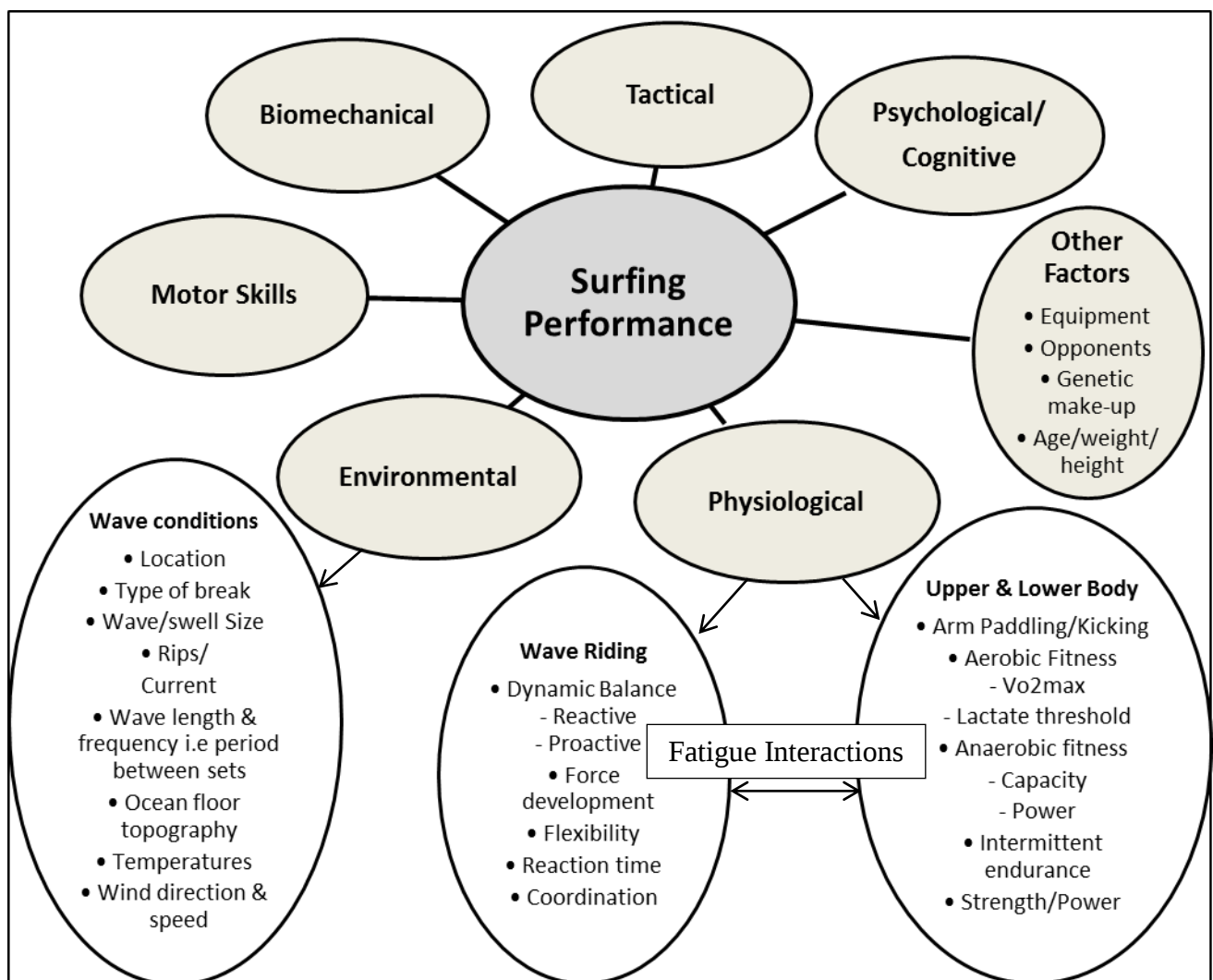


Figure 16: The variables that influence surfing performance.

(Based on Mendez-Villanueva & Bishop (2005a))

To date, research investigating surfers' aerobic and anaerobic fitness, although providing an initial insight into the physiological demands of surfing, is very limited in terms of competitive surfing and is characterized by methodological discrepancies. Therefore, this review first establishes the reliability of using swim-benches for assessing aerobic and anaerobic capacity of surfers. Subsequently it reviews the aerobic and anaerobic outputs of surfers on swim bench ergometers, and the interrelationships between these outputs. Due to the similarity between swimming and surf paddling performance, swimming research is also reviewed. Literature addressed within this review was established via searching Google Scholar, SPORTdiscus, PubMed, INFOtrieve and Scopus under the terms of surfing,

surfer's fitness, surfing performance, physiology of surfing, anaerobic output of surfers, and aerobic output of surfers. Content was limited from 1975 to present, in English.

Anaerobic power

Anaerobic power would seem to be an important determinant of surfing success, especially for catching the wave (Meir et al., 1991; Mendez-Villanueva et al., 2006). Lowdon (1983) described the surfing process as requiring up to 20 hard powerful strokes to position the board in the right location and gain the necessary momentum to catch the wave, providing theoretical support that anaerobic power is an important factor of the sport. While anaerobic power output has been thoroughly investigated in other upper-body water sports, such as swimming and kayaking (Mendez-Villanueva et al., 2005b), there is currently only one study investigating the anaerobic power output of surfers (Loveless & Minahan, 2010b). Due to the similarity of the surf paddle and the freestyle swimming stroke, in addition to the one surf specific study, we will also consider relevant swimming, board paddling and surf-lifesaving literature to further our understanding of surfing physiology.

The assessment of maximal-paddling performance could be important for monitoring improvements in surfing performance, and examining physiological adaptations to training (Loveless & Minahan, 2010b). One method of assessing maximal-intensity exercise is to measure the athlete's upper-body paddling power output. This method has been implemented in previous studies to examine power outputs of swimmers on a swim bench ergometer (Hawley & Williams, 1991; Johnston et al., 2004; Morton & Gastin, 1997; Potts, Charlton, & Smith, 2002; Rohrs, Mayhew, Arabas, & Shelton, 1990; Sharp, Troup, & Costill, 1982; Swaine, 2000). The swim bench ergometer has been used as an alternative to pool testing in the assessment of arm power. Recent developments in the design of the swim bench and improvements in technology have improved the sensitivity with which the external power output of an individual can be assessed (Konstantak & Swaine, 1999; Swaine, 2000; Swaine & Zanker, 1996). However, Loveless and Minahan (2010b) commented that due to the surfers' paddling technique involving hyperextension of the trunk and lack of hip drive, it is unknown if swim-bench ergometers can be used to assess maximal-paddling performance with similar reliability. Currently, the swim-bench

ergometers are the most sport-specific devices available for implementing surfboard paddling (Loveless & Minahan, 2010b). Therefore the following will review the literature on swim bench ergometers in terms of their reliability, relationships to surfing ergometer testing, training usage and recorded power outputs.

Reliability of power outputs from swim benches

The reliability of power outputs from swim bench ergometry has been reviewed by various authors (Loveless & Minahan, 2010b; Morton & Gastin, 1997; Swaine, 2000). Data from these studies suggests that dry-land ergometer power output testing on swimmers and surfers is reliable. Swaine (2000), investigated power outputs of the arm on 22 elite swimmers (23 ± 3.6 yrs). Ten seconds of all-out exercise at each of five resistance settings on a swim bench were performed with one hour rest in between to determine the maximal pull velocity. The following day a 30 second all-out test at the maximum pull velocity was implemented to determine power output. Peak and mean power output (PPO; MPO) were determined from regression analysis of the power vs. time relationship. The average PPO and MPO values from repeated 30 second tests were significantly related for arm-pulling (PPO, $r = 0.97$; $p = 0.01$ vs. MPO, $r = 0.96$; $p = 0.01$). The variation in PPO and MPO from repeated testing was 7.3% and 6.9% for arms, respectively. Therefore, Swaine (2000) suggested that the inter-subject variation in measurements of power output is small. In support, Morton and Gastin (1997) conducted a training study investigating board paddling, an event of Surf Lifesaving, and reported that the performance parameters' mean power and peak power were also highly reliable with test-retest correlations of 0.98 ($p \leq 0.01$) and 0.96 ($p \leq 0.01$), respectively. In a surf specific study, Loveless and Minahan (2010b) investigated anaerobic power outputs of surfers. The aim of the study was to assess the test-retest reliability of peak power output measured during maximal-intensity paddling on a swim-bench ergometer in competitive male surfers. The reliability of maximal-paddling performance in surfers was determined via peak power output measured in 11 male (17 ± 1 yr), state competitive junior surfers during six, 10-second, maximal-intensity paddling tests on a swim-bench ergometer (Vasa, Inc., Essex Junction, VT, USA). It was noted that peak power output did not change significantly ($p \leq 0.01$) across six 10-second maximal-intensity paddling trials and there was no change in the intraclass correlation coefficient when calculated for the first two trials ($r = 0.99$) compared with the value calculated for all

six trials ($r = 0.99$) (Loveless & Minahan, 2010b). Furthermore, it was established that peak power output could be determined reliably ($r = 0.98$) on separate days. Therefore, the implementations of swim-bench ergometers in studies to date indicate that they are reliable for use.

Relationship between ergometer outputs and swimming performance

The relationship between ergometer power and freestyle sprint swimming performance has been previously investigated by several studies (Johnston et al., 2004; Rohrs et al., 1990; Sharp et al., 1982). Specifically, both Sharp, Troup and Costil (1982) and Johnston Sproule, McMorris and Mail (2004) measured arm power at 1.60, 2.05, 2.66 and 3.28 m/s⁻¹ on the Biokinetic swim bench in groups of young competitive male and female swimmers. Power was calculated by dividing the work by the time of the pull, which was measured by determining the length of a force curve produced by a chart recorder. The swimming velocity was determined via timing three trials of 22.86 m sprints with five minute rests in-between tests and using each subject's fastest mean velocity in the data analysis. Sharp et al., (1982) reported the correlation coefficient between the 22.86 m and the arm power was 0.90, whereas Johnston et al., (2004) reported 0.74. Sharp et al., (1982) suggested that swim bench ergometers offer an objective way for testing arm power. The high correlation between arm power and swim velocity observed in Sharp et al., (1982) were also observed in Rohrs, Mayhew, Arabas and Shelton (1990), who implemented a 30 second maximal anaerobic power test on the Biokinetic swim bench (Isokinetics Incorporated) to determine maximal arm power in 13 males (20 ± 1 yrs). The subjects simulated swimming for 30 seconds as fast as possible using paddles. Test setting was level 3 (a speed setting typically used when training during the season) for males. Correlations between peak power output and swim velocities over 22.86m, 45.72m and 91.44m were 0.86 ($p \leq 0.01$), 0.89 ($p \leq 0.01$), and 0.88 ($P \leq 0.01$) respectively. In addition, Morton and Gatin (1997) reported that mean power correlated significantly with the 75m ($r = 0.74$, $p \leq 0.05$) and 140 m ($r = 0.79$, $p \leq 0.05$) time trials, indicating that in-water performance and Biokinetic swim bench ergometry are meaningfully related. Therefore, it can be proposed from the correlation findings (Johnston et al., 2004; Rohrs et al., 1990; Sharp et al., 1982), that studies incorporating swim-bench ergometry testing may also obtain reliable, high correlations with surf based research, such as paddling outputs.

Study	Power measure	Swim measure	Correlation
<i>Swimmers</i>			
Sharp et al., (1982)		22.86 m 1.81 (m/s)	r = 0.90*
		22.86 m 1.78 (m/s)	r = 0.86*
		45.72 m 1.69 (m/s)	r = 0.89*
Rohrs et al., (1990)	9.9 ± 1.1 (W/kg)	91.44 m 1.57 (m/s)	r = 0.88*
Johnson et al., (2004)	85 ± 23 W	22.86 m 2.04 (m/s)	r = 0.74**
<i>Surfers</i>			
Morton & Gastin, (1997)	221 ± 4.9 W	75 m	r = 0.74**
		140 m	r = 0.79**
Loveless & Minahan, (2010b)		10 second ergometer burst	r = 0.99*
* P ≤ 0.01			
** P ≤ 0.05			

Table 6: Relationship correlations of ergometers

Power output

It has been suggested that the upper-body peak power output of competitive swimmers and surf lifesavers is probably among the highest among water based sportspersons due to the physiological demands of the sports (Loveless & Minahan, 2010b). Indeed, the peak power output reported by (Loveless & Minahan, 2010b) on the swim-bench ergometer was 348 ± 78W which is higher than power outputs reported in competitive swimmers 304 ± 22 W (Swaine, 2000) and surf lifesavers 326 ± 29 W (Morton & Gastin, 1997) during front-crawl swimming or knee boarding paddling (surf lifesavers), respectively, on similar swim bench ergometers (Loveless & Minahan, 2010b).

Training

The use of a swim-bench ergometer has also featured during a training study. Morton and Gastin (1997) investigated upper-body anaerobic capacity training in board paddling, an event of Surf Lifesaving, which requires intense upper-body anaerobic training. Seven conditioned males (21 ± 1 yr) performed three high intensity training sessions per week for eight weeks, followed by ten days of reduced training. Six subjects, separate to those involved in the main study were involved in reliability testing. Subjects performed $\text{VO}_{2\text{peak}}$ and an all-out 60 second test for assessment of mean, peak and final power, and fatigue index on the Biokenetic swim-bench ergometer (Pacer 2A). For the analysis of the relationships between laboratory and in-water performance, pre and mid training and post taper time trials were paired with results from test 1, 3 and 5. The mean power correlated significantly with the 75m ($r = 0.74$, $p \leq 0.05$) and 140 m ($r = 0.79$, $p \leq 0.05$) time trials, indicating that in-water performance and Biokinetic swim-bench ergometry are well related (Morton & Gastin, 1997). Morton and Gastin (1997) also concluded that eight weeks of lactate tolerance board paddling training is effective for developing the anaerobic energy systems and improving in-water performance.

Surf specific study

To date, Loveless and Minahan (2010b) is the only study to record peak power output during maximal-intensity paddling on a swim-bench ergometer in competitive male surfers. Eleven male (17 ± 1 yr), state competitive junior surfers performed six 10-second maximal-intensity paddling tests on a swim-bench ergometer (Vasa, Inc., Essex Junction, VT, USA). Subjects performed a five-minute warm-up, 10-minute rest and three 10-second maximal-intensity paddling trials, separated by 10 minutes of rest. Subjects paddled maximally without knowing elapsed trial time before being told to stop, this prevented the surfer from slowing down prematurely (Loveless & Minahan, 2010b). The peak power output (W) was recorded from the digital display unit on the ergometer. Peak speed ($\text{m}\cdot\text{s}^{-1}$) was assessed using a custom-made speed probe (SP5000, Applied Motion Research, Gold Coast, Australia). The results from the study determined that peak power output did not change significantly ($p \leq 0.01$) across six 10-second maximal-intensity paddling trials.

Furthermore, the results suggest that the highest peak power output the group achieved was at the highest resistance setting. However, it was noted that the highest resistance setting available on the ergometer of 7 was used for all surfers in the study; therefore suggesting that perhaps if a higher resistance setting was available, it may have resulted in higher peak power outputs.

In conclusion, anaerobic power is an important factor of surfing, especially for catching the waves. However, the power output (W) of surfers has only recently been investigated, with one study to date suggesting that competitive surfers possess higher upper-body power outputs than competitive swimmers and surf life savers. Moreover, testing of surfers power outputs on ergometers does seem to be a reliable, valid method for recording anaerobic power. However, the limited studies confine our ability to draw clear conclusions.

Aerobic fitness

Aerobic fitness is required during the long and intermittent paddling bouts encountered during surfing. According to Lowdon and Pateman (1980) and Lowdon (1983), surfers require muscular endurance, power of the upper torso and excellent cardio-respiratory endurance (when paddling to reach the take-off zone), and recovery. Predominantly the research in this field has been conducted in by Lowdon and associates (Lowdon et al., 1989; Lowdon et al., 1990; Lowdon & Pateman, 1980).

The earliest study to investigate the maximum oxygen uptake (VO_{2max}) of surfers was conducted by Lowdon and Pateman (1980). Cardiovascular fitness of 76 male (22.2 ± 3.2 yrs) and 14 female (21.6 ± 3.4 yrs) competitive surfers was assessed by estimation using the Astrand-Ryhming nomogram on a bicycle ergometer; the results were then adjusted to the treadmill equivalent. Workloads required subjects to work at a heart rate of approximately 150 beats per minute. During the testing, 60 males were tested at 1200 kpm (11.77J), 13 at 1400 kpm (13.73J) and two at 900 kpm (8.87J) to give an estimated mean maximum ventilation of oxygen (VO_{2max}) of 70.2 ± 10.7 mL/kg/min (Lowdon & Pateman, 1980). Ten female surfers were tested at 1000 kpm (9.81J) and two at 700 kpm (6.87J) to give an estimated max VO_2 of (mean) 62.2 mL/kg/min. The average scores of 70 and 62 mL/kg/min of men and women respectively, suggest that the surfers' aerobic fitness levels compare well to other athletic groups, such as Nordic skiers and distance runners (Lowdon & Pateman, 1980) (See Table 2). Furthermore the recovery heart rates, measured five minutes after a submaximal bicycle ergometry test, were 77 beats.min⁻¹ in men, and 76 beats.min⁻¹ in women, which betters Olympic pentathletes (Lowdon, 1983). However, some caution in data interpretation from this study should be applied since VO_{2max} was not measured directly. Furthermore, it is arguably more appropriate to assess the sport-specific VO_{2peak} ; that is, using movement and muscle recruitment patterns that are similar to the actual sport.

Sport	Age (yrs)	VO_{2max} (mL/kg/min)	VO_{2max} (mL/kg/min)
		Males	Females
Surfers	19-30	40-70	62
Runners (middle and long distance)		72	60
Nordic Skiers	20-28	65-95	60-75
Rowing	20-35	60-72	58-65
Swimmers	10-25	50-70	40-60
U.S.A College Students		46	44
Soccer	22-28	54-64	50-60
Bicycling	18-26	62-74	47-57
Football	20-36	42-60	

Table 7: VO_{2max} of sports persons and students (mL/kg.min)

(Adapted from Lowdon, (1983);Wilmore & Costill (2004)

Since the early work of Lowdon and Pateman (1980), other studies have adopted more appropriate methodologies to quantify the aerobic fitness of surfers. For example, Lowdon Bedi and Horvath (1989) assessed 12 male competitive college surfers (20.7 ± 1.2 yrs) during three different laboratory tests (tethered board paddling (BP), prone hand cranking (HC) and (TR) treadmill running), to determine the most suitable test to measure aerobic power in surfers. Each subject completed the three maximal tests (BP, HC, TR) doing continuous incremental work tasks to exhaustion, administered in a random order. At least one week elapsed between tests or tests were repeated until the maximal criteria of levelling off of oxygen uptake (± 2 mL/kg/min), or declining oxygen uptake between 30 second intervals was attained. Subjects' metabolic parameters were obtained with the subject breathing through a Hans-Rudolf valve. Oxygen, CO₂ and minute ventilation were sampled at 100 Hz by IBM computer. Reported VO_{2peak} values were 2.87 ± 0.04 L/min (40.4 ± 2.9 mL/kg/min) and 2.95 ± 0.38 L/min (41.6 ± 4.0 mL/kg/min) for tethered board paddling and prone arm cranking, respectively (Lowdon et al., 1989). Similarly, Meir et al., (1991) investigated the peak oxygen consumption of six (21 ± 2.8 yrs) recreational surfers during graded prone arm paddling using a Repco swim bench ergometer. Incremental workloads starting at 25 W and increasing by a further 25 W each minute until maximal voluntary exhaustion were used. A closed circuit computerized gas analysis system integrated with an IBM AT computer analysed subjects data at 15 second intervals. Higher VO_{2peak} mean

values than those of Lowdon et al., (1989) (3.75 ± 0.83 L/min (54.20 ± 10.2 mL/kg/min) were reported.

Mendez-Villanueva et al., (2005b) assessed 13 (25.6 ± 3.4 yrs, European) (26.5 ± 3.6 yrs, Regional) competitive male surfers via a continuous incremental dry-land board paddling test to determine specific peak aerobic uptake (VO_{2peak}), peak power output (W_{peak}), and blood lactate. Surfers were ranked according to their competitive season performance and divided into two groups based on their performance level. The ergometer used was a modified kayak bench that had a surfboard fitted and fixed at the rails. This allowed subjects to adopt a prone position and simulate a surfboard arm paddling exercise by pulling alternately on the hand paddles (Mendez-Villanueva et al., 2005b). The continuous incremental test consisted of four 3-minute stages at 30, 45, 60 and 75 W. After the fourth workload, subjects performed a maximal effort to volitional exhaustion, which always occurred within two minutes. VO_{2peak} was determined to be the highest VO_2 measured during 30 seconds. Peak aerobic power output (W_{peak}) was defined as the highest power output achieved. Expired air was continuously measured breath-by-breath with a Vmax 29 gas analyser (SensorMedics, Yorba Linda, CA, USA) (Mendez-Villanueva et al., 2005b). Peak oxygen uptake was reported as 3.34 ± 0.31 L/min (50.0 ± 4.7 mL/kg/min) and 3.40 ± 0.37 L/min (47.93 ± 6.28 mL/kg/min) for the group of European level and regional level competitive surfers, respectively. Furthermore, peak aerobic power (W_{peak}) was significantly higher in European level than in regional level surfers (154.7 ± 36.8 W vs. 117.7 ± 27.1 W; $p = 0.04$).

In an unpublished observation (Mendez-Villanueva & Bishop, 2005a), five male competitive surfers performed a laboratory maximal arm paddling test on a modified kayak ergometer to determinate VO_{2peak} and HR peak. The group's mean ($\pm$ standard deviation) VO_{2peak} and HR peak values for the arm paddling test were 3.52 ± 0.38 L/min and 174 ± 9 b.min⁻¹, respectively. It was suggested that the high aerobic fitness values reported in surfers may be the outcome of a training effect resulting from surfing practice, based on previous reports on VO_{2peak} values and time-motion analysis.

Most recently, Loveless and Minahan (2010a) measured and compared peak oxygen uptake and paddling efficiency in recreational and competitive junior male surfers on a swim-

bench ergometer (Vasa, Inc., Essex Junction, VT, USA). Eight male recreational surfers (18 ± 2 yrs) and eight male competitive surfers (18 ± 1 yr) performed an incremental paddling test consisting of four 3-minute constant load work stages followed by a ramp increase in power output of $20\text{W} \cdot 30\text{ s}^{-1}$ until exhaustion (Loveless & Minahan, 2010a). The incremental test was conducted on day three, with day one used for familiarization and day two used for determining paddling power output via 10 second burst. This data was used in calculating the predetermined power outputs for the four stages of the incremental paddling test. The oxygen uptake-power output relationship of the four constant load work stages and peak values obtained during the incremental paddling test were used to calculate paddling efficiency (Loveless & Minahan, 2010a). No significant differences were observed between the recreational and competitive surfers for peak oxygen uptake, with the surfer's mean $\text{VO}_{2\text{peak}}$ and HR peak values for the arm paddling test (Competitive) $2.66 \pm 0.35\text{ L/min}$ ($39.5 \pm 3.1\text{ mL/kg/min}$) $188 \pm 7\text{ b}\cdot\text{min}^{-1}$, and (Recreational) $2.52 \pm 0.5\text{ L/min}$ ($37.8 \pm 4.5\text{ mL/kg/min}$) $194 \pm 5\text{ b}\cdot\text{min}^{-1}$, respectively. In addition, the incremental peak power output (W) were similar; $199 \pm 45\text{ (W)}$, and $199 \pm 24\text{ (W)}$ ($p = 0.97$), for competitive and recreational surfers respectively. The peak power recorded however is far higher than that reported by Mendez-Villanueva et al., (2005b). Loveless and Minahan (2010a) suggested that peak oxygen uptake and efficiency are not sensitive to differences in surfing ability, owing mainly to no differences recorded in peak oxygen uptake or paddling efficiency between recreational and competitive surfers.

Table 8 (adapted from Mendez-Villanueva & Bishop 2005a) presents comparisons between the reviewed studies.

Study	No. of subjects	Age (y) (mean $\pm$ SD)	Subjects	Testing mode (body position)	Vo2max (L/min)	Vo2peak (mL/kg/min)	HR max (b.min ⁻¹)	Peak Power output (W)
Non-surfers								
Morton and Gatin, (1997)	7	21.0 $\pm$ 1.0	Surf lifesavers	Swim bench (prone)	2.94 $\pm$ 0.14	40.4		
Non prone surf testing								
Lowden and Pateman, (1980)	76	22.2 $\pm$ 3.2	International surfers	Bicycle ergometer	4.73 $\pm$ 0.81	70.2 $\pm$ 10.7	148 $\pm$ 12	
Lowdon, Bedi and Horvath, (1989)	12	20.7 $\pm$ 1.2	College surfers	Treadmill Running	4.02 $\pm$ 0.44	56.3 $\pm$ 3.9	191 $\pm$ 6	
Surf specific prone testing								
Lowdon, Bedi and Horvath, (1989)	12	20.7 $\pm$ 1.2	College surfers	Tethered board paddling (prone)	2.87 $\pm$ 0.04	40.4 $\pm$ 2.9	178 $\pm$ 9	
Lowdon, Bedi and Horvath, (1989)	12	20.7 $\pm$ 1.2	College surfers	Hand cranking (prone)	2.95 $\pm$ 0.38	41.6 $\pm$ 4	177 $\pm$ 7	
Meir, Lowdon, and Davie, (1991)	6	21.2 $\pm$ 2.8	Recreational surfers	Swim bench (prone)	3.75 $\pm$ 0.83	54.2 $\pm$ 10.2	180 $\pm$ 6	

Mendez-Villanueva, Perez-Landaluce, Bishop, Fernandez-Garcia, Ortolano, Leibar & Terrandos, (2005)	7	25.6 ± 3.4	Competitive surfers (European level)	Arm paddling (prone) modified kayak ergometer	3.34±0.31	50.0 ± 4.7	176 ±13	154 ± 37
Mendez-Villanueva, Perez-Landaluce, Bishop, Fernandez-Garcia, Ortolano, Leibar & Terrandos, (2005)	6	26.5 ± 3.6	Competitive surfers (Regional level)	Arm paddling (prone) modified kayak ergometer	3.40±0.37	47.9 ± 6.3	183 ±13	118 ± 27
Unpublished observation by Mendez-Villanueva et al (2005 cited in Mendez-Villanueva & Bishop, 2005)	5	N/A	Competitive surfers	Arm paddling (prone)	3.52±0.38		174 ± 9	
Loveless & Minaham, (2010a)	8	18 ± 1	Competitive Australian junior surfers	Swim bench ergometer	2.66±0.35	39.5 ± 3.1	188 ± 7	199 ± 45
Loveless & Minaham, (2010a)	8	18 ± 2	Recreational surfers	Swim bench ergometer	2.52±0.50	37.8 ± 4.5	194 ± 5	199 ± 24

Table 8: Comparison of previous studies implementing VO_{2peak} with male surfers.

(Adapted from (Mendez-Villanueva & Bishop, 2005a))

It has conceivable that the differences in the $\text{VO}_{2\text{peak}}$ values reported (Loveless & Minahan, 2010a; Lowdon et al., 1989; Lowdon & Pateman, 1980; Meir et al., 1991; Mendez-Villanueva & Bishop, 2005a; Mendez-Villanueva et al., 2005b) are due to method differences such as testing protocol, subject characteristics, and equipment used. Furthermore, the differences in muscle recruitment caused by adopted body position during ergometer exercise has been reported to alter the haemodynamic and performance parameters during exercise (Mendez-Villanueva & Bishop, 2005a). Therefore, the $\text{VO}_{2\text{peak}}$ values obtained during arm and leg exercise have been found to be consistently lower in the horizontal posture (prone or supine) than in the erect (sitting or upright) posture (Mendez-Villanueva & Bishop, 2005a). However, Mendez-Villanueva and Bishop (2005a) indicated that despite the surfers adopting the prone position, the $\text{VO}_{2\text{peak}}$ results (3.26 L/min) are 20% higher when compared with an active young male population tested with seated arm ergometry (2.57 L/min). Therefore, current literature suggests that surfers possess a high level of aerobic fitness.

Summary

To date, research evidence indicates that surfers possess moderately high aerobic fitness levels, comparable to other athletic groups such as competitive swimmers (Swaine, 2000) and surf life savers (Morton & Gastin, 1997). Likewise, anaerobic power, an important factor of the sport that has only recently been investigated, is higher in competitive surfers than competitive swimmers and surf life savers.

Beyond describing surfers' physiological profiles, there is a limited amount of research into the physiological factors which might influence surfing performance. Research that has investigated surfers' aerobic and anaerobic fitness has been typified by a variety of methodological approaches, confounding our ability to draw clear conclusions that can inform strength and conditioning practice. With the emphasis on aerobic and anaerobic endurance required for surfing and such a large gap in surfing literature, new and innovative research needs to be conducted to expand our knowledge of physical factors

determining surfing performance. Findings from current literature suggest that competitive surfers should utilise training practices that develop aerobic and anaerobic performance. Furthermore, with developments in technology, ergometers used as an alternative to pool testing in the assessment of fitness outputs are considered to be a reliable testing method. Therefore, information on the aspects associated with surfing can lead to the developments in surf specific training programs, and implementation of specific on and off-water workouts. Physical training can be designed to help surfers enhance muscular power and endurance, as well as cardiovascular fitness to reduce fatigue related errors in the surfer's performance, and withstand competition demands.

Initial investigation determined research investigating surfers' aerobic and anaerobic fitness, provides an initial insight into the physiological demands of surfing, is limited in terms of competitive surfing and is characterized by methodological discrepancies. To date, literature suggests that surfers possess moderately high aerobic fitness levels and recently, anaerobic power too. However to our knowledge no study has reported the relationship between anaerobic power and surfing performance. Therefore, the following investigation will provide further insights into the anaerobic and aerobic outputs of competitive surfers.

CHAPTER 5: ANAEROBIC POWER AND AEROBIC FITNESS PROFILING OF COMPETITIVE SURFERS

Introduction

With the growth in competitive surfing internationally, there has been an increase in attention given to the conditioning of competitive surfing athletes. Specifically, surfers' peak oxygen uptake ($\text{VO}_{2\text{peak}}$) has been quantified using a variety of protocols and testing methods, with a range of values observed (Table 9).

Study	Subjects	Testing mode	VO _{2peak} (mL/kg/min)	Peak aerobic power (W)
<i>Recreational surfers</i>				
Loveless & Minaham, (2010a)	(n=8; 18 ± 2 yrs)	Swim bench ergometer	37.8 ± 4.5	199 ± 24
Meir et al. (1991)	(n=6; 21.2 ± 2.8 yrs)	Swim bench	54.2 ± 10.2	
<i>Competitive surfers</i>				
Loveless & Minaham, (2010a)	Australian juniors (n=8; 18 ± 1 yrs)	Swim bench ergometer	39.5 ± 3.1	199 ± 45
Lowdon et al., (1989)	Competitive College (n=12; 20.7 ± 1.2 yrs)	Tethered board paddling	40.4 ± 2.9	
		Hand cranking	41.6 ± 4.0	
Mendez-Villanueva et al., (2005)	European level (n=7; 25.6 ± 3.4 yrs)	Modified kayak ergometer arm paddling	50.0 ± 4.7	154 ± 37
	Regional level (n=6; 26.5 ± 3.6 yrs)		47.9 ± 6.3	118 ± 27
<i>Mean Total</i>			44.5 ± 6.2	167 ± 39

Table 9. Comparison of studies reporting $\text{VO}_{2\text{peak}}$ and peak aerobic power of male surfers.

Surfing is an intermittent, high performance sport requiring the athlete to perform multiple endurance paddling bouts and explosive paddling bursts to catch the wave. During a session athletes are required to paddle out through the breaking waves to the take-off zone (where

the ocean swell forms into a wave for the surfer to catch and ride) which can require up to 10 minutes of strenuous work. In addition to this, repeated duck-diving requiring breath holding under advancing broken waves adds to the intensity of surfing (Loveless & Minahan, 2010a, 2010b; Lowdon, 1983; Lowdon et al., 1989; Lowdon & Pateman, 1980; Meir et al., 1991; Mendez-Villanueva & Bishop, 2005a; Mendez-Villanueva et al., 2006; Mendez-Villanueva et al., 2005b). Once the surfer has reached the take-off zone, durations of continuous paddling to the waves, against currents, and moving to different locations will ensue. These activities stress the aerobic and anaerobic energy systems, especially when repeatedly paddling to gain enough momentum to catch the forming/breaking wave. Therefore, it has been proposed that surf athletes require muscular endurance, power of the upper torso and excellent cardio-respiratory endurance and recovery abilities (Lowdon, 1983). Surf athletes' aerobic endurance measures via peak oxygen uptake (VO_{2peak}) have been quantified using a variety of protocols and testing methods (Swim bench ergometry (Loveless & Minahan, 2010a; Meir et al., 1991), Tethered board paddling and Hand cranking (Lowdon et al., 1989), and modified kayak ergometer arm paddling (Mendez-Villanueva et al., 2005b) with a range of values observed (Recreational; 37.8 ± 4.5 ml/kg/min (Loveless & Minahan, 2010a), 54.2 ± 10.2 ml/kg/min (Meir et al., 1991), (Competitive; 39.5 ± 3.1 ml/kg/min (Loveless & Minahan, 2010a), 40.4 ± 2.9 ml/kg/min and 41.6 ± 4.0 ml/kg/min (Lowdon et al., 1989), 47.9 ± 6.3 ml/kg/min and 50.0 ± 4.7 ml/kg/min (Mendez-Villanueva et al., 2005b). To date, only two studies (Loveless & Minahan, 2010a; Mendez-Villanueva et al., 2005b) have investigated the relationship between VO_{2peak} levels and surfing performance, both reporting that no significant relationship exists.

In addition to aerobic power, surf competitions demand a high anaerobic power when producing powerful strokes to position the board in the right location and gain enough momentum to catch waves (Lowdon, 1983; Meir et al., 1991; Mendez-Villanueva et al., 2006). Anaerobic power has been assessed during maximal-intensity exercise using a swim bench ergometer on a variety of athlete populations (Hawley & Williams, 1991; Johnson, Sharp, & Hedrick, 1993; Loveless & Minahan, 2010a; Morton & Gastin, 1997; Potts et al., 2002; Rohrs et al., 1990; Sharp et al., 1982; Swaine, 2000). Literature on the use of

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ergometers to test swimmers, and surfers' anaerobic power has established their reliability (Loveless & Minahan, 2010b; Morton & Gastin, 1997; Swaine, 2000). Importantly, studies have also shown high correlations between swimming performance and power outputs obtained from swim bench ergometry testing (Johnson et al., 1993; Loveless & Minahan, 2010b; Morton & Gastin, 1997; Rohrs et al., 1990; Sharp et al., 1982), supporting the theory that swim bench power output is a potentially useful indicator of performance. However, only one study to date (Loveless & Minahan, 2010b) measured the power output of surfers using maximal-intensity paddling on a swim bench ergometer. Higher upper-body power outputs ($348 \pm 78\text{W}$) than other athletes, such as competitive swimmers (Swaine, 2000) and surf lifesavers (Morton & Gastin, 1997) ($304 \pm 22\text{ W}$ and $326 \pm 29\text{ W}$, respectively), were reported suggesting that surfers possess comparatively high upper-body power outputs (Loveless & Minahan, 2010b). Therefore, conceivably upper-body anaerobic fitness may be of importance to surfing competitors, however to our knowledge no study has reported the relationship between anaerobic power and surfing performance. Therefore, the purpose of this study was to firstly quantify the anaerobic and aerobic power characteristics of competitive surf athletes using a customized surf-paddle specific ergometer, and thereafter determine the interrelationships between anaerobic power, aerobic capacity, and competitive surfing performance.

METHODS

Experimental Approach to the Problem

The aerobic capacity and anaerobic power of nationally ranked surf athletes was determined over multiple testing occasions using a customized surf-paddle specific ergometer. Thereafter, the interrelationships between these components of physical performance and surfing performance, as assessed by season rank, were determined using correlation analysis.

Participants

Eight male (20.4 ± 6.6 yrs, 71.1 ± 11.2 kg, 181.4 ± 7.8 cm) national-level surfers volunteered to participate in an incremental $\text{VO}_{2\text{peak}}$ test and 20 male (23.3 ± 5.6 yrs, 72.8 ± 8.8 kg, 179.4 ± 6.8 cm) participated in a power test. The subjects who had a history of surfing at least three times per week and have competed for at least three years were tested during the final two events of the competitive season and the conclusion of the season. All subjects were from the current top 35 ranked surfers in New Zealand and competing in the sanctioned New Zealand Surf Association competition. Subjects were tested following their normal routine of sleep, nutritional and hydration levels prior to testing. Ethics approval from the AUT University Ethics Committee was gained prior to commencement of the study and written informed consent was obtained from each subject prior to commencing data collection.

Equipment

A Dansprint kayak ergometer (Dansprint ApS, Denmark) was modified with a surfboard and hand paddles, similar to that of Mendez-Villanueva et al., (2005b) with subjects lying prone on a six foot (1.8m) by 0.48m surfboard in an attempt to simulate a surfing-specific paddling action. Two 125mm wide and 210mm long hydro swim paddles with heavy duty

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Velcro straps held the subjects hands in place. The pulley cable ropes were attached to the middle of the Velcro straps (See figure 17 and 18).



Figure 17. Modified ergometer set up.



Figure 18. Subject performing VO_{2peak} on the modified ergometer.

The ergometer was raised by 300mm to ensure that none of the subjects touched the ground with the hand paddles. Additionally, the front of the ergometer was raised to 400mm to simulate how the board would lie in the water when paddling (as the weight of the surfer weighs down the rear end of the board). Furthermore, this reduced the amount of lumbar hyperextension needed to paddle hence was perceived as a more comfortable and natural paddle position. At the end of the ergometer, a board was attached for foot support. Raw data from the ergometer was exported into Microsoft Excel 2010 (© 2010 Microsoft Corporation) for subsequent analysis.

For $\text{VO}_{2\text{peak}}$ assessments, a mixing-chamber metabolic analyser was used (Metalyzer II, Cortex, Biophysik, Leipzig, Germany). The O_2 and CO_2 gas concentration analysers and low-resistance turbine were calibrated prior to each test with alpha gases and air of known composition and volume respectively. Subjects also wore a heart rate (HR) monitor (Polar T31, Polar Electro Oy, Kempele, Finland) fastened around the Sternum and T7-T9 Thoracic Vertebra, transmitting HR (5 sec intervals) wirelessly to the short-range telemetry receiver (Polar 4000 Sport Tester, Polar Electro, Kempele, Finland) attached to the Metalyzer.

Procedures

All physical data was collected in a temperature controlled (21° c) laboratory during and after specific sanctioned surf competitions. Specifically, the anaerobic power data was collected during two surf competitions (2 weeks apart). The $\text{VO}_{2\text{peak}}$ was collected two weeks after the conclusion of the competitive season. The dependent variable, surfing performance, was based on official season ranking from accumulated competition points.

Anaerobic power output testing

Subjects were first familiarized with all equipment and procedures within the testing sessions. After a standardized warm up (three minutes of light-intensity 30 W continuous

paddling combined with three 5-second maximal-intensity paddling efforts performed every min separated by a 20-s rest) followed by a 10-min rest, a countdown to start subjects was given to perform a 10 second maximal intensity effort. Mean and peak power outputs (W) per stroke were calculated via the Dansprint kayak ergometer software. The ergometer flywheel was set to the highest resistance setting of 10 in an attempt to simulate water resistance (Loveless & Minahan, 2010b).

Aerobic VO_{2peak} uptake testing

Subjects performed a standardized warm-up paddle (1 min incremental paddles starting at 20W) of five minutes, followed by two minutes rest prior to initiating the test protocol. The flywheel was set at the lowest resistance level (1 out of 10) to avoid accelerated local muscular fatigue. Subjects then performed an incremental ramp test starting at 20W during which power was increased by 5W every minute until volitional exhaustion. Subjects were required to stay within ± 5 W of the target power output throughout the test. Testing was terminated once subjects were no longer able to keep within the target wattage within a five second window. Ventilation and expired gases were analysed by the metabolic analyser throughout the test. After completion, oxygen uptake (VO_2) values were averaged over 30 seconds intervals with peak oxygen uptake (VO_{2peak}) taken as the highest 30-second VO_2 value.

Data Analysis

Variables of interest recorded for subsequent analysis from the anaerobic power output test were:

- Anaerobic peak power; the maximal power output (W) recorded during 10 second paddle

Variables of interest recorded for subsequent analysis from VO_{2peak} uptake testing were:

- Aerobic peak power (W)
- Peak oxygen uptake (VO_{2peak})

Statistics

Descriptive statistics throughout are presented as means and standard deviations to represent centrality and spread of data. Pearson's correlation coefficients were used to determine the interrelationships between variables of interest. Statistical significance was defined as $P \leq 0.05$. Reliability of repeated measures of the anaerobic peak power assessment was determined with intra-class coefficients (ICC). SPSS program was used for statistical analysis.

RESULTS

Table 10 displays the descriptive data (mean $\pm$ SD) of anaerobic and aerobic VO_{2peak} testing results. The ICC for three repeated anaerobic power tests was 0.97.

Measure	Mean	$\pm$	SD
<i>Aerobic VO_{2peak} test</i>			
VO_{2peak} (L/min)	3.06	$\pm$	0.32
VO_{2peak} (mL/kg/min)	44	$\pm$	8.26
Minute ventilation (L/min)	114.5	$\pm$	16.8
Respiratory exchange ratio (RER)	1.08	$\pm$	0.03
Peak Heart rate (b.min ⁻¹)	190	$\pm$	11.8
Peak aerobic power (W)	158	$\pm$	20.7
Total distance (m)	1897	$\pm$	407
Total duration (min:sec)	12:09	$\pm$	2:02
<i>Anaerobic 10s test</i>			
Absolute Peak anaerobic power (W)	205	$\pm$	54.2
Mean anaerobic power (W)	81	$\pm$	30.1
Relative anaerobic power (W/kg)	2.83	$\pm$	0.66
Peak anaerobic speed (km/h)	13.5	$\pm$	1.1

Table 10: Aerobic and anaerobic measures determined from incremental and all-out surf paddling kayak ergometer testing.

	Rank	VO _{2peak} (mL/kg/min)	VO _{2peak} (L/min)	Peak Aerobic Power (W)	Relative Anaerobic Power (W/kg)	Absolute Anaerobic Power (W)	Mean Anaerobic Power (W)
Rank	1.00						
VO _{2peak} (mL/kg/min)	-0.02	1.00					
VO _{2peak} (L/min)	-0.17	0.78*	1.00				
Peak Aerobic Power (W)	-0.26	-0.03	0.51	1.00			
Relative Anaerobic Power (W/kg)	-0.50*	0.47	0.69	0.61	1.00		
Absolute Anaerobic Power (W)	-0.55*	-0.05	0.47	0.87*	0.90**	1.00	
Mean Anaerobic Power (W)	-0.57**	0.09	0.41	0.68	0.71**	0.86**	1.00

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

**. Correlation is significant at the 0.01 level (2-tailed).

Table 11. Intercorrelation matrix between aerobic and anaerobic outputs and season rank.

Table 11 presents the intercorrelation matrix between aerobic and anaerobic outputs and season rank. Rank obtained during the time of testing in competitive season significantly correlated with relative anaerobic peak power W/kg ($r = -0.50$, $p = 0.02$), absolute anaerobic peak power ($r = 0.55$, $p = 0.01$) and mean anaerobic power ($r = -0.57$, $p = 0.01$). There were no significant correlations between any of the other measured variables and season rank. There were significant intercorrelations between absolute anaerobic power and peak aerobic power, and the aerobic VO_{2peak} values ($r = 0.87$; $p = 0.03$; $n = 6$) ($r = 0.78$; $p = 0.02$), respectively. Figure 19 shows the relationship between the absolute peak anaerobic power output ($n = 20$) and season ranking. Relative anaerobic peak power W/kg is based on absolute peak anaerobic power

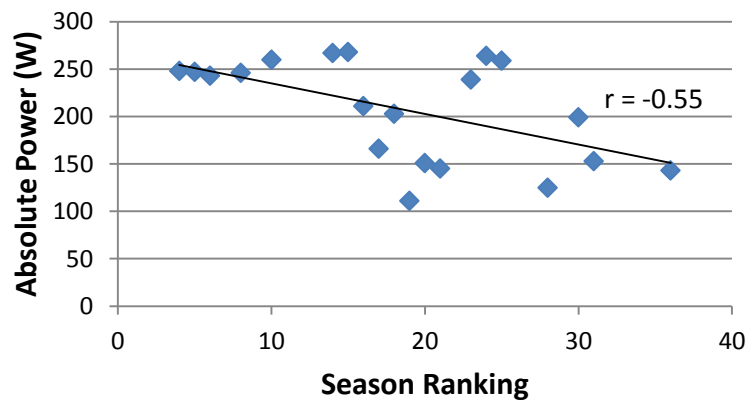


Figure 19. Relationship between surfers’ absolute anaerobic peak power output obtained during a 10 sec all-out effort and season ranking at time of assessment.

DISCUSSION

Surfers frequently implement a burst of maximal intensity paddling for several seconds to catch waves, and a high intensity paddle when paddling out through breaking waves (Lowdon, 1983; Lowdon & Pateman, 1980; Meir et al., 1991; Mendez-Villanueva & Bishop, 2005a; Mendez-Villanueva et al., 2006). Hence, the ability to produce power is conceivably important for competitive surfing athletes. The peak anaerobic power output achieved on the modified ergometer during the current study was 205 ± 54 W, lower than those recorded for maximal-paddling performance in other studies (Loveless & Minahan, 2010b; Swaine, 2000). However, we used a modified kayak ergometer rather than a swim bench ergometer adopted previously (Loveless & Minahan, 2010b; Swaine, 2000), thus possibly explaining the discrepancy. A novel finding from the current study was the significant relationship between surfers season ranking and anaerobic peak power output ($r = -0.50$, $p = 0.02$). Although we acknowledge that correlations do not imply cause and effect, and that the magnitude of the relationship is only moderate (although significant), it could be speculated that higher anaerobic power outputs allow more accomplished surfing athletes to catch some waves that their lower ranked counterparts might miss and therefore score higher. Such a finding provides theoretical support for the importance of anaerobic paddling power in assessment batteries and conditioning practice for surf athletes.

The $\text{VO}_{2\text{peak}}$ values observed in the present study (44.0 ± 8.26 ml/kg/min) were similar to those reported in previous surfing studies (2010a; Lowdon et al., 1989; 1991; Mendez-Villanueva et al., 2005b), and comparable to other upper-body athletic populations measured in the prone position such as swimmers (50-70 ml/kg/min) (Kimura, Yeater, & Martin, 1990) and surf-life savers (40 ml/kg/min) (Morton & Gastin, 1997). Given that aerobic fitness is considered a fundamental aspect of the sport (Lowdon, 1983; Lowdon & Pateman, 1980; Mendez-Villanueva & Bishop, 2005a; 2005b), it was interesting that there was no significant correlation between the surfers' season ranking and relative $\text{VO}_{2\text{peak}}$ values ($r = -0.02$, $p = 0.97$). While it is possible that low n size confounded the statistical power, our findings are supported by other previous studies utilizing similar sample sizes (2010a; Lowdon et al., 1989; 1991; Mendez-Villanueva et al., 2005b).

In the present study, the peak aerobic power (W) achieved during the incremental ramp test was 158 ± 21 W, similar to those reported by Mendez-Villanueva et al., (2005b) (155 ± 37 W) using similar protocols. In comparison, Loveless and Minahan (2010a) reported 199 ± 24 W and 199 ± 44 W for competitive and recreational surfers, respectively. The difference (20.6 %) between the findings of the present study and those of Loveless and Minahan (2010a) may be owing to differences in test protocols such as the increments used, equipment, and level of subjects' training experience. We found no significant correlation between peak aerobic power and season rank ($r = -0.26$, $p = 0.54$) suggesting that peak aerobic power is not a determinant of performance. In support, Loveless and Minahan (2010a) noted that peak aerobic power output did not differentiate between competitive and recreational surfers ($t = 0.035$, $P = 0.97$). However, Mendez-Villanueva et al. (2005b) reported that season rank significantly correlated with peak aerobic power output achieved during arm paddling ($r = -0.67$, $p = 0.01$). This could be owing to the difference in ramp protocol, or may be associated with subjects being able to generate energy anaerobically at the later stages of the test, or having improved exercise efficiency (Loveless & Minahan, 2010a). Mendez-Villanueva et al., (2005b) did not report anaerobic peak power so it is difficult to speculate on the influence of that on incremental peak aerobic power. Finally, we observed a significant correlation of ($r = 0.87$; $p = 0.03$; $n = 6$) between peak anaerobic power and peak aerobic power. Thus strength and conditioning practitioners might find it

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expedient to test only aerobic power (incorporating the anaerobic power) given that the anaerobic test does not provide prognostic and diagnostic information of unique value. Although we acknowledge that correlations do not imply cause and effect, it does provide further theoretical support for the importance of paddling power.

Peak and mean anaerobic power can be quantified reliably in the laboratory using a surf-paddling specific ergometry to provide practitioners' insights into surfers' power outputs. We found no significant relationship between peak oxygen uptake and season rank, thus suggesting that peak oxygen uptake is not a defining measure of surfing ability. However, there was a significant relationship between surfers' season rank and peak anaerobic power. Although no significant correlation was observed between VO_{2peak} and season performance, it may be contested that a certain level of aerobic capacity is still an important requisite for surfing performance given the generally reported moderate to high levels of aerobic fitness in surf athletes. It is unclear how peak power outputs measured during the current study on a modified swim bench ergometer correlate with power generated when paddling on-water during surfing. Therefore, development of a reliable and valid on-water assessment for anaerobic and aerobic outputs of surfers would be worthwhile. Future research should monitor the changes in anaerobic and aerobic outputs of surf specific exercises, and surf performance over a training intervention to better inform practitioners of assessment and conditioning priorities.

Practical Applications

The application of the study's findings should aid the strength and conditioning coach in creating training protocols designed to increase anaerobic power and endurance and aerobic endurance for surfing. Conceivably, improvements to maximal paddling power output might improve surfing performance by allowing more powerful surf athletes to paddle and catch waves that lower ranked competitors miss. Therefore, assessment and conditioning practice should emphasize anaerobic power in a surf-specific swim paddle movement and should detail the loading parameters specific to surfing. Anaerobic power and endurance, and cardiovascular endurance associated with physical performance in surfing could be developed through sport-specific and cross training.

CHAPTER 6: SUMMARY AND CONCLUSIONS, PRACTICAL APPLICATION AND LIMITATIONS

OVERALL SUMMARY AND CONCLUSION

A paucity of published literature exists for surfing owing mainly to surfing research on a whole being in its infancy. The objectives of this thesis were to use methods of performance analysis to measure the physical outputs, workloads and activity patterns of elite surfers during competitions, and to specifically measure their anaerobic power output and aerobic $\text{VO}_{2\text{peak}}$ on the modified kayak ergometer.

This research confirmed findings of previous studies (Meir et al., 1991; Mendez-Villanueva & Bishop, 2005a; Mendez-Villanueva et al., 2006) that suggest surfing is an intermittent activity, characterized by a large number of variables. This analysis of elite men's competitive surfing found that surfing involves intermittent high intensity bouts of all out paddling intercalated with relatively short recovery periods and repeated bouts of low intensity paddling, incorporating intermittent breath holding. The physiological outputs of surfers tends to suggest that depending on the location, surf conditions and environmental conditions, the surfers speeds, distances and heart rates are subject to the conditions. The ever changing variables associated with the sport ultimately dictate the degree of total time spent paddling, stationary, wave riding and performing miscellaneous activities, and therefore, the physiological demands imposed on each surfer. Variability in wave conditions (i.e., type, shape, and height) is likely to explain the high degree of variability in a surfers' performance. Wave conditions can vary drastically from day-to-day at the same surfing venue with swell size, speed and direction of swell, tides, currents, characteristics of the shore bottom, kelp, and wind direction and strength all affect wave conditions (Guisado, 2003).

Time-motion analysis conducted revealed that an average of 54% of total surfing time is spent paddling. Remaining stationary represented 28% of the total time, while wave riding, miscellaneous and paddling for a wave represented only 8%, 5% and 4% of the total time, respectively. Surfer's heart rate workloads vary, but do spend 60% of their total time working between 121 - 160 b.min⁻¹ (56% to 74% of HRmax), which lies within optimal cardiorespiratory training zone using the age predicted maximal heart rate principle. The mean HR during surf competitions was 140 b.min⁻¹, and the (mean) peak HR reached during the events was 190 b.min⁻¹. The incorporation of GPS for the first time in a surfing study revealed interesting results and data. The average distance a surfer covers in a 20 minute heat was 1605 ± 313 meters, with a range 1066.1 – 2138.5m in the two events studied. The average speed for all surfers was 3.7 km/h, with an average max of 33.4 km/h. Additionally, surfers can reach speeds up to 45 km/h, although, approximately 80% of total time is spent at low speeds 1 - 8 km/h.

By using a modified kayak ergometer fixed with a surfboard similar to that of (Mendez-Villanueva et al., 2005b) protocol, surfers' anaerobic peak power (W) and aerobic VO_{2peak} uptake values were established. The anaerobic peak power during the 10 second simulated paddle established a significant relationship ($r = -0.50$, $P = 0.02$) between surfers season rank and anaerobic peak power (W) generated. Although correlations do not imply cause and effect, such a finding provides theoretical support for the importance of anaerobic paddling power in assessment batteries and conditioning practice for surf athletes. The anaerobic peak power output achieved on the modified ergometer was 205 ± 54 W, lower than those recorded for maximal-paddling performance in other studies (Loveless & Minahan, 2010b; Swaine, 2000).

The aerobic VO_{2peak} results revealed that there is no significant correlation between the surfers' season ranking and aerobic VO_{2peak} values, suggesting that peak oxygen uptake is not defining measure of surfing ability. The aerobic VO_{2peak} uptakes we observed (44.0 ± 8.26 mL/kg/min) were similar to the results recorded in previous studies (Loveless & Minahan, 2010a; Lowdon et al., 1989; Meir et al., 1991; Mendez-Villanueva et al., 2005b). The VO_{2peak} results recorded are comparable to other upper-body athletic populations

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measured in the prone position such as swimmers (50-70 ml/kg/min) (Wilmore & Costill, 2004) and surf-life savers (40 mL/kg/min) (Morton & Gustin, 1997). Therefore, elite surfers need a certain level of aerobic capacity, given the generally reported moderate to high levels of aerobic fitness in surf athletes. The aerobic peak power output achieved during the $\text{VO}_{2\text{peak}}$ ramp test was 158 ± 21 W, comparable to that of Mendez-Villanueva et al., (2005b), but lower than Loveless and Minahan (2010a). We found no significant correlation between peak aerobic power and season rank ($r = -0.26$, $p = 0.54$) suggesting that peak aerobic power is not a determinant of performance. However, we observed a significant correlation of ($r = 0.87$; $p = 0.03$; $n = 6$) between peak anaerobic power and peak aerobic power suggesting that upper-body power outputs are related, thus providing further support for the importance of paddling power.

PRACTIAL APPLICATIONS

It was established, in this study, that elite surfers require a high level of conditioning due to the large distances covered, repeated bursts of high intensity paddling and a variety of additional physical demands associated with surfing competitions. Consequently, surfing athletes should undertake competition specific conditioning sessions. Such conditioning sessions should be underpinned by an ‘aerobic’ base, particularly given that we found at least 80% of HR intensities to be above 120 b.min⁻¹.

The development of upper-body aerobic endurance should include repeated measures of low intensity activity, short rest periods, followed by intermittent high intensity bouts (180-200 b.min⁻¹) of all-out activity and intermittent breath holds. Surf-specific training should be paddling related. Due to the intermittent nature of surfing, and variation in distances covered during the incremental test, and GPS tracking, training should be based around 1000 – 2000m. Athletes in training should mimic actual distances, then periodise down with an increase in intensity. Anaerobic power training should mimic the loading parameters specific to surfing competitions, such as four second bursts observed during paddling for waves. Training should emphasize maximal power force production for greater propulsion in water, as well as anaerobic endurance to withstand long durations of constant paddling. Training should also apply the overloading principle, mimicking the maximal paddling burst and short recovery periods. Training prescriptions addressing specific on and off-water workouts should be designed with performance analysis findings in consideration to enhance these areas. The development of recovery and energy systems should aid in reducing fatigue related errors, and withstanding competition demands.

LIMITATIONS

When using an elite group of athletes from a range of locations based around New Zealand, data collection is consequently affected. The data obtained is real and reflects current, high level performance; it is therefore directly applicable to athletes at the same and similar levels. However, the ability to obtain data from participants, both during competitions and in the laboratory to create a stable research environment is hindered. The data collected was from surfers competing for points (season ranking) and prize money, therefore, difficulties in collecting data were imminent. The study used data collected from 12 subjects for the performance analysis, eight for the incremental $\text{VO}_{2\text{peak}}$ test and 20 subjects for the anaerobic power test. The small sample size of ($n=8$) subjects used for the incremental $\text{VO}_{2\text{peak}}$ test limited statistical significance.

The present study only used two competitions for the collection of GPS, HR and video data due to limited availability of the GPS units. Different subjects were analysed under different environmental conditions at the two events limiting the statistical significance of analysis. Additionally, the GPS data collection at event one encountered difficulties in collecting correct, valid data due to loss of satellite connection. GPS units have good accuracy during basic linear movements and lower speeds, however, accuracy and reliability decrease, and errors in speed increase, as speed and path dynamics increase (Gray et al., 2010; Petersen et al., 2009; Portas et al., 2007; Witte & Wilson, 2004). Furthermore, recording at 1 Hz seems appropriate at lower velocities but greater error in data may occur at higher velocities (Portas et al., 2007).

The nature of surfing makes it hard to simulate. Water based testing would be more beneficial and produce perhaps more genuine results, as opposed to dry land paddling. Although swim-bench and kayak ergometry have been recognized as being reliable. It is unclear how closely upper-body peak power outputs measured during the current study on modified kayak ergometer or swim-bench ergometer (Loveless & Minahan, 2010b) translate or relate to the actual power generated when paddling for and through waves when

surfing (Loveless & Minahan, 2010b). Furthermore, all subjects in the current study used the same surfboard, which to some, found a little too wide and the paddle unusual. All elite surfers have their boards made to their specifications, in accordance to weight, height and style.

FUTURE RESEARCH

With such a paucity of data and studies overall, it is of importance to commence new and innovative research in all areas of surfing performance. With surfing growing in popularity and the demands of competitive surfing imposed onto the athletes increasing, future findings will help practitioners and surf athletes alike to gain a better understanding of the sport, and enhanced information on assessment and conditioning priorities. Recommendations for future research include:

- Further competition surfing performance analysis though GPS, HR and video analysis with the synchronization of video footage and GPS data, with an analysis of the effects of conditions on the performance variables
- Longitudinal studies to investigate the physiological responses and adaptations of surfing specific water based training, surfing specific gym based training, controlled with just surfing
- Future research should monitor the changes in anaerobic and aerobic outputs of surf specific exercises, and surf performance over a training intervention to better inform practitioners of assessment and conditioning priorities
- Development of reliable and valid on-water assessment for anaerobic and aerobic outputs of surfers
- Investigating the physiological attributes of elite surfers with a surfing specific assessment battery
- Investigation into upper-body, core and lower-body muscular performance of elite surfers, via surf-specific cardiovascular and muscular testing
- Research into the cardiorespiratory system such as lung capacity, metabolic outputs from work efforts and lactate threshold
- Investigation into the muscular recruitment, and patterns of recruitment during surfing
- Investigation into the energy demands of surfing and the benefits of nutrition to aid with the demands

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GLOSSARY

Take-off zone – Optimal area where the surfer paddles for the wave and pops up riding.

Pop up – When the surfer finishes paddling for the wave and pops up from the prone position onto their feet, on the surfboard.

Barrelling – When a wave is hollow, like a pipe, and breaking, enabling the surfer to position actually inside the wave as it is breaking. This is known also as a tube ride.

Point break – Where a wave breaks as it hits a point of land jutting out from the coastline, and wraps around.

Left-hand point breaking waves - When the waves break from the left at the point and the surfer rides it to their left.

Beach break – Takes place where waves break on a sandy seabed.

Reef break – Happens when a wave breaks over a coral reef or a rocky seabed, generally shallow water

Turns – The surfer manoeuvres the surfboard on the wave.

Top-turn – Turn off the top of the wave (lip). Sometimes used to generate speed and generally resulting in spray from the turn.

Snap – A quick sharp turn off the lip of the wave. Some times the surfboard's fins come out off the top of the wave, exposing the bottom end of the board.

Cutbacks – When the surfer turns back to reverse direction, generally on the lip of the wave cutting back toward the breaking part of the wave.

Bottom Turn – The first turn at the bottom of the wave

Aerials – When the board and rider become air bourn off the wave entirely, and then land on the wave.

White wash – the surfing water after the wave has broken.

Breakers – A term for when the waves have broken

Duck-dive - Pushing the board underwater, nose first, and diving under an oncoming/breaking

APPENDIX 1: ADDITIONAL INFORMATION ON THE GPS UNIT

The introduction of the GPS unit in the 1990's offered an alternative method for the measurement of speed and position during locomotion studies in the field, with the potential to circumvent some of the limitations and minimize others (Townshend et al., 2007). GPS units can now be worn during competition and training to provide detailed information about movement patterns and physical activities of athletes. The development in technology has seen the ability of a portable GPS unit to accurately pinpoint the location, speed, latitude/longitude and direction of the receiver. The complete Global Positioning System provides 24-hour, all-weather navigation and surveying capability worldwide (Leick, 1995). The GPS unit is a navigation system that uses 27 operational satellites that are in Earth's orbit (2000 to 35,786 km above Earth). Each satellite makes one revolution every 12 hours on one of six different orbital paths, each transmitting signals allowing GPS receivers to determine the receiver's location, speed and direction (Lythe, 2008; Schutz & Herren, 2000; Townshend et al., 2007). This has the advantage of providing continuous coverage in any part of the world, with up to eight satellites accessible from any point on earth (Schutz & Herren, 2000). These satellites emit radio signals with a unique code sequence and an encrypted navigation message containing the satellite ephemeris (Schutz & Herren, 2000; Townshend et al., 2007). The receiver, worn by the subject, decodes the radio frequency signals from each satellite. Information about exact time and position is constantly sent at the speed of light to the GPS receiver. The distance to the satellite is then calculated by multiplying the signal travel time with the speed of light. By multiplying travel time by the speed of light, the exact distance to each satellite is determined. By calculating the distance to at least three satellites, an exact three-dimensional position can then be calculated by trigonometry (Larsson, 2003; Schutz & Herren, 2000; Townshend et al., 2007). With measurements from four satellites, an estimate of altitude is also made (Schutz & Chambaz, 1997). In addition, in most commercially available GPS systems, the receiver is able to calculate, using sophisticated algorithm, speed of displacement by measuring the rate of change in the satellites radio frequency signal attributable to movement of the receiver (Doppler shift) (Schutz & Herren, 2000; Townshend et al., 2007).

Speed can also be calculated from changes in the given GPS distance divided by the time between each logged position (Townshend et al., 2007).

The United States of America Department of Defence funds this system for navigation. It was originally developed for military use, but is increasingly used for aviation, marine and recreational outdoor purposes (Larsson, 2003). GPS devices now range widely in terms of their abilities, purposes and size. In addition they are commercially available for cars, boats, hikers, runners, cell phone users and team sport athletes. A commercial product designed for athlete analysis is produced by an Australian company, GPSports Systems Pty. Ltd. One of the company's GPS tracking products is the GPSPI10 unit that can be implemented for monitoring athlete trainings and competition. The unit samples at 1Hz (position is recorded every second).

APPENDIX 2: SURFING LOCATION, TYPE AND CONDITIONS

The first surfing event (Event one) had a swell ranging between 1 – 1.5 meters (three to four foot faces), over the two days with an onshore westerly wind causing the waves to be choppy and messy. The type of surf break was a beach break, with waves forming and breaking on sand bars. The surf and environment conditions meant that 56% of the total time was spent paddling with 25% stationary. In addition, of the remaining activities, miscellaneous, paddling for the wave and wave riding represented 8%, 6%, and 5%, of the total time, respectively. Additionally, the wave riding average time was only 7 seconds, with paddling at 13 seconds and stationary at 10 seconds.

The second surfing event had better surf quality, producing 1.5m (4 foot faces) left-hand point breaking waves for day one and two of the event. The point break meant wave quality was better, producing waves that wrapped around the point creating longer waves. Day three produced less wind chopped waves with better quality surf, ranging around one – one and a half meters (3 to 4 feet). Time-motion analysis revealed that the percentages from Event two were slightly different from Event one. Paddling represented 54% and stationary 28% of the total time. The additional activities of wave riding, miscellaneous, and paddling for wave represented 8%, 5%, and 4% of the total time respectively. The surf conditions and type of wave break meant that the average times were very different from Event one's. The wave riding average time was more than double with 16 seconds, paddling was 17 seconds and stationary with 12 seconds respectively. The type of break, beach location, and deteriorating surf conditions meant that the percentages of time the surfers spent implementing the actions would vary from location to location. Furthermore, the type of surf also had an impact to the average time spent actually wave riding.

APPENDIX 3: RECRUITMENT EMAIL/PARTICIPANT INFORMATION SHEET AND CONSENT FORM



Hi (*Name*)

Hi my name is Oliver Farley (Olly) and I am a student at AUT (Auckland Uni) and passionate surfer. I am currently about to start my Masters research in surfing. The study is on elite male surfing: Physiological demands of competition and upper-body anaerobic power and aerobic fitness profiling. The purpose of the study is to establish the surfer's workloads, velocity of movements and durations during a competition. This will be done by using and wearing a heart rate monitor and GPS unit. Data from these will then be downloaded to a laptop for analysis of the heart rates, speeds, distance the surfer was travelling etc.

In addition, I will investigate the relationships between upper-body anaerobic power and aerobic fitness. Laboratory assessments will be conducted to assess Vo2peak and anaerobic power using a modified ergometer with a surfboard attached to properly simulate the actual surf paddle. The anaerobic power test involves paddling intensely for 10 sec and the Vo2 peak involves paddling till exhaustion.

I would like to invite you to participate in the study. If you are interested in being involved please let me know. I have been in contact with Surfing New Zealand and have discussed the research with Ben Kennings. Furthermore, if you would like more information on the study or know of people that maybe interested, please email me.

Cheers

Olly

BA Sport, PGdip

Ollyfarley@hotmail.com

AUT email: yph9838@aut.ac.nz

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Participant Information Sheet



Date Information Sheet Produced:

20 May 2010

Project Title

Elite male surfing: Physiological demands of competition and upper-body anaerobic power and aerobic fitness profiling

An Invitation

My name is Oliver Farley (Olly) and I am a student at AUT and passionate surfer. I am currently about to start my Masters research in surfing. The study is on Elite male surfing: Physiological demands of competition and upper-body anaerobic power and aerobic fitness profiling. This study is being implemented as part of a Master of Sport and Exercise qualification.

I would like to invite you and if you are interested in being involved please let me know. Participation is completely voluntary and you may withdraw at any stage without giving a reason. I have been in contact with Surfing New Zealand and have discussed the research with Surfing New Zealand National Selector Ben Kennings.

What is the purpose of this research?

The purpose of the study is to establish the surfer's workloads, velocity of movements and durations during a competition. This will be done by using and wearing a heart rate monitor and GPS unit. Data from these will then be downloaded to a laptop for analysis of the heart rates, speeds, distance the surfer was traveling etc.

In addition, I will investigate the relationships between upper-body anaerobic power and aerobic fitness. Laboratory assessments will be conducted to assess aerobic VO_{2peak} peak and anaerobic power using a modified ergometer with a surfboard attached to properly simulate the actual surf paddle. The anaerobic power test involves paddling intensely for 10 and the VO_{2peak} involves paddling till exhaustion.

How was I identified and why am I being invited to participate in this research?

You were identified as being a current top ranked surfer in New Zealand from Surfing New Zealand. You are being invited to participate as the study requires New Zealand's elite male surfers.

What will happen in this research?

Time motion analysis will be conducted at sanctioned New Zealand surf association events to determine the surfers' heart rates during the event and durations of activities. Data from these monitors will be downloaded to a laptop for further analysis of HR durations, intensities and velocities. Thereafter laboratory assessments will be conducted to assess VO_{2peak} and anaerobic power on a modified swim bench apparatus. A continuous incremental exercise test to exhaustion will be performed to determine peak oxygen uptake, peak heart rate and peak power output. Anaerobic power output will be measured from 10 seconds of all-out exercise to determine power output.

What are the discomforts and risks?

The risks involved in this study are minimal. The requirement is to wear a small GPS device and Heart Rate monitor in a surfing heat competition. This device will not place the surfer at any increased risk of injury or cause any major discomfort. The devices should not cause any impact to performance.

The fitness testing on the modified swim bench risks are paddling intensively for 10 seconds and paddling till exhaustion. These actions are the norm for the surfer, only difference is that it is on dry land.

The Fitness testing may cause minor discomfort. The discomfort of the VO_{2peak} test is till exhaustion, therefore tiredness and muscular fatigue will ensue. The power test involves paddling intensively for 10 seconds; therefore the discomfort will be the burning sensation of lactic acid building up in the muscles.

How will these discomforts and risks be alleviated?

If the equipment (HR, GPS, Surf ergometer) is causing any discomfort then you do not have to wear or use them. I will try to make the equipment usage as comfortable as possible by asking you what you prefer.

What are the benefits?

These results will improve our understanding of surfer's performances and fitness levels. This knowledge will allow us to develop exercises and variations of exercises that are specific to the muscular and energy systems required in surfing.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

All records will be kept in a locked limited access cabinet. Data will be treated as confidential and will be used only for the purpose of this study. Participants' identifications will be linked to ID numbers.

What are the costs of participating in this research?

The cost of your time during the competition to be set up with the units will be no longer than 5 minutes. Fitness testing on the surf ergometer will be a total of around 1 hour.

What opportunity do I have to consider this invitation?

Within six months.

How do I agree to participate in this research?

You will need to complete and accept the Consent Form, which I will provide you. Contact me and I will explain and answer any questions and then sign the consent form

Will I receive feedback on the results of this research?

Yes. If you would like to know your personal Heart rates, GPS data and fitness outputs I will provide you with a copy of the actual results.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, *Dr Nigel Harris*, nigel.harris@aut.ac.nz, *work phone number* 9219999 ext 7301.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTECH, Madeline Banda, madeline.banda@aut.ac.nz , 921 9999 ext 8044.

Whom do I contact for further information about this research?

Researcher Contact Details:

Oliver (Olly) Farley. BA Sport, PGdip

Ollyfarley@hotmail.com [AUT email: yph9838@aut.ac.nz]

09 4128164 – 0210617194

Project Supervisor Contact Details:

Nigel Harris PhD |Senior Lecturer, Sport and Exercise Science |Postgraduate Head |School of Sport and Recreation | Faculty of Health and Environmental Sciences | AUT University | Private Bag 92006 | Auckland 1020 | **PHONE** +64 9 921 9999 extn 7301 |

Secondary supervisor: Associate Professor **Andrew Kilding** (andrew.kilding@aut.ac.nz)

Faculty of Health and Environmental Sciences | AUT University | Private Bag 92006 | Auckland 1020

Approved by the Auckland University of Technology Ethics Committee on 24 May 2010, AUTECH Reference number (10/104)

Consent Form



Project title: Elite Male Surfing: Physiological Demands of Competition and Upper-Body Anaerobic Power and Aerobic Fitness Profiling

Project Supervisor: Dr Nigel Harris

Researcher: **Oliver Farley**

- ☐ I have read and understood the information provided about this research project in the Information Sheet dated 23 May 2010.
- ☐ I have had an opportunity to ask questions and to have them answered.
- ☐ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ☐ I am not suffering from any severe or limiting injuries and have no medical problems.
- ☐ I agree to provide my heart rates, Global Positioning System data, peak power output and Vo2 peak measurements as part of the Elite Male Surfing research.
- ☐ I agree to take part in this research.
- ☐ I wish to receive a copy of the report from the research (please tick one): Yes ☐ No ☐
- ☐ I wish to have my heart rates, Global Positioning System data, peak power output and Vo2 peak measurements returned to me in accordance with right 7 (9) of the *Code of Health and Disability Services Consumers' Rights* (please tick one): Yes ☐ No ☐

Participant' signature:.....

Participant's

name:.....

Participant's Contact Details (if appropriate):

.....
.....

Date: **Approved by the Auckland University of Technology Ethics Committee on 24 May 2010 AUTEK Reference number (10/104)**