

PHYSIOLOGICAL DEMANDS OF COMPETITIVE SURFING

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ABSTRACT

Farley, ORL, Harris, NK, and Kilding, AE. Physiological demands of competitive surfing. *J Strength Cond Res* 26(7): 1887–1896, 2012—This study was a performance analysis of surfing athletes during competitive surfing events in an attempt to inform the development of surfing-specific conditioning. Twelve nationally ranked surfers were fitted with heart rate (HR) monitors and global positioning system (GPS) units and videoed during the heats of 2 sanctioned competitions. Means and SDs represented the centrality and spread of analyzed data. From the 32 videos analyzed, the greatest amount of time spent during surfing was paddling ($54 \pm 6.3\%$ of the total time) (% TT). The remaining stationary represented $28 \pm 6.9\%$ TT, wave riding, and paddling for a wave represented only $8 \pm 2\%$ TT and $4 \pm 1.5\%$ TT, respectively. Surfers spent $61 \pm 7\%$ of the total paddling bouts and $64 \pm 6.8\%$ of total stationary bouts between 1 and 10 seconds. The average speed recorded via the GPS for all the subjects was $3.7 \pm 0.6 \text{ km}\cdot\text{h}^{-1}$, with an average maximum speed of $33.4 \pm 6.5 \text{ km}\cdot\text{h}^{-1}$ ($45 \text{ km}\cdot\text{h}^{-1}$ was the highest speed recorded). The average distance covered was $1,605 \pm 313 \text{ m}$. The mean HR during the surf competitions was $139 \pm 11 \text{ b}\cdot\text{min}^{-1}$ (64% HRmax), with a (mean) peak of $190 \pm 12 \text{ b}\cdot\text{min}^{-1}$ (87% HRmax). Sixty percent TT was spent between 56 and 74% of the age-predicted HR maximum (HRmax), 19% TT >46% HRmax, and approximately 3% TT >83% HRmax. Competitive surfing therefore 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. Surfing-specific conditioning sessions should attempt to replicate such a profile.

KEY WORDS surfboard riding, video analysis, GPS, heart rates

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.

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Performance analysis incorporates a number of applications including tactical and technical evaluation, analysis of movement and physical demands, and the development of predictive models (6,11). Coaches and sport scientists can now collect objective data on athletes' work rates via heart rate (HR) monitors (2,5,8,10), evaluate training loads, movement patterns and activity profiles of athletes via global positioning system (GPS) units (3,9,11,20) and track athletes via time-motion analysis (1,4,7,12). Developments in technology have made it possible to use such devices to record valid, reliable data, but limited studies on surfing have been conducted to date. Only 2 studies have analyzed surfers' HRs (13,14) and activity through time-motion analysis using video recordings (13,15). The mean HRs of recreational ($n=6$) (13) and ($n=5$) competitive surfers (14) were 135 ± 6 and $146 \pm 20 \text{ b}\cdot\text{min}^{-1}$ of the total duration, respectively. Meir et al. (13) also examined the activity patterns of 1 hour recreational surfing, reporting that 44% of the total time (TT) was spent paddling, 35% stationary, 5% wave riding, and 16% miscellaneous activity. More recently, world-class professional surfers were investigated during competitive heats (15) in which surfers spent 51% of the TT 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. The 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 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; HR monitor, GPS, and video footage data were obtained from nationally ranked surfers during competition. Descriptive data were subsequently produced on the surfers' HRs, durations of activities, velocities, and distances covered while competing.

Subjects

Twelve national-level male surfers (23.6 ± 5.7 years, $73 \pm 10.3 \text{ kg}$, $179.2 \pm 6.8 \text{ cm}$) volunteered to participate in this study. The subjects who had a history of surfing at least 3 times per week and have competed for at least 3 years were tested during the final 2 events of the competitive season. All the subjects were from the current top 30 ranked surfers in

TABLE 1. GPS speed zones and category of intensity.*

Zone	Speed range (km·min ⁻¹)	Category label
1	1–4	Slow-mod slow paddling
2	4.1–8	Moderate speed/very high-intensity paddling
3	8.1–12	
4	12.1–16	Moderate wave riding
5	16.1–20	
6	20.1–25	High-speed wave riding
7	25.1–30	
8	30.1–40	Extremely high speed wave riding
9	40.1–46	

*GPS = global positioning system.

New Zealand and competing in the sanctioned New Zealand Surf Association competition. The subjects were tested after their normal routine of sleep, nutritional, and hydration levels before competitions. Ethics approval from the University Ethics committee was gained before commencement of the study, and written informed consent was obtained from each subject before commencing data collection.

Equipment

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

using a 9 megapixel, 60 times optical zoom, Sony camera (Sony, DCR-SR67, Tokyo, 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

Before 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 the conclusion of the heat), position recording by the GPS unit was manually stopped. The data from the GPS unit were downloaded to a computer for subsequent analysis.

The first data collection was conducted during event 1, an event where the beach break swell ranged between 1 and 1.5 m (3- to 4-ft faces), with an onshore wind causing the waves to be choppy. Event 2, the second data collection, was conducted at a point break beach where wave conditions were consistently 1.5 m (4 ft), approximately. The point break provided a longer quality wave that enabled the subjects to ride for longer periods.

Global Position System

The GPS units were turned on to locate satellites approximately 5 minutes before use. The GPS unit was placed into a water tight sealed bag, turned on to record, then positioned under the wet suit of the subject around the upper Thoracic Vertebra and Scapula. The subjects' wet suits held the units in place. This procedure was implemented approximately 5 minutes before the subjects entered the water. Data were downloaded using the manufacturer-supplied software (GPSports Team AMS v1.6.3.0, Australia). Raw data were then exported into Microsoft Excel 2010 (© 2010 Microsoft Corporation) for analysis.

Heart Rate

During the heats, the subjects wore an HR monitor chest strap (Polar T31) fastened

TABLE 2. Heart rate zones and category of intensity.*

Zone	HR zone (b·min ⁻¹)	Approximate %HR maximum†	Category label
1	1–100	<45	Low intensity
2	101–120	>45–<55	Moderate intensity
3	121–140	>55–<65	
4	141–160	>65–<75	High intensity
5	161–180	>75–<85	
6	181–200	>85–<95	Very high intensity
7	201–220	>95	Maximal intensity

*HR = heart rate.

†Heart rate zones are measured by the age-predicted method (20).

TABLE 3. Time-motion activity criteria.

Motion category	Definitions by Meir et al. (13)	Current study definitions
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 1 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.
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.	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	Walking or running up the beach, wading, duck diving under white water, and recovering and getting back on the surfboard after falling.	Defined as duck diving under broken and 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
Paddling for wave		Recorded from the time the subject turned toward 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.

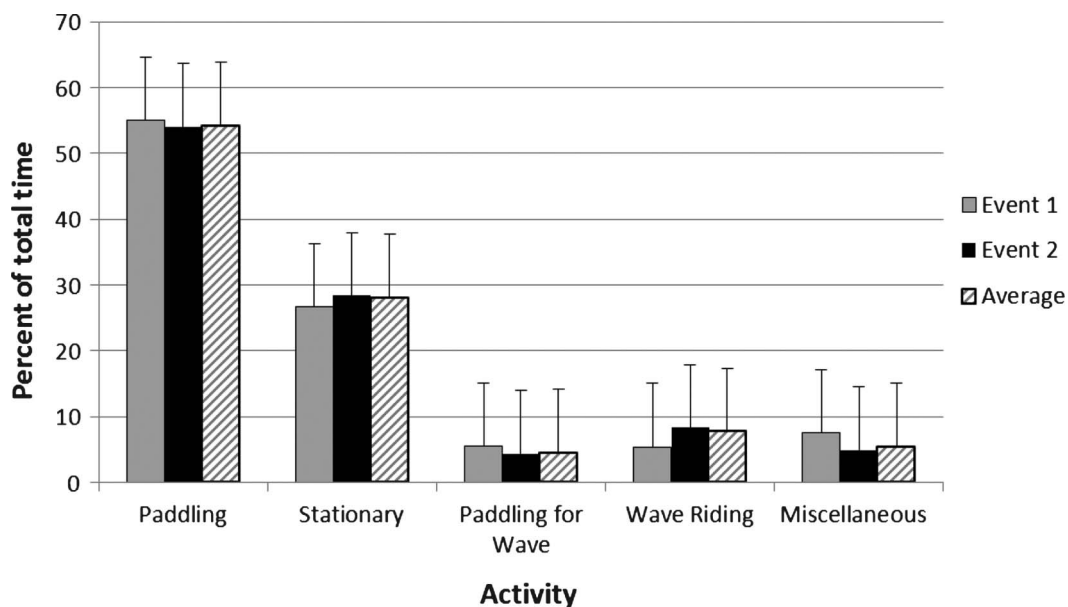


Figure 1. Mean proportion of total time spent performed during the 20-minute competitive surfing heats.

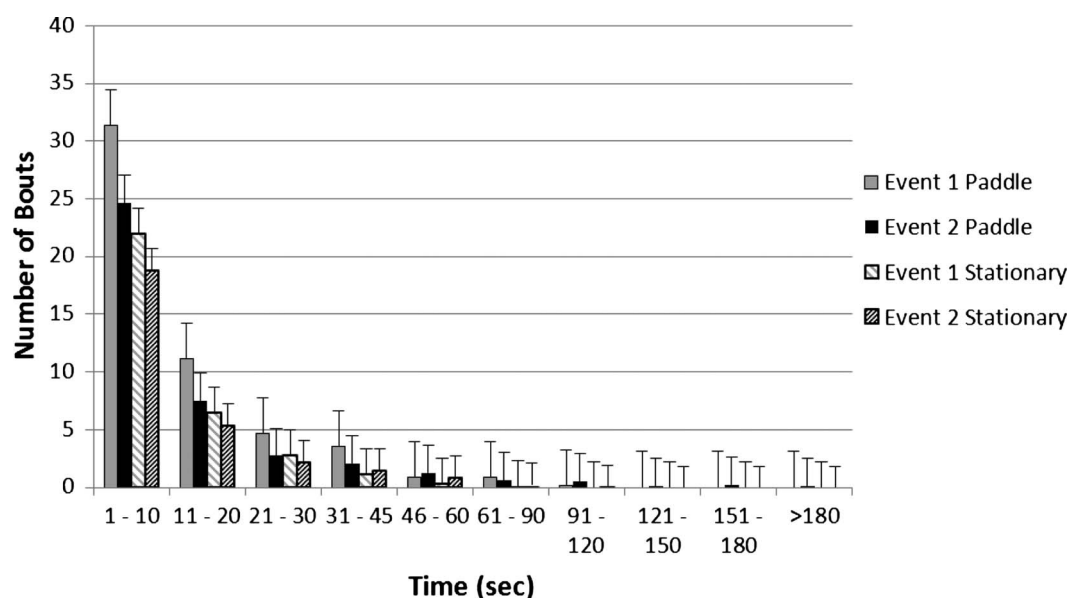


Figure 2. Mean number of paddling bouts (not including paddling for wave criteria) and stationary bouts of various durations performed during a competitive surfing heat.

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 were downloaded to the manufacturer-supplied software (GPSports Team AMS v1.6.3.0, Australia). Raw data were then exported into Microsoft Excel 2010 (© 2010 Microsoft Corporation) for analysis.

Video Analysis

Each heat recorded during the 2 events was 20 minutes in duration. Ten heats of event 1 competition were videoed with only 1 subject videoed per heat. During event 2, 26 individually videoed heats (surfers) were recorded during the 3 days of competition with 2 subjects recorded during each heat. Different subjects were videoed each time. The video camera at event 1 was positioned on a sand dune

TABLE 4. Mean time spent performing the activity and number of times the action is performed during the 20-minute competitive surfing heats ($N = 12$).

	Paddling	Stationary	Paddling for wave	Wave riding	Miscellaneous
Average continuous time (s) per action					
Event 1	13.3	10.4	4.5	8.2	3.3
Event 2	17.0	12.2	4.1	16.4	3.0
Mean	16.3	11.9	4.2	14.9	3.1
SD	4.5	3.9	0.8	5.6	0.6
Average count (n) of actions per heat					
Event 1	53	33	16	9	28
Event 2	40	29	13	6	19
Mean	42	30	13	7	21
SD	9.4	6.7	4.1	1.9	6.0

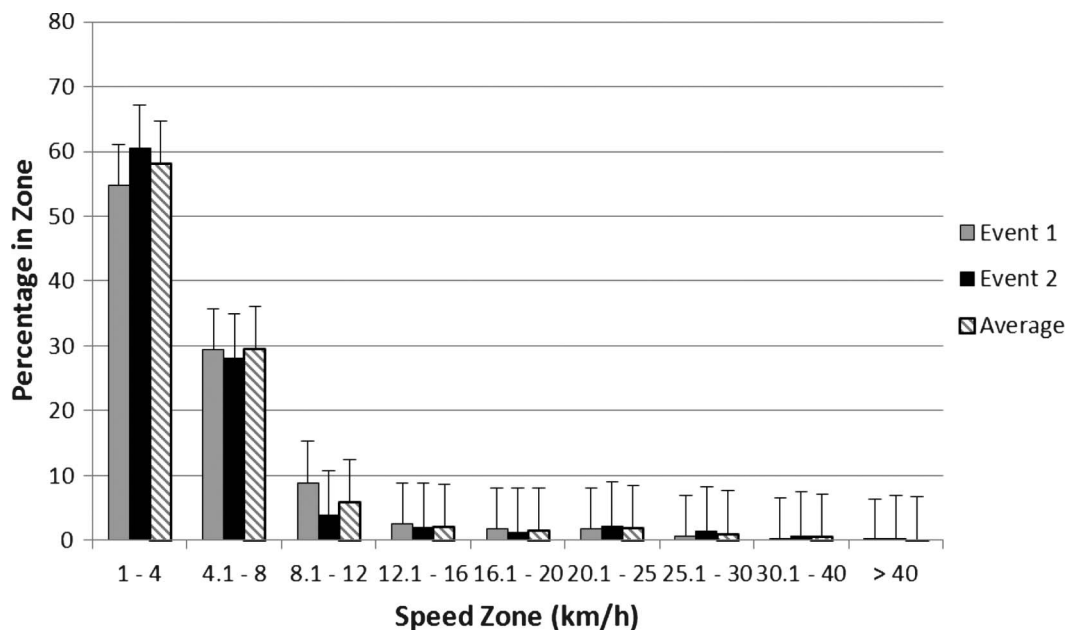


Figure 3. Percent time spent within the respective speed zone.

approximately 2 m high with the camera set at a 1 m height overlooking the surf and approximately 50 m away from the surf (depending on the tide). The location was as side-on as geography allowed. At event 2, 2 Sony cameras were positioned

on a hill approximately 10 m high overlooking the bay. Both cameras were set at a 1 m height, and approximately 5–10 m (depending on the tide) away from the sea, with the subject another 10–30 m away in the surf. The location of the camera

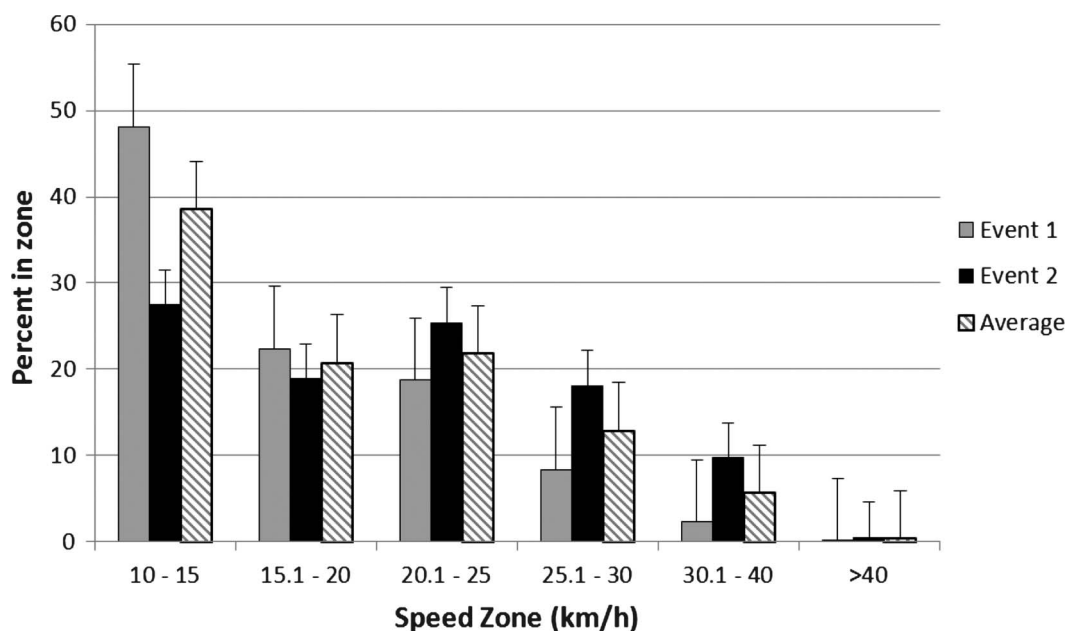


Figure 4. Percent time spent within the respective wave riding speed zones.

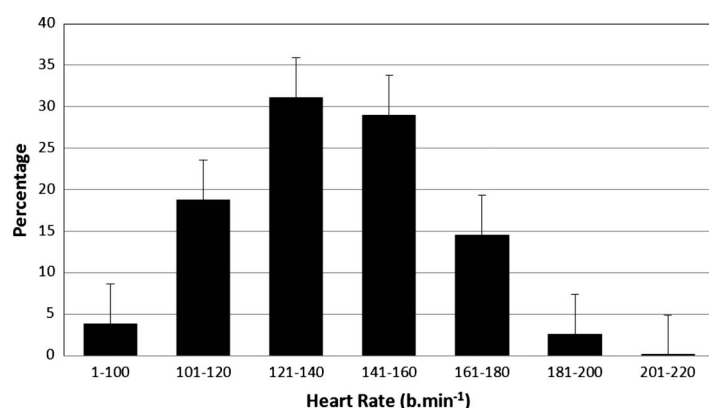


Figure 5. Mean percent of the heart rates during the competitions.

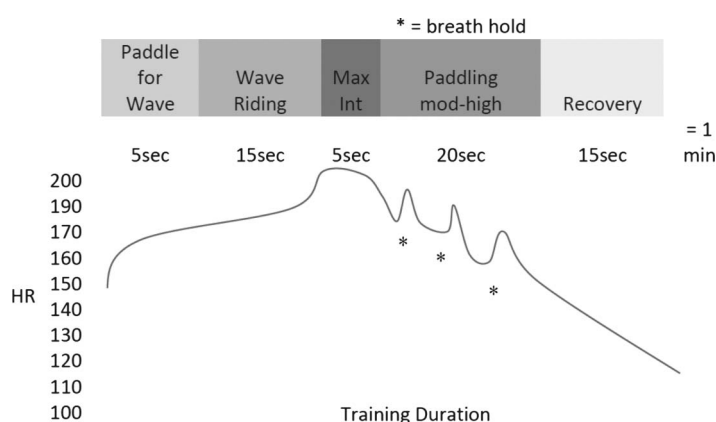


Figure 6. Intermittent training example.

was side on, looking along the waves as they broke. This position ensured that the subject was not lost when going behind the wave, as when filming from front on.

The videos were started and paused every time the activity changed, with the times recorded for each activity in a Microsoft Excel spreadsheet. Videos were rewound back and played up to 5 times for analysis of exact durations and to exclude any uncertainty in time allocated. Only one investigator was responsible for all coding of activity from video replay.

Statistical Analyses

The GPS data were edited to only include the total heat time (20 minutes) spent in the surf and then separated into 9 speed zones as presented in Table 1. Speed zones were established from the GPS data recorded. This was established by an emerging pattern of speeds the surfers traveled

at during the different activities. No previous study has established speed zones before in surfing.

Similarly, HR data were edited to only include the 20-minute surfing heats. The surfing HR data were then divided into 7 zones as displayed in Table 2. The mean and peak HRs were recorded. Mendez-Villanueva and Bishop (14) categorized HRs into exercise intensity as a percentage of peak into 6 zones. Higher HRs were obtained in this study; therefore, 7 categories (HR zones) were established.

Time-Motion Activity Criteria

A surfer's actions were classified based on Meir et al. (13), with the new addition of 'paddling for wave' added, with slight modifications also made to the classifications (Table 3).

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

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

RESULTS

Activity Durations

The mean ($\pm SD$) percent values of the time spent on each activity are presented in Figure 1. From the 32 videos analyzed, the greatest amount of time spent during surfing was paddling ($54 \pm 6.3\%$). Remaining stationary represented ($28 \pm 6.9\%$) of the TT, wave riding, and paddling for a wave represented only 8 ± 2 and $4 \pm 1.5\%$, respectively. Miscellaneous periods typically included 3 ± 1.4 seconds of continuous breath holds directly after wave riding.

In Figure 2, the mean frequencies of paddling and stationary bouts at different time intervals during a surfing heat are 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 observed during the heats. The longest period spent stationary was approximately ($64 \pm 6.8\%$) between 1 and 10 seconds, when combined 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.

Table 4 shows the average continuous time spent performing activities, before changing to another activity. The most time was spent paddling (16 ± 4.5 seconds) often because of paddling back to the take-off area. Time spent wave riding was also substantial (15 ± 5.6 seconds). In Table 3, the mean counts of the surfers' actions per heat are presented. Paddling was the largest count of the actions, performed during a heat (n) (42 ± 9.4) times. Stationary was relatively close with an average of (n) (30 ± 6.7) counts per heat. Paddling for the wave was almost double of the actual waves caught in wave riding with (n) (13 ± 4.1) and (n) (7 ± 1.9) counts, respectively.

Speeds

Average times (percent) per speed zone are presented in Figure 3. The highest percentage ($58 \pm 9.9\%$) was in the slowest zone, between 1 and 4 $\text{km}\cdot\text{h}^{-1}$. The percentage of time spent within each speed zone decreased to $<5\%$, for all the zones $>8\text{--}12 \text{ km}\cdot\text{h}^{-1}$. The average speed for all of the subjects combined was ($3.7 \pm 0.6 \text{ km}\cdot\text{h}^{-1}$), with an average maximum speed of ($33.4 \pm 6.5 \text{ km}\cdot\text{h}^{-1}$).

Figure 4 displays the averages within the wave speed zones. The top percentage accumulated was ($38.6 \pm 18.8\%$) within the speed zone of $10\text{--}15 \text{ km}\cdot\text{h}^{-1}$. The third speed zone of $20.1\text{--}25 \text{ km}\cdot\text{h}^{-1}$ has the second highest percentage surfers reach while wave riding, representing ($21.8 \pm 8.6\%$). The average speed for all the surfers combined was $22.5 \pm 3.8 \text{ km}\cdot\text{h}^{-1}$.

Distances

The average total distance covered per heat in event 1 was $1,433 \pm 249.8 \text{ m}$. The total mean distance covered per heat in event 2 was higher, representing $1,806 \pm 266.8 \text{ m}$. The average from the 2 events combined was $1,605 \pm 313.5 \text{ m}$.

Heart Rates

The surfers spent 60% of the TT from 56 to 74% of age-predicted HR maximum (HRmax), 19% above 46% HRmax and approximately 3% above 83% HRmax. Only 3 surfers from the competitions reached HRs $>200 \text{ b}\cdot\text{min}^{-1}$ (99, 103, 106% HRmax).

In Figure 5, the average HRs of the subjects during both competitions are shown. The HR zones of $121\text{--}140$ and $141\text{--}160 \text{ b}\cdot\text{min}^{-1}$ are very similar, ranging between ($31 \pm 12.7\%$) and ($29 \pm 11.3\%$), respectively, representing 60% of the total HR zones. The maximal HR zones of $181\text{--}220 \text{ b}\cdot\text{min}^{-1}$ represented just 3% of TT. At the end of each wave ride, peaks in HR were observed.

The mean HR during the surf competitions was $139.7 \pm 11. \text{ b}\cdot\text{min}^{-1}$, which equated to 64.4% HRmax. The peak HR reached during the events was $190 \pm 12. \text{ b}\cdot\text{min}^{-1}$ 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 (13,14,16,17) 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 because of 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 level of motivation of the participant (13–15). Moreover, during competition, tactical decisions because of different factors (e.g., heat opponent's scores or wave selection) might have also have had an impact on the TT surfers' spent in these activities (14,15). Ultimately, the environmental conditions are a substantial factor which greatly influences the degree of TT spent paddling, stationary or riding waves and therefore the physiological costs associated with this activity (13). The reader should be cognizant of this limitation when interpreting these findings. Nonetheless, the results and data collected from the 2 sanctioned surfing events still provide an insight into the physiological aspects, time, and activity patterns associated with surfing.

Paddling was performed for 54% of the TT, which was noticeably higher than that previously reported (13), but comparable with some other time-motion studies (15). Stationary representing 28% of the TT was lower than in the previous studies (13,15). Meir et al. (13) reported that 44 and 35% of the TT was spent paddling and remaining stationary, respectively. Mendez-Villanueva et al. (15) reported that paddling and stationary represented 51 and 42% of the TT, respectively. The durations of time spent wave riding, performing miscellaneous activities, and paddling for a wave represented 8, 5, and 4% of the TT, respectively in this study. In comparison, Meir et al. (13) reported 5% for wave riding, and 16% for miscellaneous activities for the TT, respectively. Moreover, Mendez-Villanueva et al. (15) reported that wave riding accounted for 3.8% of the TT, whereas miscellaneous activity accounted for the remaining 2.5% of the TT.

Based on the video analysis, 80% of the total paddling time was performed for 1–20 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 because of 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. The HR data support this typical activity pattern with HR dropping by 10–21 beats ($\sim 5\text{--}13\%$ HR max) 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 3 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 the 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 this study) are likely to be higher; however, judging is based on the 2 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.

This study has recorded higher activities in some movement categories and lower in others in comparison to those previously reported (13,15). By combining the current and the 2 previous studies (13,15), it appears that surfers spend approximately 50% of their TT paddling, approximately 35% of their TT stationary, approximately 6% wave riding and approximately 8% performing miscellaneous activities.

In this 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 (18). We determined that surfers spent most of their time ($58 \pm 10\%$) within the slowest speed zone ($1\text{--}4 \text{ km}\cdot\text{h}^{-1}$), 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 $8 \text{ km}\cdot\text{h}^{-1}$. 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 $3.7 \pm 0.6 \text{ km}\cdot\text{h}^{-1}$, with an average max of $33.4 \pm 6.5 \text{ km}\cdot\text{h}^{-1}$.

The distances covered provide an insight into how far surfers travel and may be useful in designing training routines. The average from the 2 events combined was $1,605 \pm 313.5 \text{ m}$ in 20 minutes. Approximately $947 \pm 185.6 \text{ m}$ was spent paddling ranging from slow to high-intensity bursts for the waves, and approximately $128.4 \pm 25 \text{ m}$ was spent wave riding. The larger distances traveled at event 2 (1,806 m) were most likely because of waves wrapping around the point producing longer rides and conditions. Once the surfer was up and riding a wave at event 2, 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 with the beach break of event 1. It has been asserted that the surfing environments and conditions profoundly affect the performance variables associated with surfing (13,14,16,17). The reader should be cognizant of this when interpreting these findings.

We hypothesized that the HR would peak when paddling to catch the wave; 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 the so-called HR lag (2).

The surf athletes spent 60% of the all surf heats ranging from 56 to 74% of HRmax. The 2 HR zones the surfers encountered the most during competitions are a useful insight into the physiological workloads surfers encounter. By using the age-predicted maximal HR 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 HR. This study recorded a similar mean HR and a higher peak HR to the 2 previous studies of Meir et al. (13) and Mendez-Villanueva and Bishop (14). The mean HR during the surf competitions was $140 \pm 11.6 \text{ b}\cdot\text{min}^{-1}$, whereas, Meir et al. (13) recorded $135 \pm 6.9 \text{ b}\cdot\text{min}^{-1}$ during recreational surfing, and Mendez-Villanueva and Bishop (14) recorded $146 \pm 20 \text{ b}\cdot\text{min}^{-1}$ during simulated heat surfing. The peak HR reached during the events was (mean) $190 \pm 12 \text{ b}\cdot\text{min}^{-1}$, whereas, Meir et al. (13) recorded a peak HR of $171 \pm 7 \text{ b}\cdot\text{min}^{-1}$.

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. (13) recorded HRs during recreational surfing over a 60-minute period; therefore, the physiological and psychological demands would have been less because of there being no pressure on performance nor competition for the waves and number of waves they caught. The subjects used were recreational surfers who were simply catching waves without the competitive element of this study, hints to the lower HR intensities. In addition, the HRs were recorded at 15-second intervals on 6 subjects and hence should be considered as approximations only, because HR will fluctuate over any given 15-second interval. Mendez-Villanueva and Bishop (14) recorded the HR continuously at 5-second intervals on only 5 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 HRs 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 this study recorded HRs at 1-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 cardiorespiratory fitness in healthy adults (19).

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 (14,21). Surfers also cover considerable distances, approximately 1,600 m in a 20-minute heat, and can reach speeds up to 45 km·h⁻¹, although approximately 80% of the TT is spent at low speeds. The physiological demands imposed on each surfer and activity durations are subject to conditions.

PRACTICAL APPLICATIONS

Our data provide 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 6 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 >120 b·min⁻¹.

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 on around 1,500–2,500 m as observed from distances covered in the competitions from the GPS tracking. Training should also include forms of crosstraining, such as cycling, running, and swimming for periods of 20–40 minutes. The crosstraining should also include bouts of high-intensity HR workloads (180–200 b·min⁻¹), to simulate the sport-specific aspects of surfing observed in the current data. Athletes should mimic base training distances, then periodize down with an increase in intensity.

The prescription for anaerobic power should detail the loading parameters specific to surfing competitions such as 4-second bursts, observed during paddling for waves. Power training should emphasize maximal power force production for greater propulsion in water and 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 gymnasium-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 to investigate the physiological attributes of elite surfers with a surfing-specific assessment battery.

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