THE EFFECT OF WAVE CONDITIONS AND SURFER ABILITY ON PERFORMANCE AND THE PHYSIOLOGICAL RESPONSE OF RECREATIONAL SURFERS.

Matthew John Barlow. Carnegie Faculty of Sport and Education, Leeds Metropolitan University, Leeds, United Kingdom.

Karen Gresty. Faculty of Science and Technology, Plymouth University, Plymouth, United Kingdom.

Malcolm Findlay. University College of St Mark & St John, Plymouth, United Kingdom.

Carlton Cooke. Carnegie Faculty of Sport and Education, Leeds Metropolitan University, Leeds, United Kingdom.

Mark Davidson, Faculty of Science and Technology, Plymouth University, Plymouth, United Kingdom.

Corresponding Author: Matthew John Barlow

Fairfax 108,

Headingley Campus,

Leeds Metropolitan University,

Leeds,

United Kingdom.

LS6 3QS

Tel: +44 (0)113 8124022

Email: matthew.barlow@leedsmet.ac.uk

ABSTRACT

This study investigated the effects of wave conditions on performance and the physiological responses of surfers. Following institutional ethical approval 39 recreational surfers participated in 60 surfing sessions where performance and physiological response were measured using GPS heart rate monitors. Using GPS the percentage time spent in surfing activity categories was on average 41.6%, 47.0%, 8.1% and 3.1% for waiting, paddling, riding and miscellaneous activities respectively. Ability level of the surfers, wave size and wave period are significantly associated with the physiological, ride and performance parameters during surfing. As the ability level of the surfers increases there is a reduction in the relative exercise intensity (e.g. average heart rate as a percentage of laboratory maximum, $r_{partial} = -0.412$, $P < 0.01$) which is in contrast to increases in performance parameters (e.g. maximum ride speed ($r_s = 0.454$, $P < 0.01$). As wave size increased there were reductions in physiological demand (e.g. total energy expenditure $r_{partial} = -0.351$, $P < 0.05$) but increases in ride speed and distance measures (e.g. the maximum ride speed, $r_s = 0.454$, $P < 0.01$). As wave period increased there were increases in intensity (e.g. average heart rate as a percentage of laboratory maximum, $r_p = 0.490$, $P < 0.01$) and increases in ride speed and distance measures (e.g. the maximum ride speed, $r_{partial} = 0.371$, $P < 0.01$). This original study is the first to show that wave parameters and surfer ability are significantly associated with the physiological response and performance characteristics of surfing.

INTRODUCTION

The activity profile of surfers has been previously described with surfers participating in activities of waiting (28-42% of total time), paddling (35-54% of total time), riding (3.8-8% of total time) and miscellaneous activities (2.5-5% of total time) (7, 16, 17). The physiological result of meeting the demands of surfing has been found to cause surfers to have an average heart rate during surfing between 64.4% and 85% of their laboratory tested maximum heart rate (7, 16, 17). Farley *et al.* (7) further developed the analysis of surfing by using GPS to identify the total distances travelled and the representative speeds over the session. The GPS data from the Farley, Harris and

Kilding study (7) found that 58 ± 10% of the time was spent in a low speed zone of 1-4 $km.h^{-1}$ which, was attributed to the large proportion of time spent paddling (54%). The second largest amount of time (29 ± 5.5%) was spent between 4.1 and 8 $km.h^{-1}$ which, was determined as sprint paddling. The average speed was determined as 3.07 ± 0.6 $km.h^{-1}$ with an average maximum speed of 33.4 ± 6.5 $km.h^{-1}$. In terms of distances covered it was found that on average the surfers covered 1605 ± 313.5 meters in 20 minutes, of which 947 ± 185.6 meters was spent paddling and 128.4 ± 25 meters was spent wave riding.

The intensity of breaking waves and the quality of the waves for surfing is dictated by the wave height, wave period, slope and nature of the beach (i.e. sand or reef) and the direction and intensity of local winds. The bathymetric profile of a beach will not be constant along the length of a beach, thus waves will not generally peel in a consistent manner but will break in sections creating interesting and challenging surfing conditions where the surfer can perform different manoeuvres on each section. The sections occur where there is a change in wave height, peel angle or breaker intensity (21). The wind can also have a significant effect on the waves; if the wind is offshore it has the effect of "cleaning up" the swell/waves. This is the result of the off shore wind flattening out short period swell, leaving only the longer range "ground swell" and also the offshore wind physically holds up the wave and delays breaking. This causes the waves to break in shallower water and with much more intensity and the waves become steeper and more likely to tube. Onshore winds however have negative effects on the quality of waves for surfing, causing the waves to break early in a disorganised "mushy" manner that can often be unsurfable (2). Surfers will utilize locations with optimal wind and wave conditions in order to enhance their surfing experience.

Surfing conditions, although predictable, can vary from location to location and with meteorological changes. The physiological and performance characteristics of surfing have been previously described with surfers who all had competitive experience (7, 16, 17). However, the influence of surfer ability and different wave conditions on the physiological demand and performance profile associated with surfing has not been researched. The aim of this study was to investigate the effect of wave conditions and surfer ability on the physiological, ride and performance characteristics of surfing measured through GPS and heart rate monitoring.

METHODS

Experimental Approach to the problem

Speed thresholds were calculated from the GPS data to identify the speed and distance characteristics of individual rides (5). Descriptive data was subsequently produced on the intensity of surfing activity relative to laboratory based blood lactate and $\dot{V}O_{2max}$ measurements, durations of activities, average velocities and total distance covered, and ride velocities and distances while surfing. The values of the physiological and performance measures were then correlated with the wave conditions of the surfing session.

Subjects

Following institutional ethical approval and informed consent participants underwent laboratory and field based assessments. In total 39 male participants completed 60 surfing sessions for the performance analysis aspect of the study. A subset (n = 19) of participants underwent laboratory testing to facilitate the physiological analysis of

39 surfing sessions. All participants were rated using the Hutt *et al.* (8) surfer skill rating scale (HSSR) all surfers have participated in surfing consistently at least three times a week for at least three years. Participants were instructed to avoid surfing and other training exercise in the 24 hours preceding the exercise tests.

Procedures

Submaximal oxygen uptake, blood lactate response, and $\dot{V}O_{2max}$ were measured using an incremental exercise test performed by paddling in a prone position on a Vasa Ergometer (Vasa Inc, Essex town, Vermont, USA). The test began with the participant paddling at 30 watts, for three minutes following which the participant was given a one minute rest period while a 400 µL fingertip capillary sample was taken which was then analysed for blood lactate concentration using a YSI2300 stat analyser (Analytical technologies, Farnborough, UK). Following the one minute rest period the exercise intensity was increased by 20 watts for three minutes before the next sample was taken. The test proceeded in this manner until a blood lactate sample of $4mmol{\cdot}L^{-1}$ or greater was measured. The participant was then allowed 10 minutes to recover before they returned to the ergometer to perform the $\dot{V}O_{2max}$ element of the test. The initial workload was set as 20 watts less than that which elicited OBLA and the participant paddled continuously, increasing their power output by 10 watts every minute until they reached volitional exhaustion or were unable to maintain the prescribed power output. Oxygen uptake was measured continuously throughout both aspects of the test via a face mask (Hans Rudolph, inc, USA.) using the Metalyzer 3B (Cortex Biophysik, GmbH, Leipzig, Germany) metabolic system. Heart rate was measured throughout using a Polar T31 chest strap (Polar Electro, Oy, Finland) through the Metalyser 3B.

Following completion of the laboratory exercise test the heart rate $\dot{V}O_2$ relationship was established through linear regression to predict the $\dot{V}O_2$ associated with heart rate during surfing. Energy expenditure was calculated using the $\dot{V}O_2$ derived from the heart rate assuming 5 kcal per Litre of Oxygen utilised (15). The heart rate, $\dot{V}O_2$ and blood lactate parameters were used to identify the heart rates associated with the exercise intensity zones of Easy (Below the lactate threshold), Steady (above lactate threshold but below the lactate turn-point), Tempo (above the lactate turn-point and up to the heart rate associated with 90% of $\dot{V}O_{2max}$) and the Intermittent zone which, is defined as within 10% of $\dot{V}O_{2max}$ (9, 10).

The surfers were each equipped with a Polar RCX5 heart rate monitor and G3 GPS monitor (Polar Electro, Oy, Finland). This was used in conjunction with a T31 transmitter belt to allow for transmission of the heart rate signal through the seawater. The G3 GPS monitor was placed in a dry-bag (one litre dry pouch, Overboard, Surrey, UK) due to its poor waterproofing properties and the heart rate monitor was also placed in the bag to reduce potential loss of signal.

The perceived wave height was recorded as the estimated wave face height by the surfers (3). Perceived wave heights were generally given in feet as perceived relative to the surfer – head high ~ 6ft, waist high ~ 3ft, etc. by the surfers and then converted into meter units for analysis. Wave buoy measurements of wave height and wave period were taken from the national wave buoy data centre (http://www.ndbc.noaa.gov/maps/United_Kingdom.shtml), with station 62107 (the Seven Stones Lightship) providing much of the data for Devon and Cornwall sessions, and station 62001 (the Gascogne Buoy) providing the data for the sessions in South West France. The heart rate files were analysed using Matlab

(R2012b, Mathworks, Cambridge, United Kingdom) with an algorithm to identify the percentage time spent in each of the training zones. The heart rate / $\dot{V}O_2$ regression equation for each participant was used to predict total energy expenditure during the surfing session.

The GPS files were also analysed using Matlab. Using the 1Hz sampling the velocities derived from the second by second difference of Longitude and Latitude allows the distance covered (m) to be calculated by multiplication of the speed ($m \cdot s^{-1}$) by the time in seconds. A ride was identified when the speed of the surfer is greater than the minimum ride speed threshold of 2.5 $m \cdot s^{-1}$ for a minimum of 4 seconds. This was done to minimise the interference of high speed paddling on the calculation of rides and to maximise the boundaries (start and finish point) of rides; this was performed on a subjective basis. Data that were above the minimum wave speed threshold but lasted less than 4 seconds were discounted as waves and reported as miscellaneous; where the wave speed dropped below the minimum riding threshold for a period of less than 4 seconds the analysis removed the seconds of data and interpolated the data to allow the two (or more) discreet bouts to be counted as one wave. GPS can occasionally produce spurious data through loss of signal or through the surfer performing free falls or aerial manoeuvres. A maximum wave speed threshold was incorporated using (4) theoretical max speed threshold for a surfer:

$$\text{Max Speed Threshold} \approx 6.04 \sqrt{H_b}$$

H_b is the breaker height as calculated by 1.29 x the significant wave height. Any data points that were in excess of 1.2 times of the max speed threshold were removed and interpolated using the data points immediately preceding and following the spurious point. The times when the surfers are travelling at less than 0.5 $m \cdot s^{-1}$ were identified as “waiting” (there may be some movement due to local tides, wind or current). Surfers were identified as “paddling” when their speeds were in excess of the “waiting” threshold but below the minimum ride speed threshold. The totals of “riding”, “waiting” and “paddling” were summed and any outstanding data was classified as “miscellaneous”. The miscellaneous data would include those above the minimum speed threshold but lasting less than 4 seconds (sprint paddling, missed waves, wipe outs) and periods when data were lost due to submersion (potentially during duck-diving or wipe-outs). Percentages were given for time spent in each of these activities and the distance covered per hour both surfing and paddling were calculated. This method allows the participants to surf in a natural manner without being constrained to surf in a specified area where they can be observed by a camera or observer as required for traditional notational analysis.

Statistical Analyses

Analysis of the wave data allowed calculation of maximum, minimum, mean and standard deviation values for ride distances, speeds, and time. Total number of rides, total distance covered, total distances ridden, total and percentage time riding, total time and percentage time waiting, total time and percentage time paddling, total time and percentage time in miscellaneous were also calculated. It should be noted that surfing sessions ranged in duration from 40 minutes to 3hrs but absolute values were converted to per hour values to allow for comparison.

Means and standard deviations were calculated for the physiological parameters such as time spent in each exercise zone, the ride parameters of ride time, distance, speed and performance parameters i.e. percentage of total time spent in each activity. Spearman`s rank correlations (r_s) were used to determine the relationship for HSSR with wave conditions, physiological parameters, ride parameters and performance parameters. Pearson's correlations (*r*) were performed between the wave parameters of perceived wave height, wave height and wave period with the physiological parameters, ride parameters, and performance parameters. These comparisons were also evaluated using partial correlations (r_p) controlling for the HSSR of the participants to ensure that the wave conditions were the sole independent variables. All statistical analyses were performed using IBM SPSS statistics (v20).

RESULTS

Table 1 shows the participant and condition descriptors (mean ± SD) for physiological and performance analysis for the whole sample of participants (*n* = 39) who underwent performance measurement using GPS devices and the subset of participants (*n* = 19) who also underwent laboratory assessment to facilitate physiological analysis based on heart rate measurement during their surfing sessions.

Table 2 gives the mean (± SD) physiological, ride and performance parameters of surfing measured in this study. The physiological parameters were measured during 39 surfing sessions involving the participants underwent laboratory testing (*n* = 19). The ride parameters were measured for the whole sample (*n* = 39) during sixty surf sessions; these values were derived from the GPS data and provide an overview of the speed, time and distance characteristics of the surfer's rides.

Table 3 gives the correlations between the physiological, ride and performance parameters with HSSR, perceived wave height, wave height, wave period and ride parameters; partial correlations corrected for HSSR.

There was a significant relationship between the Hutt rating of surfer skill and the perceived wave height of the conditions measured during the course of this study (r_s = 0.349, P = <0.001). This result shows that the participants with the higher HSSR tended to surf in larger waves. The effect of this correlation was considered when analysing the effect of the wave conditions and as such Table 3 presents partial correlations controlling for HSSR allowing the influence of wave conditions on the physiological response, ride parameters and performance parameters to be assessed independently of the ability of the surfers.

DISCUSSION

The sample of participants in the present study (Table 1) were of similar stature, body mass and age to those reported in the wider literature (6, 13, 19). However, the average ability of the surfers in this sample can be described as skill rating 5 or "surfers able to execute standard manoeuvres consecutively on a single wave" (8) and thus are generally lower in ability than in those studies that have utilised professional or competitive surfers (6, 7, 11, 12, 14, 17-19). It should be noted however that the current sample included a range of surfers from level 2 HSSR who are "learner surfers able to successfully ride laterally along the crest of a wave" to level 8 "professional surfers, able to consecutively execute advanced manoeuvres" (8). The measured (wave buoy) wave height during the study averaged close to 1.0 meter, which would be described by surfers as approximately 3 feet or as waist to chest high. The perceived wave height is slightly higher at 1.5 metres. The differences between the observed perceived wave height and the wave height measured by the wave buoy might be reflective of differences in offshore waves and those that break on the beach having interacted with the local bathymetry.

Physiological responses

The average heart rate (146.4 ± 16.8 $b.min^{-1}$) during surfing in the current study was similar to the values reported by Mendez-Villanueva *et al.* (17) for surfers in simulated competitive heats (146.20 ± 20.0 $b.min^{-1}$) and comparable to the average heart rates reported during competition by Farley *et al.* (7) (139.7 ± 11.0 $b.min^{-1}$) and during 1 hour of surfing by Meir *et al.* (16) (135 ± 6 $b.min^{-1}$). The average heart rate during surfing as a percentage of the maximum heart rate during the laboratory test (80.3 ± 7.6 %) was also comparable to the values reported in previous studies, being slightly greater than the values reported by Farley *et al.* (7) (64.4 %) and Meir *et al.* (16) (75 ± 4.2 %), but 5 % lower than the values of Mendez-Villanueva *et al.* (17) (84 %). Thus far no study has reported heart rate zones during surfing, with respect to blood lactate profiles measured through laboratory testing. Surfers were found to spend 19.9% of the time in the "easy" zone, which is defined as work rates below the lactate threshold and can be considered as the moderate exercise domain; where exercise can be maintained for extended periods of time (10). Mendez-Villanueva *et al.* (17) reported a similar amount of time (20%) spent as less than 75% of maximum heart rate, suggesting this might represent portions of activity where the surfers are resting during waiting and between bouts of paddling. The percentage of time in the "steady" zone is defined as exercise above the lactate threshold but below the lactate turn point. This is an approximation of the heavy domain of exercise which, if performed constantly, can be maintained for 40 to 60 minutes (10). The upper boundary of the steady zone is defined by the lactate turn-point, and 33.9% of the total time was spent in this zone. This supports the strong relationships between blood lactate parameters measured in the laboratory and the performance levels of surfers (19). Furthermore, Snyder *et al.* (22) identified that the maximum lactate steady state can be approximated to 85% of maximum heart rate, which compares well to the average heart rate reported in published literature (7, 16) and in the current study, with surfers working less than 5% of the total time surfing in this zone. The intermittent zone is associated with heart rates within 10% of the heart rate eliciting $\dot{V}O_{2max}$. Surfers in the current study performed for 12.4% of the total time in this zone supporting previous studies showing that surfing consists of mainly moderate to heavy exercise, utilising aerobic metabolism interspersed with high intensity exercise. This requires both aerobic and anaerobic elements and indicates that surfing meets the American College of Sports Medicine training intensity criteria for developing and maintaining cardio-respiratory fitness in healthy adults (7, 16, 20). The hourly energy expenditure in the current study of 493 kcal is similar to that reported by Meir *et al.* (16) who found hourly energy expenditure of 496.41 kcal (2077KJ).

Ride parameters

The number of rides identified as 20.6 rides per hour is significantly higher than the value of 5 rides during a 25 minute heat (12 rides per hour) as recorded by Mendez-Villanueva *et al.* (18) but is similar to the 7 rides during a 20 minute heat (21 rides per hour), reported by Farley *et al.* (7). These differences might be due to the surfers in the study of Mendez-Villanueva *et al*. (2006) making tactical decisions to ensure that they achieved the highest possible score from their two scoring waves within the wave limit set within competition (1). Alternatively, it might be due to differences in the definition of wave riding; Mendez-Villanueva *et al*. (2006) and Farley *et al.* (7) recorded riding as the time from the last arm stroke to the moment the surfer's feet lost contact with the board, whereas the current study identified rides using speed thresholds. However, the similarities in results presented here with those in the published literature (7, 18) support the use of the current methodology as a method of surfing performance analysis.

The maximum ride speed was measured as the mean maximum ride speed over all of the maximum speeds from each surf session. This averaged 6.1 $m.s^{-1}$ and is considerably slower than the average maximum speed reported by Farley *et al.* (7) of 33.4 $km.h^{-1}$ (9.3 $m.s^{-1}$). Differences might be due to the variations in the ability of the surfers in the current study in comparison to the participants of the Farley *et al.* (7) study, who were all described as nationally ranked surfers and as such would be rated as 7 or above on the HSSR. Farley *et al.* (7) also reported that the wave height during their study was 4ft (1.2m) and using maximal sustainable speed calculation (4) this would give a maximal sustainable speed of 9.63 $m.s^{-1}$ in those conditions. The mean ride time of the current study (13 seconds) was slightly longer than the values reported by Mendez-Villanueva *et al.* (18) who found mean ride times of 11.6 seconds but similar to the 14.9 ± 5.6 values reported by Farley *et al*. (2012), suggesting that these values are within the normal range of ride times. The maximum ride times of the current study were found to be 27.3 seconds which is considerably higher than the data presented by Mendez-Villanueva et al. (2006). The long maximum ride distances presented in the current study might have been influenced by the interpretation of the GPS data when differentiating between riding and non riding. Often surfers will end a surfing session by riding a wave and then dropping to the prone position once the wave has broken and then riding that broken wave to the shoreline; using the algorithm employed in the current study the total distance of this activity would be classsed as one ride and might have had a slight influence on the final data. The minimum ride time found in the current study was 4.71 seconds. This value is slightly lower than the 6 seconds minimum ride time reported by Mendez-Villanueva et al. (2006). It should be considered that the minimum ride time values published in the literature are likely to be affected by the subjective way in which a ride has been classified by the investigators; specifically the determination as to the points at which a rides begins and ends.

Thus far no other study has reported the distance parameters of individual rides within a surfing session, although Farley *et al.* (7) did produce values for total distance of the session. It would be expected that the ride distances could be affected by the surf conditions and the location, with point breaks offering the maximal ride distances. The majority of the sessions included in the present study were performed at beach breaks or at reef breaks that might offer a more intense ride but not necessarily longer rides (2).

Performance parameters

Riding accounts for 25.6% of the total distance accrued during the surf session with the remainder being explained through paddling and drifting due to currents.

The percentage of the total time spent waiting was found to be 41.8% (1453 $S.hr^{1}$) and this is in line with time spent waiting reported in the literature which, ranges from 28% (7) to 42% (18). The value identified in the current study is based on a speed threshold and single arm paddling or sculling to maintain position might be included whereas it might be classified as paddling in other studies. The total time spent paddling in the current study was found to be 47.0% (1636 $S.hr^{-1}$) which aligns with the range of values presented in the literature, from 35% (16) to 54% (7). The percentage time riding in the current study was found to be 8.12% (282.6 $S.hr^{-1}$) compared with 3.8% of Mendez-Villanueva *et al.* (18) and 8% with Farley *et al.* (7). The percentage time recorded for miscellaneous activities was 3.1% (107.9 $S.hr^{-1}$), similar to the 2.5% and 5% values presented by Mendez-Villanueva *et al.* (18) and Farley *et al.* (7) respectively. These values are substantially smaller than the values presented by Meir *et al.* (16) who found that 16% of total time was spent performing miscellaneous activities.

The data presented in this study, using GPS as a method of measuring the activity profile of surfers, has found values that are comparable to those in the literature and supports the use of this method for future objective assessment of surfing activity. Using this method the percentage time spent in each activity can be described as 41.6%, 47.0%, 8.1% and 3.1% for waiting, paddling, riding and miscellaneous activities respectively.

Relationships between surfer skill, wave characteristics and measured physiological, ride and performance parameters

Thus far no study has reported how surfing ability or wave conditions might affect surfing performance or the distribution of activities during surfing. A significant relationship was found between HSSR and the perceived wave height. Similar correlations were not found with the wave height and period measured through the off-shore wave buoy. Therefore it can be determined that in comparison to those of lower ability, the better surfers were seeking and riding comparatively larger waves breaking on the beach for a given wave size measured at the off-shore wave buoy. Thus when considering the effect of wave size on the parameters of surfing activity, ability should be taken into consideration.

Table 3 shows that the HSSR was significantly and negatively related to the average heart rate as a percentage of the maximum measured in the laboratory. This suggests that the better surfers work at a lower intensity than those who are less adept. This is supported by the significant relationships ($P < 0.01$) between HSSR and the percentage of time in the various exercise intensity zones.

The significant relationships with HSSR suggest that surfers with higher ratings of ability will have higher proportions of their total surfing distance accounted for by ride distance and that they will spend comparatively more time paddling perhaps to maximise their wave count. The higher the level of ability the lower the percentage of time spent in miscellaneous activities and thus the surfers are spending less time unsuccessfully paddling for waves, wiping out or choosing waves that are closing out and therefore presenting short rides (<4sec).

A significant negative relationship was found between total energy expenditure and perceived wave height and perceived wave height when controlling for HSSR, suggesting that as the wave height increases then total energy expenditure decreases. The explanation for this relationship might lie in the significant negative relationship between perceived wave height and the number of rides (Table 3). Therefore, it appears that as wave height increases then the number of waves ridden decreases and so does the associated “wave-catching” activity.

The relationship of maximum ride speed with ability demonstrates that the better surfers are able to utilise more speed from the wave, but generally as wave size increases then so does the maximum ride speed. This relationship is to be expected, considering the maximum theoretical ride speed has been shown to be a function of wave size (4). The perceived wave height is a function of both the wave height as measured from the wave buoy, the period of the wave and the interaction of these variables with the local bathymetry. The wave period was found to be significantly correlated to the average heart rate, as a percentage of the maximum measured in the laboratory both generally and when controlling for HSSR. This suggests that as wave period increases the average heart rate increases. This is reflected in the significant negative relationships that are seen with the percentage time in the "easy zone" as wave period increases.

As the wave height increases (perceived wave height or measured wave height) there is a concomitant increase in the ride speeds, durations and distances. With increases in miscellaneous activities and decreases in the percentage of time spent waiting. It is unclear how these relationships might have impacted the differences in previous studies as generally wave sizes have not been reported but Farley *et al.* (7) reported that the wave sizes during their study were consistently larger (1-1.5 m) than the current study (1.0 m) and the surfers in that study spent less time waiting, more time involved in miscellaneous activities, and covered comparatively greater distances; all of which would be supportive of the present findings.

This study has found that the ability levels of surfers, the wave size and period influence the physiological, ride and performance parameters during surfing. As ability levels of the surfers increase there is a reduction in the relative (metabolic) intensity and time spent in miscellaneous activities, but increases in the proportion of time spent in the steady zone, time spent paddling, riding and increases in both the speed and distance of rides. As wave size increases there is a reduction in the total energy expenditure, number of rides and the proportion of time waiting. Increases in the ride speed, ride distances, the variation in ride speed and distance were also observed with increases in wave size. The proportion of total time riding, the proportion of time in miscellaneous activities and the total distance covered in the session increased with wave size. As wave period increases there is a decrease in the proportion of time spent in the "Easy zone", with increase in the average heart rate and increases in maximum ride speed, time and distance. Thus far no other study has investigated these relationships.

This study concludes that wave parameters and surfer ability have significant effects on the physiological response and performance characteristics of surfing. Future studies on surfing performance should report the conditions in which the study is performed and authors should recognise the effect of changes in surf conditions on the response of the surfers.

PRACTICAL IMPLICATIONS

The data provides some guidelines for training to replicate the intensity of surfing; this can be achieved by spending 20% 34%, 34% and 12% of the training session time into the “easy, “steady”, “tempo” and “intermittent” training zones based upon the surfer’s heart rate. These values should be adapted based on the ability levels of the surfer and the expected wave conditions at the locations at which surfing are to take place. The data suggests that for given wave conditions beginner and intermediate surfers will spend a greater proportion of their time in the intermittent zone which is within 10% of the intensity associated with their $\dot{V}O_{2max}$ than surfers with higher levels of ability. Surfers of lower levels of ability should develop their ability to cope with working at this intensity in their training. Where longer wave periods (>9 seconds) are expected to accompany the wave size surfers should place less focus on training in the “easy” zone and increase the intensity of training in the other zones.

In terms of training for surfing in relation to the expected wave size at a given location it is possible to see that there is a tendency of increased energy expenditure when surfing larger waves. The average wave height (1.5m) in this study elicited an average energy expenditure of 493 $kcal.h^{-1}$. This provides a good benchmark from which to manage energy intake for performance assuming surfing in smaller waves will require greater energy intake to maintain energy balance and vice versa.

Surfers should tailor their training for the expected wave climate of upcoming surfing sessions. If small wave sizes are expected the surfers should train in order to maximise their wave count to and concentrate on performing manoeuvres that can be completed quickly within a short ride. However, if the wave sizes are expected to be larger; surfers should expect to complete longer rides and focus on linking manoeuvres to capitalise on longer ride durations.

Table 1. Participant and condition descriptors for physiological and performance analysis (Mean ± SD).

	Performance analysis Mean ± SD	**Physiological analysis (subset) Mean ± SD**
Sample size (n)	39	19
Stature (m)	1.77 ± 0.12	1.75 ± 0.15
Body Mass (kg)	72.6 ± 9.9	72.1 ± 8.5
Age (years)	24.5 ± 6.3	26.5 ± 7.4
Surfer Skill Rating	5.2 ± 1.2	5.5 ± 1.3

$\dot{V}O_{2max}$ (L·min^{-1})		2.6 ± 0.5
$\dot{V}O_{2max}$ (ml.kg^{-1}·min^{-1})		35.9 ± 6.1
Perceived wave height (m)	1.0 ± 0.4	1.1 ± 0.4
Wave height (m)	1.5 ± 0.8	1.5 ± 0.7
Wave period (s)	9.2 ± 1.6	9.4 ± 1.7
Total number of surf sessions analysed	60	39

Table 2 Physiological, ride and performance parameters of surfing (Mean ± SD).

	Mean ± SD
Physiological Parameters	
Average heart rate (b·min^{-1})	146.4 ± 16.8
Average heart rate as percentage of maximum of laboratory test	80.3 ± 7.6
Percentage of time in “easy” zone	19.8 ± 19.2
Percentage of time in “steady” zone	34.0 ± 22.0
Percentage of time in “tempo” zone	34.0 ± 22.3
Percentage of time in “intermittent” zone	12.4 ± 15.6
Energy expenditure (kcal·h^{-1})	493.0 ± 231.7
Ride Parameters	
Number of Rides (per hour)	20.6 ± 11.4
Maximum of ride speeds (m·s^{-1})	6.1 ± 1.2
Stdev of Maximum of ride speeds (m·s^{-1})	1.1 ± 0.5
Mean ride time (s)	13.0 ± 5.0
Maximum ride time (s)	27.3 ± 13.3
Minimum ride time (s)	4.7 ± 1.5
Stdev of the ride times (s)	7.3 ± 4.2
Mean ride distance (m)	54.8 ± 25.4
Maximum ride distance (m)	117.7 ± 63.4
Minimum ride distance (m)	16.5 ± 7.3

S of ride distances (m)	32.0 ± 18.8
Performance Parameters	
Total distance covered whilst surfing (%)	25.6 ± 9.6
Total time spent waiting (%)	41.8 ± 9.8
Total time spent paddling (%)	47.0 ± 6.1
Total time spent riding (%)	8.1 ± 5.3
Total time miscellaneous (%)	3.1 ± 1.9
Total time spent waiting per hour (s)	1452.9 ± 440.7
Total time spent paddling per hour (s)	1636.6 ± 374.8
Total time spent riding per hour (s)	282.6 ± 195.2
Total time spent miscellaneous per hour (s)	107.9 ± 69.2
Distance covered whilst surfing (m.hour^{-1})	891.4 ± 378.9
Total distance per hour (m)	3925.5 ± 1239.8
Average speed (m·s^{-1})	4.2 ± 1.1

Table 3. Correlations between physiological, ride and performance parameters with skill rating and wave conditions.

	HSSR	Perceived wave Height (m)		Wave Height (m)		Period (s)	
Physiological Parameters							
Average heart rate (beats.min^{-1})	r_s = -0.248	r_s =-0.029	r_p=-0.101	r=-0.107	r_p=-0.133	r=0.120	r_p=0.310
Average % HR Max	r_s = -0.412**	r_s =-0.151	r_p=-0.193	r =-0.054	r_p=-0.253	r=0.312*	r_p=0.490**
% time "Easy"	r_s =-0.058	r_s =-0.017	r_p=0.80	r =0.224	r_p=-0.223	r=-0.405*	r_p=-0.408**
% time "Steady"	r_s =0.435**	r_s =0.174	r_p=0.130	r =0.001	r_p=-0.053	r=0.002	r_p=-0.072
% time "Tempo"	r_s =-0.136	r_s =0.006	r_p=-0.009	r =-0.118	r_p=-0.140	r=0.280	r_p=0.316
% time "Intermittent"	r_s =-0.483**	r_s =-0.291	r_p=-0.234	r =-0.097	r_p=-0.192	r=-0.097	r_p=0.173
Energy Expenditure (Kcal.HR^{-1})	r_s =-0.123	r_s =-0.416**	r_p=-0.351*	r =0.047	r_p=0.083	r=0.087	r_p=-0.263
Ride Parameters							
Number of Rides (1·HR^{-1})	r_s =-0.167	r_s =-0.262*	r_p=-0.102	r =-0.166	r_p=0.175	r=-0.192	r_p=-0.165
Maximum of ride speeds (m·s^{-1})	r_s =0.454**	r_s =0.707**	r_p=0.866**	r =0.464**	r_p=0.510**	r=0.236	r_p=0.371**
S of Max of ride speeds (m·s^{-1})	r_s =0.181	r_s =0.500**	r_p=0.654**	r =484**	r_p=0.415**	r=0.009	r_p=0.221
Mean ride time (s)	r_s =0.193	r_s =0.463**	r_p=0.354**	r =0.231	r_p=0.228	r=0.322*	r_p=0.283*
Maximum ride time (s)	r_s =0.175	r_s =0.362	r_p=0.296*	r =0.204	r_p=0.199	r=0.271*	r_p=0.236
Minimum ride time (s)	r_s =0.000	r_s =0.070	r_p=0.128	r =0.199	r_p=0.200	r=0.027	r_p=0.033
Performance Parameters							
% Total distance riding	r_s =0.267*	r_s =0.280*	r_p=0.231	r =0.313*	r_p=0.310*	r=0.076	r_p=0.035
% time waiting	r_s =-0.188	r_s =-0.146	r_p=-0.200	r =-0.275*	r_p=-0.272*	r=-0.107	r_p=-0.082
% time paddling	r_s =0.364**	r_s =0.117	r_p=-0.017	r =-0.44	r_p=-0.058	r=0.099	r_p=0.038
% time riding	r_s =0.046	r_s =0.062	r_p=0.227	r =0.394**	r_p=0.396**	r=0.0269	r_p=0.036
% time miscellaneous	r_s =-0.299*	r_s =0.180	r_p=0.452**	r =0.452**	r_p=0.471**	r=0.0157	r_p=0.211

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