PERFORMANCE ANALYSIS of SURFING: A REVIEW

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Performance Analysis of Surfing

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Abstract:

Despite the increased professionalism and substantial growth of surfing worldwide, there is limited information available to practitioners and coaches in terms of key performance analytics that are common in other field based sports. Indeed, research analyzing surfing performance is limited to a few studies examining male surfers’ heart rates, surfing activities through time-motion analysis (TMA) using video recordings and Global Positioning Satellite (GPS) data during competition and recreational surfing. These studies have indicated that specific activities undertaken during surfing are unique with a variety of activities (i.e., paddling, resting, wave riding, breath holding and recovery of surfboard in the surf). Furthermore, environmental and wave conditions also appear to influence the physical demands of competition surfing. It is due to these demands that surfers are required to have a high cardio-respiratory fitness, high muscular endurance and considerable strength and anaerobic power, particular within the upper torso. By exploring various methods of performance analysis utilised within other sports, it is possible to improve our understanding of surfing demands. In so doing this will assist in the development of protocols and strategies to assess physiological characteristics of surfers, monitor athlete performance, improve training prescription and identify talent. Therefore, this review explores the current literature in order to provide insights into methodological protocols, delimitations of research into athlete analysis and an overview of surfing dynamics. Specifically, this review will describe and review the use of TMA, GPS and other technologies (i.e. HR) that are used in external and internal load monitoring as they pertain to surfing.

Keywords: Video analysis, GPS, Heart rate, External loads, Internal loads, Surfing performance

INTRODUCTION

When observing athlete performances, coaches are able to gain greater understanding of the physical demands and technical aspects of a sport. In doing so, coaches are able to better inform training prescription and ultimately enhance performance of the athlete. The systematic collection and analysis of data in order to provide a valid record of athletic performance is known as performance analysis and this aspect of sport science has become increasingly important in the last decade (17, 60, 93). The present methods of performance analysis, utilizing comprehensive notational analysis systems, were first developed in football (73, 75, 76) and have since evolved to incorporate modern technologies (21, 30, 43) and analytical techniques (60, 82, 86). Performance analysis methods rely on human observation and therefore would involve a degree of subjectivity (59). As a result, it should be stressed...
that researchers and coaches have precise procedures when entering and examining data correctly to reduce inter-observer variability and different interpretations of performance being made (11). Furthermore, performance analysis methods such as codes/definitions utilized should also coincide with a gold standard (41).

Monitoring of athletes’ work-rate profiles (i.e. active and passive durations and intensities of bouts) during competition was originally achieved using manual video-based time-motion analysis (TMA) techniques (77). Modern performance analysis methods incorporate analysis of physical demands and movements, technical and tactical aspects of performance and development of predictive models (38, 59). Advancements in technology have also enhanced performance analysis through the incorporation of a variety of devices such as heart rate (HR) monitors, video analysis software programs (used during TMA), Global Positioning System (GPS) devices, accelerometers and gyroscopes, which have been incorporated into GPS units (these are in addition to GPS as they are different technology and not global positioning). The portable GPS unit is becoming increasingly applied to a range of sporting codes, providing further detailed information about external workloads such as movement patterns and physical activities of athletes during training and competition (21, 59). In addition, advances in video cameras and software now allow for the collection of high speed, high definition videos that can be downloaded for rapid and comprehensive TMA. When used in combination, such technology offers an opportunity to provide detailed and meaningful insights into sport and athlete internal (HR) and external (TMA, GPS) performances that are useful for coaches and training professionals.

While various methods of performance analysis have long been utilized within a wide range of sporting codes (59), few studies have implemented such analysis in the
sport of surfing. With an ever-increasing rise in professionalism and global growth of surfing, there is currently a paucity of research to assist coaches and practitioners on assessment and conditioning practices. Indeed, research analyzing surfing performance is to date limited to a few studies examining the internal loads of male surfers’ HR (10, 30, 64, 65, 82) and external loads of surfing activities through TMA using video recordings (30, 64, 66) and GPS data (10, 30, 82); during competition (30, 66, 67), training (82) and recreational surfing (10, 64).

The monitoring of internal (such as HR and ratings of perceived exertion (RPE)) and external (TMA, GPS) load during surfing provides valuable insights into the work rates and physiological demands encountered, energy systems utilized and intensities and durations of activity. Based on this literature, the sport of surfing has been reported to involve intermittent exercise bouts of activity that vary in intensity and duration. These intensities and durations differ as a result of the conditions and environmental variables (i.e. wave formation, type of wave break, wave size, weather, currents, rips, frequency of waves, tides) encountered at surfing locations. As a result, the physiological responses of surfers to specific activities (i.e. paddling, wave riding, sprint paddling) will vary. Therefore, surfing athletes are required to have well developed muscular endurance, cardio-respiratory fitness and anaerobic power, particularly of the upper-torso (52-55, 65).

By exploring various methods of performance analysis utilized within other sports, it is possible to improve our understanding of surfing demands. In so doing this will assist in the development of protocols and strategies to assess physiological characteristics of surfers, monitor athlete performance, improve training prescription and identify talent. Therefore, this review explores the current literature in order to provide insights into methodological protocols, delimitations of research into athlete analysis and an overview of surfing dynamics. Specifically, this review will describe and review the use of TMA, GPS and other
technologies (i.e. HR) that are used in external and internal load monitoring as they pertain to surfing.

MEASUREMENTS of EXTERNAL LOADS

External load refers to the movement or work performed by an athlete during exercise that is independent of internal responses to a stimulus (20, 92). Such information includes power output, distance travelled and time and speed data (39). There are a large number of methods available to coaches and athletes in order to determine the external workloads experienced by athletes during exercise. For example, monitoring of such loads can be measured through but not limited to strain gauges, simple speed sensors, TMA, GPS tracking and other video based analytical systems (35). Interestingly, there are also several variables that could be monitored in surfing (i.e. forces encountered whilst wave riding, speeds and forces encountered during aerial maneuvers, power output while paddling in surf) that have not yet been examined that may warrant investigation. Such research is necessary given that aspects of the sport involve aerialist movements (57) with landings important to success but also related to injury risk (56). To date, performance analysis within surfing literature has focused on the use of TMA and GPS to monitor the external loads, which will be the focus of the review.

Time-Motion Analysis

TMA is a reliable method (37, 66) of performance analysis involving the frame-by-frame examination of video footage recordings from individual or teams of athletes. Video data is typically analyzed for the determination of the time and distance completed in an
activity (45), movement patterns (i.e. speeds, durations and distances) of such activities (25), frequency and total time spent performing various activities (27). As a tool used for external load monitoring, TMA has been utilized to assess the activity profiles within a range of sports including, soccer (9, 62, 77), soccer refereeing (48), rugby (24, 26, 27), rugby league (45), badminton (16), basketball (61, 63), field hockey (42, 85) and wrestling (70). TMA is useful in providing insight into the movement patterns and physical demands of an activity (87). Such information is often used by sports associations and teams to make objective decisions regarding the design and structure of testing protocols, conditioning programs and match preparation strategies (17) according to the characteristics of the sport (47, 87). Additionally, TMA is often used to quantify fatigue and or pacing through examination of distance covered and intensity over the duration of an event (68).

**Time-Motion Analysis of surfing**

TMA of surfing performance has indicated that surfing is a sport which entails intermittent exercise bouts of activity that vary in intensity and duration (30, 64, 66, 82). The specific TMA activities undertaken during surfing have been described as paddling, remaining stationary, wave riding and miscellaneous (i.e. duck diving, recovery of board, single arm paddle movements etc.) (30, 64, 66, 82), with many variables affecting the durations spent in each activity and resulting intensities (30, 64, 66, 82). More recent studies (30, 82) have further broken down and redefined the TMA activity categories and included paddling for wave, paddling to return to line-up and recovery of the surfboard (82) as separate activities. A summary of the classifications for data analysis used within the literature can be observed in Table 1.

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To date, there have only been four studies investigating the TMA of surfers during either competition (30, 66), training (82), or recreational surfing (64). These studies have all used a similar methodology, whereby video recordings of surfers were taken during a one hour surfing session (64), 25 minute international contest (World Qualifying Series) heat (66), 20 minute competitive heat (30), or two hour training sessions (82). Within this research, other variables likely to influence performance were also recorded, including the swell size, wind direction, tide and number of other participants in the water. Due to the varying surf conditions, filming locations within these studies were changed to ensure the most advantageous viewpoint. Furthermore, a single observer calculated the time (average and total) and frequency ($n$) of occurrences, as well as the percentage of the total time spent on each activity in each study.

Due to the nature of surfing, the influence of the variables associated with the sport (swell size, swell period, currents, wave frequency or length), beach type and break, geography and environmental conditions will likely influence the external loads encountered. The aforementioned studies analyzed movement characteristics under a variety of surfing conditions, surfing locations and different surfing level of ability. Therefore, it is likely that the percentages of durations will differ due to the locations subject to the multiple fascists associated with the sport. Surf conditions that entail a short swell period (less time between waves) with onshore winds and a strong current would greatly affect the time spent stationary and paddling back to the wave take-off zone. In contrast, on a calmer day with a long swell period, surfers will likely be stationary for longer durations, waiting for the ‘right’ wave to
move in. With the nature of the surfing environment being ever changeable, the length and frequency of the associated surfing activities performed are likely to be highly variable too.

As such, the differences found between recreational surfing (64), competitive surfing (30, 66) and training (82) are likely attributable to the mentioned variables associated with the sport as well as skill level of participants and scenarios of surfing. The TMA data from the studies mentioned provides a valuable insight into the percentages and durations of time spent performing activities associated with surfing. The results of these studies can be observed in Table 2 with the addition of a recent study (10) where percentages of time spent within surfing activities calculated were based on GPS recordings, rather than TMA.

The percentages reported in the associated activities are to a certain degree comparable, with paddling and stationary periods dominating the total time spent surfing. Further, it has been indicated that the movement characteristics are somewhat similar during competition and training. Indeed, several studies have broken down the paddling bouts into zones, with surfers typically spending between 60 and 80% (30, 66, 82) of the total paddling time between 1 and 20 s. Of this paddling zone, 56 to 61% (30, 82) is spent paddling between 1 and 10 s. Similar to paddling, it has been reported that surfers spend between 51% (66, 82) and as high as 83% (30) of the total time stationary, between 1 and 20 s. Of the 1 to 20 s zone broken down, surfers are resting between 32% (82) and 64% (30) between 1 and 10 s, which is a large difference between training (82) and competition (30). These data indicate that periods of being stationary are short, which would be due to the relatively consistent changes in activity. Furthermore, it was suggested that the high percentage of time
within the lower timed segments (1 – 10 s) (paddling and stationary) during competition (30) were due to the surfers paddling between the sets of broken waves, waiting for the waves or resting, then having to paddle to reposition in the take-off area. This is likely to be associated with the ever-changing environmental factors mentioned earlier. Additionally however, it has been suggested that the specific demands imposed during competitive surfing might have an impact on surfers’ activity patterns, such as tactical decisions, opponent’s heat scores or wave selection (65). This comment is highly relevant to competitive surfing literature as surfers involved are competing with opponents for a short duration (20 – 30 mins), during which competition performance pressures (i.e. physiological, tactical, technical) and wave selection pressures (i.e. maximal number of waves caught rules allow, competition for waves, quality of wave, judgment of wave type) are encountered. In contrast, the training of recreational (64) and competitive surfers (82) allow for simply catching waves over a 60 and 120 minute period, with no pressure on performance, maneuvers executed, competition for the waves, or the number of waves caught. Indeed, there does appear to be a pattern emerging from these studies, which suggests that surfing is characterized by short (1 – 10 s) paddling and stationary (recovery) durations, particularly in competition.

From the literature to date, it can be suggested that the physical demands of surfing are similar to that of mainstream team sports (i.e. Rugby, AFL and Soccer), in that it is characterized by high-intensity, intermittent efforts, interspersed with low-to-moderate physical activity. As such, monitoring methods and prescription activities from these sports may aid in the development of specific training drills based on the TMA from surfing competitions. Such information would benefit coaches and competitive surfers alike, aiding in the design of training programs and conditioning methods to best prepare these athletes for the location demands and monitoring athletes’ workloads (i.e. paddling durations, distances
Coaching benefits may include providing feedback to athletes on activities such as paddling to get into the critical part of wave (maximizing point scoring) and technical execution, such as maintaining speed during turns and driving low enough on the wave to generate higher speeds for bigger execution of scoring turns on the lip of the wave.

Summary

The TMA and GPS data reported from previous studies are for the most part in agreement. Though some differences do exist, the differences are likely due to the unique variables associated with the sport and the various surfing locations and the differences between the definitions of surfing activities. It appears that competitive surfing demands are greater than that of recreational and training sessions. These differences are likely attributed to surfing tactics, wave selection and pressures, as well as environmental conditions, which ultimately dictate the workloads experienced. However, despite the latest observations (30, 66, 82), there is still a lack of sport-specific information on the physiological and environmental aspects, intensities encountered, durations, distances covered and the differences between training, recreational and competitive surfing. Additionally, all studies mentioned have only used male athletes for research; therefore, research investigating female surfers and differences between genders is warranted.

GLOBAL POSITIONING SYSTEM ATHLETE ANALYSIS

The utilization of GPS technology has been proposed as a means to monitor athletes’ physical activity and has seen a growing trend in the addition of GPS units to collect additional data on movement patterns, speeds, distances and movement demands (7, 42, 43). GPS technology has been applied to a range of sporting codes during
training and competitions (22, 28, 34, 42, 49, 59, 71, 79, 80, 88) as a popular method to quantify athletic movement and physical demands in sport (6, 22, 23, 36, 42, 49, 59, 79). Recently improved miniaturization, signal strength and enhanced battery life have made athlete-tracking GPS units more convenient and less time-consuming (71). To date, there are only four studies that have utilized GPS technology in surfing competitions (29, 30), training (82) and recreational surfing (10). Such technology utilized during surfing can assist in the monitoring of athletes’ external workloads and quantify training/surfing loads.

Reliability and Validity of GPS Measurement

GPS devices are currently manufactured with 1, 5, 10, 15 and 20Hz sampling rates (the speed at which the unit gathers data) with modern GPS units recording at the faster sampling rate. Earlier studies incorporating GPS units have been limited to units operating at 1Hz, with a general consensus reporting that GPS data recording at 1Hz is appropriate for recording distances at lower velocities, however, athletes travelling at higher speeds results in greater error in estimation (28, 34, 71, 74). Additionally, these GPS units have good accuracy during basic linear movements, however, accuracy, and reliability decrease as speed and movement intensity increase, along with activity over circular paths (34, 71, 95). It is generally accepted that speed of movements influence the accuracy of GPS devices with mean error of (5.6%) during running compared with walking (0.71%) (74) and differences between linear and non-linear walking and jogging (34).

Studies have further reported typical error (TE) of 5.5% (intra-tester reliability) during sports specific movements (28). Additionally, a TE of ≤2% has been reported for walking and striding over different distances, including an underestimation of the actual distance of walking (1%) and striding (3%), for the same GPS units (71). These results provide evidence that such devices provide reliable assessment of
movement during a variety of activities, particularly with limited change of direction. In relation to surfing, the movements are typically paddling in more or less straight lines, with typically sharper movements and changes of direction when paddling for a wave and also when riding and performing maneuvers on the wave. Interestingly, a ‘W’ shape field course, that resembled surfers movement patterns if on a wave, were reported to have moderate levels of repeatability for distance and time (6.15 – 9.50%) (29).

It appears that GPS with a higher frequency rate indicates greater validity for measurement of distance, therefore the sample rate is likely to influence GPS data recorded (6, 43). There is evidence to suggest that a low sample rate (1 – 5Hz) may be too slow and that accuracy and validity is considerably improved with faster sample rates (10 – 15Hz) (21, 89). Indeed, studies have shown that the standard error when comparing between the precision of a sprint and actual distance have been reported to be 32.4% (1Hz) and 30.9% (5Hz) (42) for 10m, and 10.9% over 15m and 5.1% for a 30m sprint via a 10Hz GPS (18). Furthermore, GPS units operating at 10Hz have been reported to be more valid (p=>0.05) and reliable (%TEM = 1.3%) than that of 15Hz units (p=0.20, %TEM = 1.9%) for measures of total distance, (43) demonstrating greatly improved recorded measures compared to 1 and 5Hz units. More recently, GPS units operating at 10Hz also demonstrated valid measures and small effect size differences reported between all measures and the actual measured distances (r≤0.7) for 100m sprint (GPS recording, 101.1 ± 4.5m), ‘W’ shape jogging course (28.4m) (GPS, 28.6 ± 5.6m), with slightly lower distance (r≤0.6) (GPS, 334.6 ± 7.8m) during the walking test (walking around a rugby field), when compared with actual distance (336m) (29).
While literature to date suggests that GPS devices have an acceptable level of accuracy and reliability, GPS reliability decreases during short distances and duration, involving sharp changes in direction and velocity (19, 29, 42) especially movement demands performed at ≥20 km·h\(^{-1}\) (43). Additionally, GPS units record changes in horizontal direction; therefore, it may contribute to an underestimation of distance travelled and an over estimation of velocity (29). This is an important point to consider when it comes to determining the limitations of GPS applications to surfing research. Surfing is categorized by surfers riding both horizontally and vertically along the wave at speed and performing sharp turning movements (10, 29, 30, 82). Accordingly, caution is needed when analyzing wave speeds and rapid changes in both direction and velocity (21), especially during aerial maneuvers and critical turning movements performed at high speeds. As such, the previous information recorded on land can provide valuable insights into the likelihood of errors measured during surfing. Therefore, surfing speeds and the distances reported from GPS units should be viewed with caution. Not only with the sampling rate, but also a likelihood that errors can be recorded for distances travel while at speed on a wave (≥20 km·h\(^{-1}\)) and perhaps an underestimation of the total distances while paddling (≥7 km·h\(^{-1}\)). From the surfing literature to date (10, 29, 30, 82), a variety of units and sample rates have been used during the research, which may influence the ability to compare across studies. With the differences in units recording capabilities, differences are a likely to occur when reporting on the actual speeds and distances surfers have reached.

Ultimately, the reliability and validity of the portable GPS unit relies on the accuracy and reliability of the GPS hardware and software to establish distances and velocities. Unit reliability further comes down to the manufacturing process of the actual hardware within the GPS units. Different hardware will work differently during movements, such as body twisting...
and turning and will result in the unit locking onto new satellites. The measurements reported
during surfing are subject to the environment they were recorded in (10, 30, 82), therefore,
the variables encountered (i.e. weather, sea conditions and location) are likely to disrupt
satellite tracking (29).

Considerations for use of GPS in surfing

The application of GPS units while surfing has only recently been implemented with
just three studies to date, recording data from competitive surfing heats (29, 30) competitive
surfers during a training session (82) and recreational surf sessions (10). During these studies,
participants were fitted with units on their upper vertebra, with the positions, durations,
distances and speeds recorded. It is plausible that the placement of these devices on an athlete
may influence the assessment of surfing performance, yet this has not been examined.
Devices that are positioned on the back may move around potentially in the surf, causing the
unit to lose track to the satellites, or hinder recordings. A key aspect of surfing is essentially
rapid changes in center of mass; therefore, units need to be secured. Ideally, the unit should
face upwards to have a strong signal lock of the satellites; however, surfers are paddling in a
prone position, therefore the units GPS antenna could potentially be facing out towards the
horizon in the water. Additionally, once a surfer has fallen off at a high speed on a big wave,
GPS signal is likely be lost and would likely record speeds and distances that are not accurate
(personal observations).

Nonetheless, studies to date have provided valuable insights into the external
demands of competitive surfing, such as the distances surfers’ paddle, speeds generated while
surfing and how far they travel while on a wave. These variables provide insights of the sport
and workloads encountered, thus providing coaches’ valuable information that can be used for developing and prescribing training programs.

**Distances**

The distances recorded during surfing sessions provide coaches and athletes valuable insights into workloads encountered during sessions. Given that TMA has indicated such a large portion of time is spent paddling, it appears that surfers may travel a great distance paddling. However, there is also evidence that the total distance travelled differs between training and competition surfing and recreational surfing. For instance, during training, the total distances ranged between 1538m and 1600m per 30 minute quarter (82), whereas competitive surfing heats have reported varying distances with 1433m at a beach-break (30), to between 997m (29) and 1806m (30) at a point-break per 20 minute heat and 3925m per hour during recreational surfing (10). A difference in distance travelled is also evident during wave riding with studies reporting wave riding distances greater than 100m in competition (120 – 132m) (29, 30) but only 55m in training (10). However, caution should be taken when interpreting these results since such differences are likely due to the superior surfing conditions observed in competition studies when compared to current training studies. The longer distances recorded in one study on competitive surfing (30) is likely due to waves wrapping around the point producing longer quality rides for the surfers. This in turn also results in a longer paddle back to the take-off zone, unlike the shorter beach-break waves (30) which may also explain the shorter distances reported in training (82). These findings indicate that the type of surf break and conditions may influence total load and paddling distances experienced. Indeed not only is the surf location likely to affect results, but also the quality of the surf conditions with correlations identified between wave size and the total distance covered ($r=0.55$, $p=0.04$) in conditions that had favorable offshore winds, which would have
improved wave quality (82). To date however, no study has specifically compared external 
load between surfing competition and training or under differing environmental and wave 
conditions. As such, further research examining training and competition demands under 
similar surfing conditions is needed in order to gain a greater understanding of how 
accurately training replicates the demands of competitive surfing. Likewise, research 
examining loads under a variety of surf conditions to gain a greater understanding of the 
associations between environmental conditions and training/competition demands is 
warranted.

**Speeds**

The total distances reported in previous surfing literature equate to an average speed 
between 72 to 90 m·min\(^{-1}\) (30) in competition, 37 to 79 m·min\(^{-1}\) (82) during training and 65 
m·min\(^{-1}\) (10) recreationally. Collectively these studies indicate that the workload (paddling 
speed, wave-riding distance and paddling distance) during competitive surfing may be 
slightly greater than training and recreational surfing. The higher paddling speeds and wave 
distances would be suspected given the time constraints of the heats. Hence, surfers need to 
paddle harder/faster for waves and maximize wave-riding distances to improve point scoring 
opportunities. Further, the lower workloads reported during surf training (82) are also 
typically seen in other team based field sports, where intensity of activity during training 
sessions are lower compared to that of competition (23, 36).

Within surfing literature, the speeds athletes achieve during various surfing activities 
have been categorized into nine separate zones (Table 3) (30). It should be noted that these 
speeds are absolute and not relative to the wave size or athletes. Therefore, higher speeds (i.e. 
>30 km·h\(^{-1}\)) maybe very different between a junior and an elite surfer, or between a large
(1.9m tall 90kg) and small (1.7m tall 65kg) surfer. The mean maximal speed surfers encountered during wave riding are typically reported to range between 22 and 35 km·h⁻¹ (10, 30, 82), yet speeds greater than 40 km·h⁻¹ have also been documented (30). The average speed encountered while not riding a wave range between 3 km·h⁻¹ (82) and 4 km·h⁻¹ (30), in 0.76 to 1.22m and 1 to 1.5m swell, respectively. In relation to the wave speeds, studies utilizing GPS have minor discrepancies with the actual wave speed recorded threshold, as anything greater than 8.1 km·h⁻¹, (30) or greater than 2.5 m·s⁻¹ (9 km·h⁻¹) for a minimum of 4 s (10) recorded from the GPS unit. Whereas a true indication of wave riding and entry speed into the wave, including other measures (i.e. paddling, sprint paddling) should be via the synchronization of GPS data and video recordings together (30, 82).

The faster speeds previously reported during competition (30), compared with training (82) are possibly due to the level of surfing ability, quality of wave conditions and the size of the waves. Indeed, it has been reported that maximum surfing speed is correlated with the surfers wave riding ability (spearman rank-order coefficient = 0.35, p<0.001) indicating that better surfers utilize more speed from the wave (10). However, it was also noted that participants with the higher ability rating tended to surf in larger waves, which would have resulted in faster speeds accumulated. Additionally, it has been proposed that the speeds surfers reach may potentially relate to the physical and physiological capacities of the surfing athletes, not solely the wave size (81).

Insert Table 3 here
Further research is needed in this field to clarify whether or not the surfers’ skill level does in fact relate to speeds generated while surfing and examine speed zones relative to the individual athletes. The skill level would seem logical, given that a higher speed while surfing would relate to the amount of power surfers put into their turns, which from a judging perspective in competition is a cue from the amount of spray generated from the turn. The more spay generation and impressive the turn, the higher the judging points awarded (5). Additionally, surfing at a higher speed would require greater skill and muscular contraction during key turning phases on the wave, which could also be relative to the physiological characteristics of each athlete. Therefore, it could be hypothesized that speeds generated while surfing are a complex interaction of the waveform, shape, power and the interaction of the surfers input. Future research should examine relative speeds through longitudinal data on the same athlete/s, aligning GPS and other technologies such as TMA or by making these zones relative to physiological/performance characteristics based off paddling performance tests (83). Such research may indicate the need for speeds zones to be adjusted so that they are relative to the surfing conditions in order to better understand the demands placed on athletes.

Summary

The application of GPS units during surfing has provided necessary insights into the external workloads surfers encounter, such as distances paddled, paddling speeds and velocities obtained while wave riding. This information is useful in quantifying surfing loads and useful when designing training programs and testing protocols. However, the literature on surfing, implementing such devices to date is prominently limited. Methodological protocols and units used between the studies are slightly different and this may result in different total distances recorded per activity. GPS unit reliability is to some extent, expected to give errors during high speeds and sudden rapid movements however. Therefore, caution is
needed when analyzing wave speeds and rapid changes in both direction and velocity, especially during aerial maneuvers and during critical turning movements performed at high speeds. Nonetheless, it appears that during competition, surfers can paddle up to 1km per 20-minute heat, with most surfers reaching speeds greater than 30 km·h⁻¹ on a wave. Additionally, training appears to be completed at a reduced intensity compared to competitive heats with environmental conditions ultimately affecting the speeds and distances covered.

**MEASUREMENTS of INTERNAL LOADS**

An athletes’ internal load refers to how an individual responds to the demands of an exercise task and the resulting physiological strain imposed (40). As such, internal load monitoring is often used by coaches and sports scientists to aid in determining physiological demands of an exercise task and whether an athlete is adapting to a training program (35). In order to determine these loads, a number of measurement devices/methods are available. Some of the methods of monitoring internal load that have been used include heart rate (HR), training impulse (TRIMP), blood lactate (Bla) and the assessment of perception of exertion (RPE) during exercise or over an entire training session (sRPE). These methods are discussed in detail below.

A common perceptual measure of internal load is through the rating of perceived exertion (RPE) (13, 15). While several issues have been highlighted with the use of various RPE scales (1), it is generally accepted that RPE provides a non-invasive measure of the degree of strain experienced during physical work (13). Given the importance of RPE a modified method of reporting internal load has been developed by Foster, Daines, Hector et al., (31) based on the sessional rating of perceived exertion (sRPE). In order to determine a
training impulse this method involves multiplying the athletes RPE by the duration of the session (min). Previous aquatic studies have suggested that sRPE method is a practical and reliable method to quantify internal training load (58, 92). RPE is also typically recorded in conjunction with the use of HR monitors during training. Indeed, RPE correlates well with HR during stable exercise and high-intensity cycle training (35), but not necessarily during short-duration high-intensity efforts (15).

HR monitoring is considered an important component for the assessment of cardiovascular fitness, training prescription and monitoring workloads (50). Vast improvements in technology have seen rapid development and evolution of HR monitors (2). HR monitors have since become a widely used tool for monitoring training in the general population and a variety of sports codes. Indeed HR monitors have been used to monitor internal load in sports such as rugby (24, 51, 86), soccer (3, 8), surf-life-saving (84), basketball (61, 78), hockey (44), as well as exercise-based fitness research (2, 32, 33, 46, 50, 90, 91). The validity of these devices has been previously described (2, 32, 50). Similar to the assessment of TRIMP using RPE, research has also examined the use of TRIMP using HR, which may be calculated from the training duration and the average HR during the session (35, 69). Given the delay associated with changes in HR, the calculation of TRIMP based on HR may be somewhat limited during dynamic high-intensity activities (14), such as surfing.

Bla is a marker that is often used to assess an athlete’s physiological/metabolic response to and exercise bout and therefore can provide information regarding an athlete’s endurance capacity and their response to intermittent exercise (12, 94). However, in addition to changes in exercise intensity and duration, Bla concentration is also sensitive to changes in diet, glycogen content, hydration, temperature and sampling procedure (14). As such, caution
should be taken when using Bla as a direct measure of internal load. Due to surfing literature being in its infancy few studies have examined internal load experienced by athletes in detail. Indeed, no study has examined RPE, sRPE and TRIMP. As such, the focus of the section below outlines and reviews the current literature on the monitoring of HR during surfing.

**Heart Rate Monitoring in Surfing**

Previous surfing studies have reported HR and estimated energy expenditure during recreational surfing (10, 64), simulated competitive surfing (65), competitive surfing heats (30) and training (82). The first study examining HR responses during a one hour recreational surf session (64) indicated that surfing may induce a relatively high degree of cardiovascular strain. Indeed, the peak HR attained was 171 b·min\(^{-1}\), or 95% of the HR\(_{\text{peak}}\) measured from quantification of relative exercise intensity on a swim-bench ergometer. However, the prolonged period of rest or stationary activity during surfing resulted in a lower average HR of 135 b·min\(^{-1}\) (75% HR\(_{\text{peak}}\)) during the entire session. The results of this study are supported by the work of Mendez-Villanueva and Bishop (65) who also observed a high HR during simulated 20 minute surfing heats using competitive male surfers. It was found that the mean HR was 84% of HR\(_{\text{peak}}\) (174 b·min\(^{-1}\)) obtained during a laboratory based maximal arm paddling test on a modified kayak ergometer. In this study, surfers’ spent 25% of the total time above 90% HR\(_{\text{peak}}\). Details have emerged that during competition (30), surfers spend 60% of the total time ranging between 56% to 74% of heart rate maximum (HR\(_{\text{max}}\)) and approximately 3% above 83% HR\(_{\text{max}}\). These moderate to high HRs indicate the intermittent and relatively high cardiorespiratory demand associated with surfing. There is however, a large variation in mean and HR\(_{\text{peak}}\) measures reported to date (Table 4).

*Insert Table 4 here*
The moderate and high intensities encountered indicate that surfing has an important aerobic contribution, which is also likely to be associated with overall performance in the sport. The HR reported from these studies provide an insight to the workloads/energy expenditure and energy systems encountered while competing, training and during recreational surfing. Interestingly the average HR reported between studies are relatively similar, except in that of a training study (82) which reported slightly lower HR (Table 4). This lower HR may be associated with reduced external load of different surfing conditions within the training study. Further research systematically comparing internal training load over training and competition is warranted.

Technological advancements in HR monitoring now allows the simultaneous collection of GPS and HR data, which has featured within more recent surfing literature (10, 30, 82). The technologies combined provide a better indication of the cardiorespiratory demands of different surfing activities (i.e. wave-riding, paddling etc.) in comparison to individual GPS and HR recordings. Software combining GPS and HR data allowed for the observation of competitive surfers HR_{peak} after the athletes had finished riding the wave (30). These findings provide added insights into the physiological responses to different situations and activities that are useful for training intensities. The response of the HR_{peak} was likely attributed to a delay in the HR response (2) and the high-intensity effort associated with paddling for the wave. It was also suggested that such a response might be due to the demands of riding a wave, combined with an adrenaline release ensued from the wave ride and fall. Once a surfer has finished riding the wave/fallen off, breath holding during the duck diving process and harder paddling bouts were required for the surfer to paddle through the breaking waves (30).
Given that HR provides information regarding exercise intensity, a decline in HR may be related to the development of fatigue. Indeed, HR has been shown to decline throughout prolonged match-play during water-polo (72) and soccer (4, 8), with the intensity during this time also decreasing. This decline is also in accordance to the findings from surf training (82), with surfers having significantly higher HRs in the first 30 minute quarter than the remainder of the training session, with a decline in HR over the three quarters to quarter four. It can be speculated that this change in HR was the result of less time spent paddling (Quarter 1: 46%, quarter 4: 43%) and more time stationary (Quarter 1: 49%, quarter 4: 51%) during later stages of the training, resulting in a lower intensity. Whether this decline in intensity is the result of fatigue, changes to environmental conditions, or a pacing strategy adopted by the surfers is unclear and warrants further investigation. However, it does highlight the importance of collecting details on internal and external load simultaneously.

The TMA from surfing mentioned earlier (Table 2) can be used to propose that the time spent paddling and stationary are likely to correlate with the HR measures reported. The results from competitive surfing (30) suggest that it has the shortest percentage of time spent stationary from the studies to date, while also reporting the highest HR_{peak} and percentage spent paddling. Whereas training (82), produces the highest percentage spent stationary and lowest percentage spent paddling, potentially resulting in the lower HR measures reported. Therefore, it appears that the time spent per activity could dictate the intensities, as indicated by the simulated heats (67) which reported the longest paddling periods from studies to date, which maybe a reflection of the higher mean HR reported. Then again, the higher HR measures during the competition and simulated competition would tend to suggest that a higher physiological intensity was achieved during the competitive environment. This could
be due to stress, competitive demands, intensity of the short heat duration requiring a higher workload and the lack of long rest periods compared to training/recreational surfing (30, 67) ENREF_9.

Competitive surfing, like any other sport is ultimately going to have an impact on the HR measures. The high levels of concentration, heat pressures such as wave scores, opposition and their scores, time constraints, pressures if losing during last minutes of the heat and the emotional stress resulting from these would induce an elevation of the HR (65). To our knowledge there are no studies reflecting on how the stresses of the sport related to HR measures. However, it is important to note these aspects are likely to alter HR response during different surfing stations, including stresses of perhaps bigger waves that maybe out of comfort zones of surfers.

The HR measures from the studies are also likely to be subject to the equipment, the surfing environmental variables, participants used and their fitness levels. Given the number of variables that are likely to associate with the HR measures, caution is needed when interpreting these HR measures, especially with HR monitors used within the surfing environment that have designed for land based monitoring. The vast range of environmental variables associated with surfing (i.e. beach type and break, swell size, swell period, currents, wave frequency or length, weather and wind) are all likely to change. Therefore, the environment is highly likely to dictate the workloads surfers encounter per session and even per 30 minutes of surfing (82). Locations with a shorter swell period (less time between wave) and bigger waves would ultimately mean a higher work rate, as opposed to a beach that has smaller, longer swell period with clean/calm conditions. Finally, subjects are likely to vary in fitness levels and ability within the competitive levels, let alone recreational level surfers. However, given the values recorded, it is hard to ascertain such a suggestion that the
level of surfing ability and physical characteristics are likely to cause a difference within the HR measures. Clearly more studies are needed to provide further information on these measures and if there are any differences in the measures between surfers’ physicality and level of surfing ability. Indeed, many factors in addition to exercise intensity may influence HR response, some of which may be pertinent to surfing and surfing performance.

**Summary**

Due to the limited studies, it is difficult to establish definitive parameters of HR profiling for surfing, with HR measures conceivably elevated due to a number of factors and variables associated with the sport. These factors and variables include, but are not limited to external environmental variables and surf conditions, individual physiological characteristics and fitness levels and internal psychological stress from the competitive environment. However, despite the number of variables that are likely to be associated with the HR measures, there seems to be an emerging understanding of the workload surfer’s encounter. Combining data from previous studies, approximately 137 b·min<sup>-1</sup> is the mean HR and 177 b·min<sup>-1</sup> is approximately the HR<sub>peak</sub> reached during surfing. HR measures suggest that the sport is made up of moderate intensity activity periods (60% of total time from 56% to 74% of HR<sub>max</sub> (30)) soliciting mainly the aerobic system, with intercalated bouts of high-intensity activity (>90%HR<sub>peak</sub>), stressing both the aerobic and anaerobic energy system during higher intensity bouts. With only HR measures recorded, perhaps RPE scores or other internal load methods could be utilized in conjunction to HR measures during surfing for a better perspective of the internal workloads of surfing.

**CONCLUSION**
Performance analysis within surfing is necessary for understanding the internal and external loads experienced. Without implementing such methods, practitioners would lack specific understanding of the sport regarding the workloads, durations and stress involved. Therefore, coaches would be limited to speculate on training requirements for these athletes. There is currently a lack of studies detailing the physiological demands of competitive surfers during competition, training and free surfing. An increase in research of the sport will add to the overall level of professionalism within surfing and raise awareness of the benefits of certain training methodologies developed from performance analysis. Currently, to our knowledge, there is no performance analysis research on female surfers during any form of surfing. However, the studies to date suggest that all forms of surfing are characterized by repeat high intensity intermittent bouts of paddling interspersed with moderate to high HRs and substantial paddling distances.

**PRACTICAL APPLICATIONS**

With recent developments in technology, studies have been able to provide valuable insights into the sport of surfing. The utilization of HR monitors, GPS units and TMA have been suggested to be valid and reliable when collecting data on athletes during different sports codes. Additionally, synchronization of such technology is recommended to accurately determine the loads athletes endure. Future use of such technology is essential to help enhance our understanding of the physical demands and characteristics of surfing. As a result, future studies would provide vital information on surfers’ workloads and as such, support the development of specific, on and off-water training programs that aim to enhance surfing athletes’ performance.

**References**


59. 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.


86. Suarez-Arrones L, Arenas C, López G, Requena B, Terrill O, and Mendez-Villanueva A. Positional differences in match running performance and physical collisions in...


Table 1: Time-motion analysis activity definitions for analyzing surfing workloads

<table>
<thead>
<tr>
<th>Motion Category</th>
<th>Definition as defined by Meir et al. (64)</th>
<th>Definitions as defined by Farley et al. (30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paddling</td>
<td>All forward board propulsion using alternate-arm paddling action.</td>
<td>Forward board propulsion using alternate-arm paddling action.</td>
</tr>
<tr>
<td>Stationary</td>
<td>Subjects sitting or lying on their boards, including a slow one arm paddling action to maintain position in the take-off zone.</td>
<td>All situations in which subjects were sitting or lying on their boards, with no locomotion activity.</td>
</tr>
<tr>
<td>Wave riding</td>
<td>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.</td>
<td>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.</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Walking or running up the beach, wading, duck diving under white water and recovering and getting back on the surfboard after falling.</td>
<td>Duck diving under broken/unbroken waves, recovering and getting back on the surfboard after falling, slow one-arm paddling action aiming to maintain position in the take-off zone and sitting on the board moving the arms in water to move around but not paddling forward</td>
</tr>
<tr>
<td>Paddling for wave</td>
<td>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.</td>
<td></td>
</tr>
</tbody>
</table>
Table 2: Analysis of durations and percentages of time spent in each surfing activity and number of occurrences per activity

<table>
<thead>
<tr>
<th>Study</th>
<th>Paddling</th>
<th>Stationary</th>
<th>Riding Waves</th>
<th>Miscellaneous</th>
<th>Paddling for wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meir et al. (64) (Recreational)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity count</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average bout (s)</td>
<td>0:25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total time %</td>
<td>44%</td>
<td>35%</td>
<td>5%</td>
<td>16%</td>
<td></td>
</tr>
<tr>
<td>Barlow et al. (10) (Recreational) *</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity count</td>
<td>20.6 per hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average bout (s)</td>
<td>0:13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total time %</td>
<td>47%</td>
<td>42%</td>
<td>8%</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Secomb et al. (82) (Training)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity count</td>
<td>35 – 43</td>
<td>24 – 30</td>
<td>5 – 6</td>
<td>4 – 5</td>
<td>10 – 13</td>
</tr>
<tr>
<td>Average bout (s)</td>
<td>0:19</td>
<td>0:34</td>
<td>0:07</td>
<td>0:08</td>
<td>0:06</td>
</tr>
<tr>
<td>Total time %</td>
<td>42%</td>
<td>52%</td>
<td>4%</td>
<td>2%</td>
<td>4%</td>
</tr>
<tr>
<td>Mendez-Villanueva et al. (66) (Competitive)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity count</td>
<td>15 – 37</td>
<td>10 – 26</td>
<td>2 – 8</td>
<td>1 – 13</td>
<td></td>
</tr>
<tr>
<td>Average bout (s)</td>
<td>0:30</td>
<td>0:37</td>
<td>0:11</td>
<td>0:05</td>
<td></td>
</tr>
<tr>
<td>Total time %</td>
<td>51%</td>
<td>42%</td>
<td>4%</td>
<td>2.5%</td>
<td></td>
</tr>
<tr>
<td>Farley et al. (30) (Competitive)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity count</td>
<td>40 – 53</td>
<td>29 – 33</td>
<td>6 – 9</td>
<td>19 – 28</td>
<td>13 – 16</td>
</tr>
<tr>
<td>Average bout (s)</td>
<td>0:16</td>
<td>0:12</td>
<td>0:15</td>
<td>0:03</td>
<td>0:04</td>
</tr>
<tr>
<td>Total time %</td>
<td>54%</td>
<td>28%</td>
<td>8%</td>
<td>4%</td>
<td>4%</td>
</tr>
</tbody>
</table>
Table 3: Classification of speed zones during surfing

(Adapted from Farley et al. (30))

<table>
<thead>
<tr>
<th>Zone</th>
<th>Speed Range</th>
<th>Intensity</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 – 4 km·h⁻¹</td>
<td>Slow – Moderate</td>
<td>Paddling</td>
</tr>
<tr>
<td>2</td>
<td>4.1 – 8 km·h⁻¹</td>
<td>Moderate – Very High</td>
<td>Paddling</td>
</tr>
<tr>
<td>3</td>
<td>8.1 – 12 km·h⁻¹</td>
<td>Slow</td>
<td>Wave Riding</td>
</tr>
<tr>
<td>4</td>
<td>12.1 – 16 km·h⁻¹</td>
<td></td>
<td>Wave Riding</td>
</tr>
<tr>
<td>5</td>
<td>16.1 – 20 km·h⁻¹</td>
<td>Moderate</td>
<td>Wave Riding</td>
</tr>
<tr>
<td>6</td>
<td>20.1 – 25 km·h⁻¹</td>
<td>High Speed</td>
<td>Wave Riding</td>
</tr>
<tr>
<td>7</td>
<td>25.1 – 30 km·h⁻¹</td>
<td></td>
<td>Wave Riding</td>
</tr>
<tr>
<td>8</td>
<td>30.1 – 40 km·h⁻¹</td>
<td>Extremely High Speed</td>
<td>Wave Riding</td>
</tr>
<tr>
<td>9</td>
<td>40.1 – 46 km·h⁻¹</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Surfing heart rate measures from studies to date

<table>
<thead>
<tr>
<th>Study</th>
<th>HR mean b·min⁻¹</th>
<th>HR&lt;sub&gt;peak&lt;/sub&gt; b·min⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meir et al. (64)</td>
<td>135 ± 7</td>
<td>171 ± 7</td>
</tr>
<tr>
<td>(Recreational surf)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meendez-Villanueva et al. (65)</td>
<td>146 ± 20</td>
<td></td>
</tr>
<tr>
<td>(Simulated heat)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farley et al. (30)</td>
<td>140 ± 11</td>
<td>190 ± 12</td>
</tr>
<tr>
<td>(Competitive heats)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secomb et al. (82)</td>
<td>128 ± 13</td>
<td>171 ± 12</td>
</tr>
<tr>
<td>(Training)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barlow et al. (10)</td>
<td>146 ± 17</td>
<td></td>
</tr>
<tr>
<td>(Recreational surf)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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