WORKLOADS of COMPETITIVE SURFING: WORK to RELIEF RATIOS, SURF-BREAK DEMANDS and UPDATED ANALYSIS

[1,2,3] Oliver R. L. Farley, [1,2,4] Josh L. Secomb, [2,5] Ellen R. Raymond, [1,2,6] Lina E. Lundgren, [1,7] Brendon K. Ferrier, [1] Chris R. Abbiss and [1,2,8] Jeremy M. Sheppard

[1] School of Exercise and Health Science, Edith Cowan University, Joondalup, WA, Australia, [2] Hurley Surfing Australia High Performance Centre, Casuarina Beach, NSW, Australia, [3] SPRINZ, Auckland University of Technology, New Zealand, [4] Queensland Academy of Sport, Australia, [5] Department for Health, University of Bath, Bath, [6] School of Business, Engineering and Science, Halmstad University, Sweden. [7] England School of Applied Sciences, Edinburgh Napier University, Edinburgh, Scotland, United Kingdom, [8] Canadian Sport Institute, Pacific Region, Canada

Abstract. *The study provides an in-depth descriptive and quantitative time-motion analysis of competitive surfing, using Global Positioning System (GPS) units and video synchronization, which serves to extend upon the results of Farley, Harris and Kilding [Journal of Strength and Conditioning Research, 26, 7 (2012)]. Additionally, comparisons between locations and surfers competing in the same heats were performed. GPS and video data were collected from 41 male competitive surfers (23.2 ± 6.1 years, 71 ± 10.3 kg, 177.2 ± 6.4 cm) participating in three professional domestic surfing events, with competitive heats of 20 minutes duration. Fifty data sets were analyzed across the three competitions, with velocities and distances covered, proportion of time spent performing various surfing activities, and total work to relief ratio determined. Results revealed surfers paddled 44% of the total time, followed by stationary periods (42%). Surfers performed at a significantly ($p \leq 0.05$) higher work-to-relief ratio (1.7:1) at the Beach-break (An exposed beach) compared to Point-break 1 and 2 (Waves breaking around a rocky point). Point-breaks 1 and 2 had longer continuous durations of paddling, with significantly longer rides at Point-break 1 over the Beach-break ($p \leq 0.01$) and Point-break 2 ($p \leq 0.01$). The average maximal speed (24.8 $km \cdot h^{-1}$) from Point-break 2 was significantly faster than Point-break 1 ($p \leq 0.01$) and Beach-break ($p \leq 0.05$). This information should influence surfing drills and conditioning methods to prepare these athletes for the disparate demands, such as, training for a point-break competition involving longer durations of continuous paddling, and short, high intensity workloads for a beach-break.*

Key Words: *Surfing, Exercise Durations, GPS, Time-Motion Analysis, Performance Analysis*

INTRODUCTION

Competitive surfing has undergone substantial growth and as a result, there has been a rapid increase in the examination of methods to enhance abilities and fitness qualities of surfers (8, 11, 22, 24). In order to improve our understanding of the physical and technical activity profile of sports, various methods of systematic performance analysis have been established (14, 19, 26). Coaches are able to make objective decisions by evaluating athletes' workloads, movement patterns, distances, and activity profiles using Global Positioning System (GPS) tracking (5, 17, 19, 29) and by analyzing athletes' activity durations through time-motion analysis (TMA) (1, 7, 15, 20). Such analyses can shape testing protocols and support the development of sport-specific predictive models, from which appropriate conditioning training programs can be created (8, 14, 16, 19, 26, 28). However, the utilization of such methods to record valid data is limited within surfing literature, with only a few published research articles (9). To date, research analyzing surfing performance has been limited to examining male surfers' HRs (11, 21, 22), activity durations with TMA (11, 21, 23, 27), and GPS data (3, 11, 27). These studies have been implemented during competitive surfing events (11, 24), training (27), and recreational surfing (3, 21). See Farley, Abbiss and Sheppard (9) for an in-depth literature review on performance analysis in surfing.

Competitive surfing consists of judges evaluating a surfers' performance during wave riding, in reference to the specified criteria. The scoring system is based on the performance of maneuvers (i.e. turns, airs, rotations) the surfer completes with commitment, difficulty and in combination of other major maneuvers (2). Surf locations and their associated environmental variables vary at each competition. This includes variables such as; surf break type, ocean floor topography, weather, swell, and tides to name a few. The competitive format requires surfers (2 – 4 per heat) to compete in a maximum of five heats per day, with each heat lasting between 20 to 40 minutes which is dependent on the competition format, level of competition and surf conditions. Additionally, surfers encounter intermittent paddling bouts, varying in intensity and duration (11, 21, 22, 27) with short periods of recovery (32 – 64% of total paddle bouts performed between 1 – 10 s). Surfing also includes a short (4 – 5 s), powerful burst of paddling for the wave take-off as well as prolonged periods of endurance paddling (11, 18), accumulating to approximately 50% of the total surfing time (3, 11, 21, 22, 27). This equates to approximately 1km of paddling in a 20 minute heat (11), or 1538m to 1600m of paddling during 30 minutes of training (27).

Detailed performance analysis data is lacking within competitive surfing; therefore, the purpose of this study is to establish surfers' workloads, distances covered, and activity durations during surfing competitions through performance analysis using GPS and TMA methods. In conjunction with video recording for TMA, the addition of GPS tracking will broaden our understanding of surfing and provide an extension to the results of Farley, Harris and Kilding (11). The aims of the study were to determine the workloads (i.e. exercise durations, distances, velocity of movements, and work-to-relief ratios) experienced during competitive surfing and determine whether the demands differ between locations offering different surfing conditions and surfers competing in the same heats. This information may provide a better understanding of the activity profiles associated with competitive surfing, thus greatly benefiting the training and preparation of elite surfers.

METHODS

Experimental Approach to the Problem

Competition data, including GPS and video recordings were obtained from nationally ranked surfers to determine the activity profile of surfing competition. Descriptive statistics were subsequently determined to capture durations of surfing specific TMA activities, maximum and average wave riding velocity, and distances covered for each heat and participant. Additionally, beach location and environmental/surfing conditions (i.e. wave size, type of surf break, surf conditions) were noted when determining differences between events. It should be noted that there are other types of surf break (i.e. reef break) that warrant investigation into workloads, however, due to competition logistics only 2 types of surf break (point-break and beach-break) were used for analysis in this study.

Surf conditions were observed during filming and analysis, and swell heights were noted from surf reports. Point-break 1 generated calm surf conditions with small, clean, 1 to 1.2m (3 – 4ft faces, approximately) waves during data collection. The right-hand point break (waves broke from the right to the left) provided long, high quality waves that enabled surfers to ride for long periods at times (subject to wave). Point-break 2 also produced a right-hand point break, however, the wave quality changed with the tide and swell, altering the prominent point-break wave to a beach-break. The wave conditions at Point-break 2 were clean and small, ranging from 1.2 to 1.5m (4 – 5ft faces, approximately). Point-break 2 was less consistent, and surfers had to position themselves effectively for quality waves. In comparison, Beach-break data was collected from an exposed beach break (range of waves breaking from left to right and right to left), with swell ranging between 1.2 and 2.5m (4 – 8ft faces). Wave quality was inconsistent on day one but improved on day two.

Subjects

A total of 41 nationally ranked competitive level male surfers (23.2 ± 6.1 years, 71 ± 10.3 kg, 1.77 ± 0.06 m) volunteered to participate in this study. The surfers were monitored individually and 18 of the 41 surfers were monitored whilst competing against each other in one of nine heats. All participants involved were competing in the 2014 state professional competition series. The first data set was recorded at the Currumbin Alley Pro (Point-break 1), (n = 21, 16 – 30 years) where eight pairs of surfers competed against each other in different heats. The second data set was recorded at the Sunshine Coast Pro, Coolum beach (Beach-break) (n = 18, 17 – 24 years) including four pairs of surfers in two heats. The third and final data set was recorded at the Burleigh Heads Pro (Point-break 2) (n = 11, 17 – 24 years) where six surfers paired up in three heats. Prior to data collection, all participants were informed of the experimental procedure and provided informed consent (including parent/guardian) in accordance with the Declaration of Helsinki. The project was approved by the Human Research Ethics Committee at Edith Cowan University.

Procedures

Global position system

The GPS unit (SurfTraX, Southport, Australia), specifically developed for surfing analysis, was used to record the position coordinates of the participants. The recording frequency was 10Hz, from which velocity of movement, speed and distance were derived. Five minutes prior to the surfer preparing to enter the water for their heat, GPS units were turned on to locate satellites and positioned. The GPS unit was placed in a sealed arm strap and tightened around the bicep, (goofy stance = left arm, natural stance = right arm) with the unit positioned on the triceps, or, if the surfer wore a chest-zip wetsuit, the unit was positioned on the upper vertebrae and held in position in the back pouch of the suit. Pilot testing revealed GPS measurements were not affected by placement of the unit.

Although movements occur during arm paddling, this range is small and the precision of the satellite tracking for these GPS units does contain small (≤0.6) to moderate (0.7) effect size differences for all GPS measurements. A combined horizontal dilution of position (HDOP) for the GPS units was 0.95 ± 3.7 for the 10 Hz devices. The rash shirt color and unit number were noted for filming and data synchronization purposes. After collection, data was downloaded using the manufacturer-supplied software (SurfTraX Motion-Studio, Southport, Australia) and synchronized with the heat video. The GPS units were previously established to be reliable and valid (10).

Video analysis

During the competitive heats, surfers were filmed using a high definition Sony camera (Sony, HXR-NX100, Tokyo, Japan) mounted on a tripod. The video footage was recorded to an SD memory card and subsequently synchronized to the GPS-data using data analysis software (SurfTraX Motion-Studio, Southport, Australia). The data from the GPS unit was downloaded to a laptop for subsequent analysis.

Filming coincided with the start and finish of heats, which was signaled by an air horn. Data recorded during this period was used for data analysis and synchronization. Heats were filmed to determine the TMA of activities associated with the sport. The video cameras were positioned for best possible viewing at the competition locations. At Point-break 1, two video cameras were positioned on a rocky point, side on to the breaking waves. At the Beach-break, the cameras were positioned on a hill facing out to sea from a height to capture all movements behind the waves. Similarly, the cameras at Point-break 2 were positioned on a hill, but instead faced side on to the breaking waves.

A review of camera footage allowed documentation of the total time for each heat, and the time spent performing each activity was recorded for paddling, paddling for a wave, remaining stationary, wave riding, and miscellaneous (Table 1) (11). The time surfers spent during each TMA activity (average and total), frequency (*n*) of occurrences of each activity, and the percentage of the total time spent on each activity were then calculated. Additionally, bouts of paddling, remaining stationary, and paddling for a wave were recorded and subdivided into separate time zones for analysis. GPS data was used to investigate differences between the variables such as speeds and distances covered at each event, and differences between surfers competing within the same heat.

Activity analysis

The videos of each surfer were synchronized with the GPS data and played simultaneously, with the times recorded for each activity in a Microsoft Excel spread sheet. Videos were paused and played frame by frame to determine exact durations and provide accurate time allocation for each activity. One investigator was responsible for all coding of activity from video replay. GPS variables were reported from the synchronization of the video recording to ensure accurate analysis.

Table 1: Time-Motion Analysis Activity Definitions from Farley et al. (2012)

Motion Category	Definitions
Paddling	All forward board propulsion using alternate-arm paddling action.
Stationary	All situations with participants sitting or lying on their boards, with no locomotion activity.
Wave riding	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.
Miscellaneous	Actions such as duck diving under broken/unbroken waves, recovering and getting back on the surfboard after falling/wave riding, slow one-arm paddling action aiming to maintain position in the take-off zone
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.

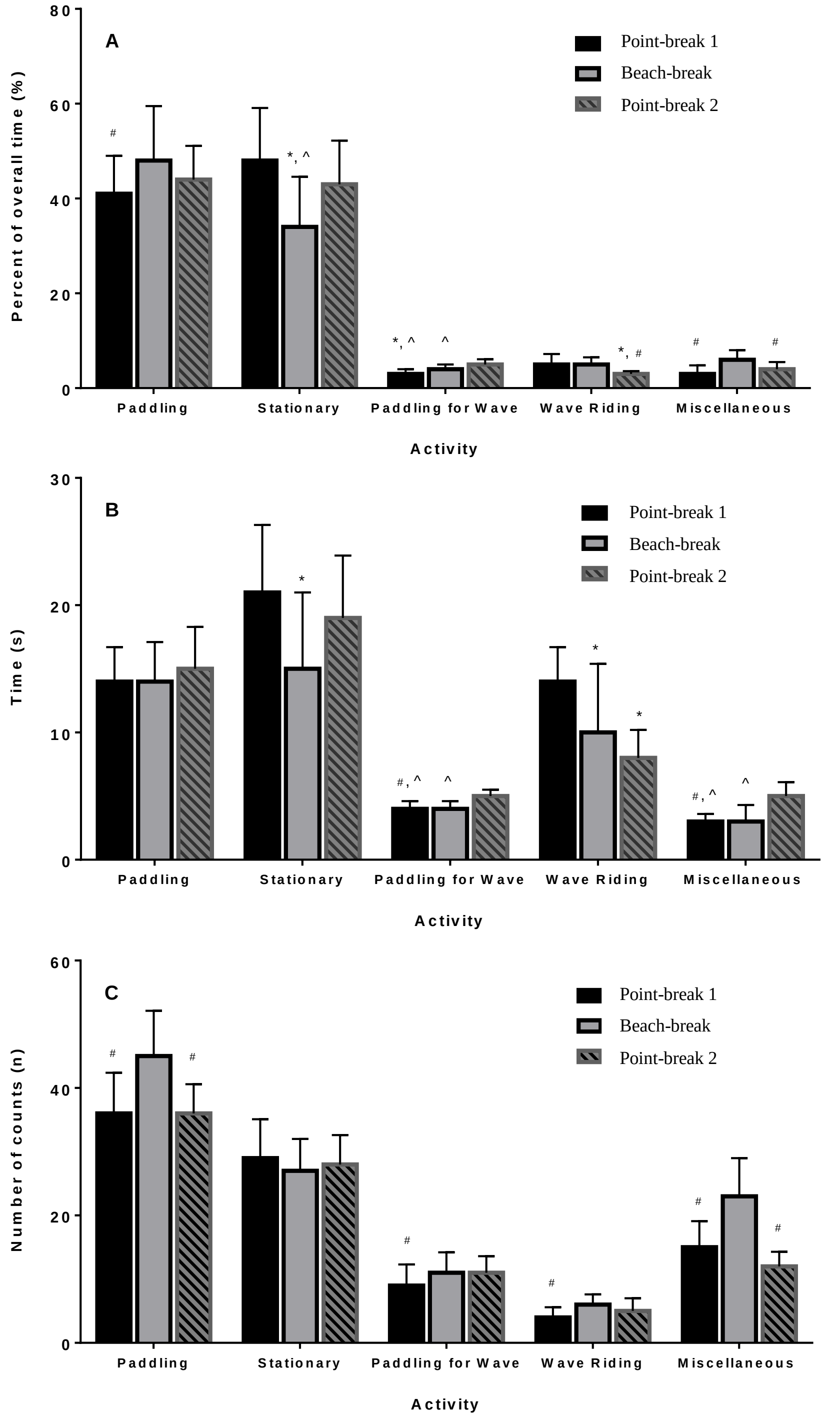
Statistical Analyses

Descriptive statistics are presented as means, standard deviations (±SD) and ranges in tables, figures, and the results section. A one-way ANOVA was performed on the TMA variables of interest, including differences between the GPS recordings from 18 paired surfers competing in heats. Additionally, an LSD post-hoc was performed on the variables from the TMA analysis and the work to relief ratios. Cohen's *d* was calculated to determine the effect sizes of work to relief ratio, GPS wave differences between heat winners and losers (within same heat), average wave speeds, and the distances covered per wave at each event. The criteria for interpreting effect size was: ≤0.2 = trivial, 0.2 – 0.6 = small, 0.6 – 1.2 = moderate, 1.2 – 2.0 = large and >2.0 = very large (13, 25). All statistical analyses (except Cohen's *d)* were performed using a statistical analysis package (IBM SPSS, Version 22; Chicago, IL), with statistical significance defined as $p \leq 0.05$ and data reported as means and SD.

RESULTS

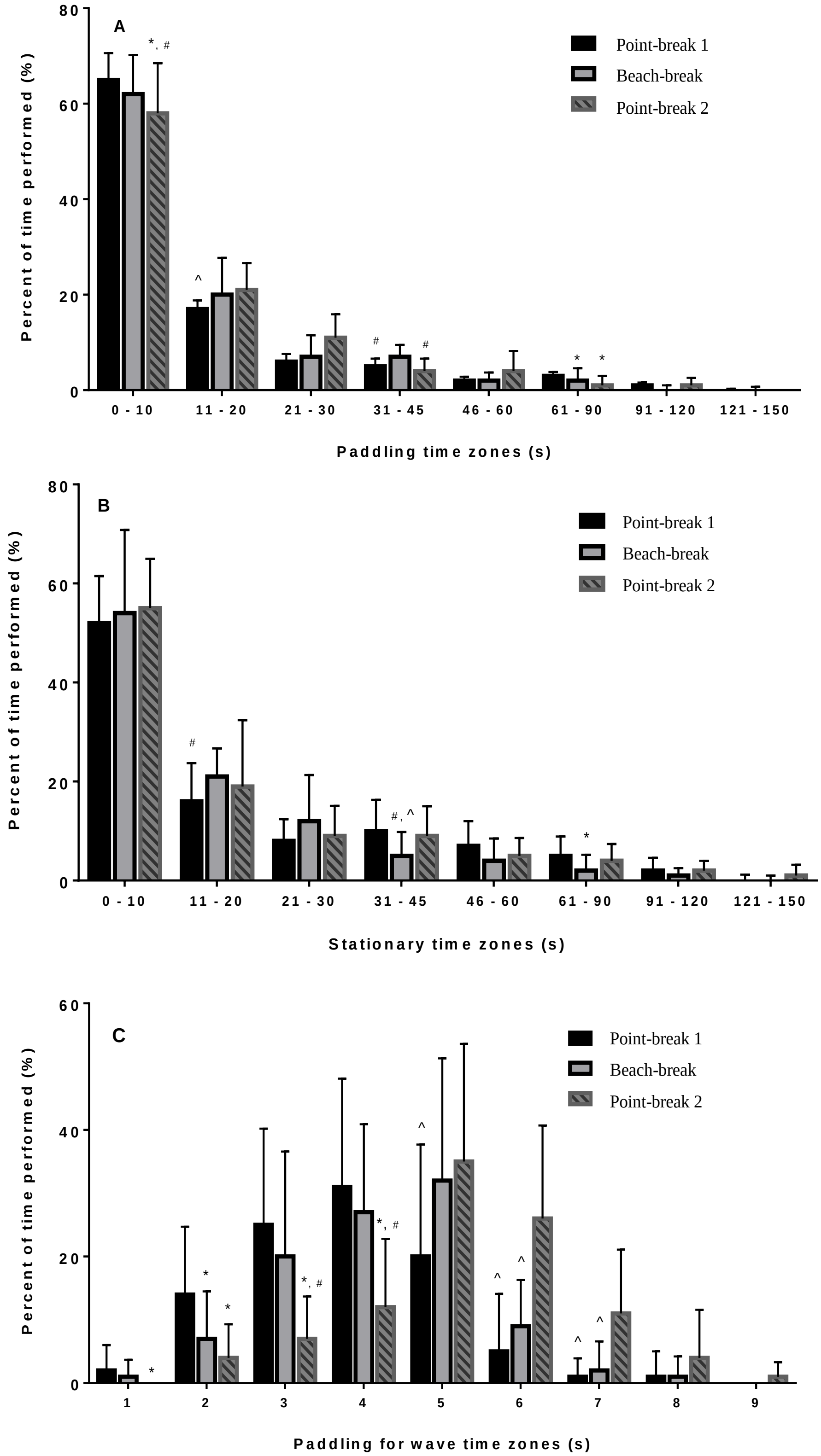
Activity Durations

TMA activity. The results from 50 videos are reported below. Figure 1A displays the percentage (%) of total time spent performing activities at each location, Figure 1B details the average time (s) a surfer performed each activity at the three locations, and Figure 1C identifies the number (n) of times each activity was performed. Paddling was the most frequently performed activity (n = 39) at all locations and consumed the greatest percentage of total time (44%), followed closely by stationary periods (42%). The average stationary time (18 s) was identified as the greatest consumption of time. There were significant differences between each location. The Paddling count and percentage of time spent Paddling at Beach-Break was significantly greater (48%, n = 45, $p \leq 0.05$) than Point-break 1 and Point-break 2, and respectively, percentage of time spent Stationary at the Beach-break was significantly less (34%, $p \leq 0.05$) than at the other two locations. The percentage and time spent Paddling for a Wave at Point-break 2 (5%, 5 s) was significantly greater ($p \leq 0.05$) than the other two locations, with the count significantly greater (n = 11, $p \leq 0.05$) than Point-break 1. The percentage of total time spent Wave Riding at Point-break 2 was significantly less (3%, $p \leq 0.05$) than at the other two locations compared to Point-break 1 where time spent Wave Riding was greater (14 s), but also performed less often (n = 4); The percentage of time and count of Miscellaneous activities was significantly greater ($p \leq 0.05$) at the Beach-break (6%, n = 23) though the time it was performed for was significantly greater at Point-break 2 (5 s).



* = p<0.05 to Point-break 1, $^{\#}$ = p<0.05 to Beach-break, $^{\wedge}$ = p<0.05 to Point-break 2

The paddling zones in Figure 2A display percentage differences between the events and identifies Paddling durations between 1 and 10 s as the largest consumption of total paddling time. Paddling time performed within the 1 – 10 s zone at Point-break 1was significantly greater (65%, $p<0.05$) than at the two other locations. Point-break 2 had a significant higher percentage of Paddling (21%, $p<0.05$) than Point-break 1 in the 11 – 20 s time zone. Following on, Beach-break had a significantly greater amount of Paddling in the 31 – 45 s time zone (7%, $p<0.05$), compared to the other locations. Finally, 3% of time was spent Paddling within the 61 – 90 s time zone at Point-break 1, which was significantly greater than at the two other locations. Figure 2B displays Stationary percentage differences between the events and identifies stationary periods between 1 and 10 s as the largest consumption of total stationary time. The Beach-break reported a significantly greater amount of time (21%, $p<0.05$) spent Stationary within time zone 11 – 20s. Compared to Point-break 1, the Beach-break percentage of time Stationary was significantly less (5%, $p<0.05$) than both Point-breaks within time zone 31 – 45 s, and was significantly less (2%, $p<0.05$) than Point-break 1 within time zone 61 – 90 s. Finally, Figure 2C displays the percentage of time spent Paddling for a Wave. The largest percentage spent within a time zone was Paddling at 5 s from all events, with 4 s the second largest. Point-break 1 reported 92% of paddling percentage spent <6 s, which was significantly different to the other two locations between zones 2 s to 4 s. In contrast, Point-break 2 reported 77% of Paddling for a Wave >4 s. Significant differences were reported between Point-break 1 for 5 s and between both events for the times of 6 s and 7 s.



* = p<0.05 to Point-break 1, $^{\#}$ = p<0.05 to Beach-break, $^{\wedge}$ = p<0.05 to Point-break 2

Table 2: Average Total Workloads to Relief Ratio per 20min Heat

	Total Work (s)	Relief (s)	Effect size (*d*)	
Point-break 1				
Stationary		571 ± 121.9 [c]	*1.37*	
Paddling	488 ± 95.7 [c]		*-1.26*	
Paddling for Wave	34 ± 11.6 [c, d]		*-1.08*	*-2.05*
Wave Riding	63 ± 26.5 [d]			*1.49*
<u>Work to Relief Ratio</u>	**1 [c]**	**1.1**	***-1.14***	
Beach-break				
Stationary		408 ± 116.4 [b, d]	*-1.37*	*-0.99*
Paddling	608 ± 94.9 [b, d]		*1.26*	*0.87*
Paddling for Wave	48 ± 14.2 [b, d]		*1.08*	*-0.86*
Wave Riding	58 ± 13.1 [d]			*2.26*
<u>Work to Relief Ratio</u>	**1.7**	**1 [b, d]**	***-1.30***	***-0.98***
Point-break 2				
Stationary		520 ± 110.1 [c]	*0.99*	
Paddling	529 ± 85.7 [c]		*-0.87*	
Paddling for Wave	60 ± 13.7 [b, c]		*2.05*	*0.86*
Wave Riding	34 ± 7.4 [b, c]		*-1.49*	*-2.26*
<u>Work to Relief Ratio</u>	**1.2 [c]**	**1**	***-0.90***	

[b] = Sig.diff to Point-break 1, [c] = Sig.diff to Beach-break, [d] = Sig.diff to Point-break 2

The work to relief ratio displayed in Table 2 identifies the amount of work surfers perform in comparison to stationary relief time. Significant differences and the effect sizes (*d*) between the events and activities are also displayed. The Beach-break had the highest work to relief ratio with an average 1.7 s of work to every second of relief. The total workload of the Beach-break resulted in a moderate (1.14 *d* and 0.90 *d*) significant difference ($p \leq 0.05$) to Point-break 1 and 2, respectively. The relief ratio of the Beach-break resulted in a moderate (-0.98 *d*) significant difference to Point-break 1 ($p \leq 0.01$) and a large (-1.30 *d*) difference to Point-break 2 ($p = 0.02$).

GPS data. From 50 GPS samples, Point-break 1 maximum speed and average speed were significantly lower than Beach-break and Point-break 2 ($p \leq 0.01$), with Beach-break maximum speed significantly lower than Point-break 2 ($p=0.04$) (Table 3). The total wave distance from both Beach-break and Point-break 2 were significantly lower than Point-break 1 ($p \leq 0.01$).

Table 3: Average GPS Wave Speeds and Distances Covered per Wave at Each Event and the Wave Differences Between Heat Winners and Losers Within the Same Heat

	Wave Count	**Maximum Speed ($km \cdot h^{-1}$)**	**Average Speed ($km \cdot h^{-1}$)**	**Total Wave Distance (m)**	**Between Waves Distance (m)**
Point-break 1	4.4 ± 2.2	21.8 ± 3.3 $^{c, d}$	17.5 ± 1.9 $^{c, d}$	73.3 ± 44.6	735.1 ± 146.3 ^{c}
Effect size (*d*)		*-0.60, -0.88*	*-0.95, -1.06*		*-1.72*
Heat Winner	5.3 ± 1.3	22.1 ± 1.3	17.8 ± 0.9	68.2 ± 11.4	
Heat Loser	3.3 ± 1.9	21.1 ± 2.5	17.1 ± 1.1	54.9 ± 33.6	
Effect size (*d*)	*1.22*	*0.50*	*0.70*	*0.53*	
Beach-break	6.2 ± 1.5	23.6 ± 2.7 ^{d}	19.3 ± 1.9	55.4 ± 29.4 ^{b}	934.8 ± 74.7
Effect size (*d*)		*-0.38*		*-0.47*	
Heat Winner	4.5 ± 0.7	24.7 ± 2	19.4 ± 0.2	80.6 ± 24	
Heat Loser	6 ± 1.4	23.6 ± 0.7	19.6 ± 0	52.5 ± 3.3	
Effect size (*d*)	*-1.35*	*0.73*	*-0.20*	*1.64*	
Point-break 2	4.9 ± 0.6	24.8 ± 3.5	19.8 ± 2.4	44.8 ± 20.8 ^{b}	730.3 ± 80.4 ^{c}
Effect size (*d*)				*-0.82*	*-2.63*
Heat Winner	4.3 ± 1.5	25.1 ± 3.5	19.2 ± 1.4	54.1 ± 13.5	
Heat Loser	5.7 ± 3.5	24.5 ± 3.2	19.4 ± 1.6	49.8 ± 29.1	
Effect size (*d*)	*-0.52*	*0.18*	*-0.13*	*0.19*	

^{b} = Sig.diff to Point-break 1, ^{c} = Sig.diff to Beach-break, ^{d} = Sig.diff to Point-break 2

The total (combining wave riding) distance covered per heat in Point-break 1 and Point-break 2 was 808.5 ± 190.9m and 775.1 ± 101.2m, respectively. The total average distance covered per heat at the Beach-break reported a moderate, and large (1.18 *d*, 2.09 *d*) significant difference ($p \leq 0.01$) compared to Point-break 1 and Point-break 2, respectively, representing 990.2 ± 104.1m.

Surfers who placed higher in the heats at Point-break 1 had a small (0.50 *d*) difference in maximal speed, and a small (0.53 *d*) difference in total wave distance. Whereas, surfers who placed higher in the heats at Beach-break had a moderate (0.73 *d*) difference in maximal speed and a large (1.64 *d*) difference in total wave distance. These findings however, were not significant but warrant further investigation.

DISCUSSION

The purpose of the study was to determine the workloads (i.e. exercise durations, distances, velocity of movements, and work to rest ratios) experienced during competitive surfing and to ascertain whether activity profiles differ between locations or between surfers competing in the same heats. The paper also provided a much-needed update on the analysis of competitive surfing. Data from this study reported differences from location to location with greater paddling bouts, paddling percentage, and work to relief ratio at the exposed beach break (Beach-break), with longer wave rides and longer continuous paddling bouts at the first point break (Point-break 1). Surfers who placed higher (1^{st} – 2^{nd}) also appeared to surf waves for longer, and at faster speeds than those placed lower (3^{rd} – 4^{th}). Riding waves for longer and at faster speeds presents greater opportunity to perform scoring maneuvers. Faster velocities may also suggest the selection of larger waves, as wave height will influence maximal velocity (3, 6). Therefore, the wave selection process from the heat winners appears to have an influence on surfing performance.

From the current study, it was reported that surfers spent, on average, the most time paddling (44%), followed closely by stationary periods (42%). These results are similar to previous literature (3, 21, 23, 27), however, stationary periods were vastly different to previous data (23%) (11). Further, the time spent paddling for a wave was the same as previous studies (11, 27) and the wave riding percent was also similar to previous studies (21, 23, 27). However, wave riding percent, percentage of time spent performing each TMA activity, and the stationary percent were also noticeably different to previous literature using similar caliber surfers (11, 27). Such differences may be due to the influence of surfing conditions on performance. These differences between the studies would be expected given each location of surfing has its own set of unique variables associated with the surf break and surf conditions vary throughout the day. Indeed, in this study it was found that differences exist between the three events, notably between the beach-break and the two point-breaks. Paddling (not including paddling for wave) percent only ranged from 41% and 44% at Point-break 1 and Point-break 2 respectively, to 48% at Beach-break. The paddling percent at Beach-break was significantly greater than at Point-break 1, which was to be expected given the nature of the surf break. Interestingly, Point-break 1 and 2 had the same count of paddling action (36), but Beach-break had significantly more (45) ($p<0.05$), which can be attributed to the conditions and type of surf break.

The Beach-break had surfers paddling for shorter periods between the sets of waves; this meant a high count of short paddle bouts (82% <21 s), as well as miscellaneous bouts (23), compared to just 12 and 15 at Point-break 2 and Point-break 1, respectively. Consequently, a significantly higher work to rest-relief-ratio was achieved at Beach-break (1.7:1) ($p<0.05$). On the other hand, the point breaks dictated longer continuous durations of paddling back to the take-off zone. This was due to the significantly ($p<0.05$) longer rides at Point-break 1, and the lack of surf at Point-break 2 which had surfers paddling to different positions to locate better waves. Point-break 1 and Point-break 2 reported 6% and 7% of total paddling times >46 s, whereas Beach-break only reported 4% of total paddling time. A point-break with smaller and inconsistent conditions means longer continuous stationary periods waiting for waves, as seen at Point-break 1 and Point-break 2. This meant that Point-break 1 and Point-break 2 reported a higher stationary percent (48% and 43%, respectively), average stationary time (21 and 19 s, respectively), and percent of time spent continuously stationary for longer durations (13% and 12% of total paddling times >46 s, respectively). Whereas, Beach-break only reported 34% of total heat time stationary, averaging just 15 s per bout, which was significantly different ($p<0.05$) to Point-break 1, and only 7% of time >46 s.

The percent of time spent paddling for a wave, counts, and average time spent performing the action were surprisingly similar, with Point-break 2 reporting a minor difference in percentage of total heat time and time performing it. Interestingly, Point-break 1 and Point-break 2 had contrasting sprint paddle durations with Point-break 1 reporting 92% of paddling percentage spent <6 s, whereas Point-break 2 had 77% >4 s, which was significantly different ($p<0.05$). These results are likely due to the power/momentum of the waves and the ways in which they were breaking. This was observed at Point-break 2 where surfers had to generate as much speed as possible and paddling for a longer duration. On day 2, the swell was lacking at Point-break 2, this effected the wave breaking and the location became a combination of a beach-break and a point-break, depending on the swell, tide and the best wave options. In addition, several waves at Point-break 2 took longer to break once reaching the breaking zone, whereas Point-break 1 waves broke in a consistent location.

Finally, Point-break 1 reported the longest average wave riding time (14 s), which was significantly greater than that of the Beach-break (10 s) and Point-break 2 (8 s). This was due to longer, quality waves featuring at the location. Further, the Beach-break sustained a higher average wave count with six per heat, as opposed to four at Point-break 1 and five at Point-break 2. These results are also supported by previous data for difference in surf break type (11).

The speeds recorded from the current study (21.8 $km \cdot h^{-1}$, 23.6 $km \cdot h^{-1}$ and 24.8 $km \cdot h^{-1}$) are somewhat similar to that of previous studies (21.9 $km \cdot h^{-1}$) (3), (25.2$km \cdot h^{-1}$) (10), for the average maximal speed surfers reach, however, they are much slower than that of Farley, Harris and Kilding (11) who reported speeds of 33.4 $km \cdot h^{-1}$. The lower speeds reported in the current study are likely due to the size of the waves. The decreased wave quality and size likely contributed to the moderately significant ($p \leq 0.01$) differences between Point-break 1 maximum speed (-0.60 *d*, -0.88 *d*) and average speed (*-0.95 d, -1.06 d),* compared to Beach-break and Point-break 2 respectively, with Beach-break maximum speed reporting a small (*-0.38 d*), significant (p=0.04) difference to Point-break 2. Due to the quality of the waves at Point-break 1, total wave riding distances were longer than the small (-0.47 *d*) and moderate (-0.82 *d*) significant ($p \leq 0.01$) wave riding distances reported at Beach-break and Point-break 2. This reiterates the differences between locations, surf breaks, and surf conditions on the day.

Data between the surfer's heat placing, speeds obtained, and distances travelled warrants further investigation due to the small (0.50 *d*) and moderate (0.73 *d*) differences in maximal speed, and small (0.53 *d*) and large (1.64 *d*) differences in total wave distance at Point-break 1 and Beach-break, respectively. Although not significantly verified, it is an interesting finding nonetheless.

Potentially, those who win/place higher in their respected heats are able to generate more speed, equating to increased power and spray generation during turns on the wave. Spray generated is a judging cue and would therefore result in higher points being awarded.

It should be noted that GPS recording alone is not a reliable source to quantify wave riding times and distances. Although the units had a software algorithm installed determining when a surfer started and finished a wave, GPS data at times suggested that the surfer was still riding a wave, when in fact they had fallen off. The momentum of that fall was also found to be recorded as surfers' speed on a wave. Therefore, the authors suggest that GPS data recorded per session should not be interpreted alone and instead be synchronized with video data in order to ascertain correct durations of time and distance.

Conclusion

The results of this study provide a much-needed update of surfing performance and information regarding comparisons between surf locations and conditions, workloads, and surfers competing in the same heats. The differences found between the three locations were likely due to environmental variables such as the swell and how the waves were breaking, as well as the skill level of participants, particularly when riding the waves. The majority of time however, is spent performing moderate to high intensity activity, with surfers covering distances of approximately 770 to 990m in a 20-minute heat. This is in contrast to previously reported data. Point-break 1 and Point-break 2 had longer continuous periods of paddling than Beach-break due to their geographical locations as point-breaks. In comparison, Beach-break consisted of more consistent short periods of paddling and duck-diving under breaking waves to get beyond the waves to the take-off zones. This resulted in a significantly higher work-to-relief ratio and distance covered. Additionally, within these events, it appeared that there may be a relationship between the surfers' heat placing, speeds obtained, and distance travelled. However, the associations between these variables were not statistically verified within the study. Ultimately, the activity profiles and demands experienced during competitive surfing differ between locations and types of surf break.

PRACTICAL APPLICATIONS

This study provides a greater in-depth analysis determining the workloads (i.e. exercise durations, distances, velocity of movements, and work-to-relief ratios) experienced during competitive surfing. Point-breaks appear to have longer continuous periods of paddling and longer wave rides, whereas the Beach-break exhibited significantly higher work-to-relief ratio. The monitoring of the activities from this study can be used to develop specific training drills based on the TMA results. Such information would benefit coaches and competitive surfers alike, through aiding in the design of training programs and monitoring of surfers' workloads (i.e. paddling durations, distances, and intensities). From a training perspective, surfers expecting to surf at a point-break should work on longer durations of continuous paddling, whereas for a beach-break scenario, they should work on short maximal sprint paddle bouts and repeated long sprint paddling for waves. See Farley, Secomb, Parsonage, Lundgren, Abbiss and Sheppard (12) on HITT and SIT training and Coyne, Tran, Secomb, Lundgren, Farley, Newton and Sheppard (4) on the benefits of strength training to maximize paddling performance. However, given the differences noted between the two point-breaks from to the environmental conditions, it can be suggested that planning and preparation must be further tailored to a specific location due to differences within similar surf breaks. Consequently, one method of training does not necessary suit specific locations due to changes that can occur, therefore, a crossover of training styles is recommended. To enhance their competitive potential, surfers should aim to generate higher maximal speeds and ride waves for as long as possible by improving speed generation and other athletic competencies that improve strength, power, and balance coordination. This could be particularly useful during longer waves (i.e. excess over 120m), where surfers are likely to encounter muscular fatigue, consequently limiting the execution of maneuvers. A strength and conditioning routine focusing on upper-body power and lower body strength is strongly recommended. For future research and performance analysis application with athletes, it is highly recommended that TMA and GPS must be synchronized for accurate analysis.

References

1. Abdelkrim NB, El Fazaa S, and El Ati J. Time–motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br J Sports Med* 41: 69-75, 2007.
2. ASP. Association of Surfing Professionals Rule Book 2013. Coolangatta, QLD, Australia: Association of Surfing Professionals LLC, 2013.
3. Barlow MJ, Gresty K, Findlay M, Cooke CB, and Davidson MA. The effect of wave conditions and surfer ability on performance and the physiological response of recreational surfers. *J Strength Cond Res* 28: 2946-2953, 2014.
4. Coyne JOC, Tran TT, Secomb JL, Lundgren LE, Farley ORL, Newton RU, and Sheppard JM. Maximal Strength Training Improves Surfboard Sprint and Endurance Paddling Performance in Competitive and Recreational Surfers. *J Strength Cond Res* 31: 244-253, 2017.
5. Cunniffe B, Proctor W, and Baker JS. An evaluation of the physiological demands of elite rugby union using global positioning system tracking software. *J Strength Cond Res* 23: 1195-1203, 2009.
6. Dally WR. Improved stochastic models for surfing climate. *J Coast Res*: 41-50, 2001.
7. Duthie GM, Pyne D, and Hooper S. Time motion analysis of 2001 and 2002 Super 12 rugby. *J Sport Sci* 23: 523-530, 2005.
8. Farley ORL, Abbiss CR, and Sheppard JM. Testing protocols for profiling of surfers' anaerobic and aerobic fitness: A review. *Strength Cond J* 38: 52-65, 2016.
9. Farley ORL, Abbiss CR, and Sheppard JM. Performance analysis of surfing: a review. *J Strength Cond Res* 31: 260-271, 2017.
10. Farley ORL, Andrews M, Secomb JL, Tran TT, Lundgren L, Abbiss C, and Sheppard JM. The validity and inter-unit reliability of custom-made Surtrax GPS units and use during surfing. *J Aust Strength Cond* 22: 102-105, 2014.
11. Farley ORL, Harris NK, and Kilding AE. Physiological demands of competitive surfing. *J Strength Cond Res* 26: 1887–1896, 2012.
12. Farley ORL, Secomb JL, Parsonage JR, Lundgren LE, Abbiss CR, and Sheppard JM. Five Weeks of Sprint and High-Intensity Interval Training Improves Paddling Performance in Adolescent Surfers. *J Strength Cond Res* 30: 2446-2452, 2016.
13. Hopkins WG. How to interpret changes in an athletic performance test. *Sportsci* 8: 1-7, 2004.
14. Hughes MD. Performance analysis – a 2004 perspective. *Int J Perform Anal Sport* 4: 103-109, 2004.
15. King T, Jenkins D, and Gabbett T. A time–motion analysis of professional rugby league match-play. *J Sports Sci* 27: 213–219, 2009.
16. Kovacs MS. Energy system-specific training for tennis. *Strength Cond J* 26: 10-13, 2004.
17. Larsson P. Global positioning system and sport-specific testing. *Sports Med* 33: 1093-1101, 2003.
18. Lowdon BJ. Fitness requirements for surfing. *Sports Coach* 6: 35-38, 1983.

19. Lythe J. *The physical demands of elite men's field hockey and the effects of differing substitution methods on the physical and technical outputs of strikers during match play*. Auckland, New Zealand: Auckland University of Technology, 2008.
20. Matthew D and Delextrat A. Heart rate, blood lactate concentration, and time–motion analysis of female basketball players during competition. *J Sports Sci* 27: 813–821, 2009.
21. Meir RA, Lowdon BJ, and Davie AJ. Heart rates and estimated energy expenditure during recreational surfing. *Aust J Sci Med Sport* 23: 70–74, 1991.
22. Mendez-Villanueva A and Bishop D. Physiological aspects of surfboard riding performance. *Sports Med* 35: 55–70, 2005.
23. Mendez-Villanueva A, Bishop D, and Hamer P. Activity profile of world-class professional surfers during competition: A case study. *J Strength Cond Res* 20: 477–482, 2006.
24. Mendez-Villanueva A, Perez-Landaluce J, Bishop D, Fernandez-Garcia B, Ortolano R, Leibar X, and Terrados N. Upper body fitness comparisons between two groups of competitive surfboard riders. *J Sci Med Sport* 8: 43–51, 2005.
25. Portas MD, Harley JA, Barnes CA, and Rush CJ. The validity and reliability of 1-Hz and 5-Hz global positioning systems for linear, multidirectional, and soccer-specific activities. *Int J Sports Physiol Perform* 5: 448-458, 2010.
26. Reilly T and Thomas V. A motion analysis of work-rate in different positional roles in professional football match-play. *J Hum Movement Stud* 2: 87-97, 1976.
27. Secomb JL, Sheppard JM, and Dascombe BJ. Time-motion analysis of a 2-hour surfing training session. *Int J Sports Physiol Perform* 10: 17-22, 2014.
28. Taylor J. Basketball: Applying time motion data to conditioning. *Strength Cond J* 25: 57-64, 2003.
29. Townshend A, Worringham C, and Stewart I. Assessment of speed and position during human locomotion using non-differential GPS. *Med Sci Sports Exerc* 40: 124-132, 2007.

Acknowledgements

The authors would like to acknowledge the involvement and gratitude towards the surfers involved during the research, and Olivia Baudinet for her input. No funding was received for this study and there were no conflicts of interest.