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Physiological, Musculoskeletal & Anthropometric Characteristics & Performance Between Competitive & Recreational Surfers: A Scoping Review

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ABSTRACT

International Journal of Exercise Science 14(6): 1277-1293, 2021. Surfing is the ability to ride a surfboard along the unbroken section, wall or face of a wave, as it moves closer towards the shore. The purpose of this review is to provide an overview of the physiological, musculoskeletal and anthropometric characteristics that can differentiate between paddling and wave riding performance in competitive and recreational surfing populations. The eligibility criteria for this scoping review included articles that distinguished between multiple surfing ability groups, identified physiological, musculoskeletal or anthropometric characteristics, were peer reviewed, and directly related to the sport of surfing. The databases used to search for relevant literature included PubMed, CINAHL, EMBASE, SPORTDiscus and Google Scholar. All relevant articles were screened and assessed for full text eligibility. This resulted in 28 full text articles to be synthesized and included in this review. A range of significant physiological, musculoskeletal, and anthropometric characteristics were able to differentiate between surfing abilities. The most common differentiating physiological characteristics seen in competitive surfers were faster sprint paddling velocity, greater anaerobic power, higher VO2 peak, and greater lower limb power. The most common differentiating musculoskeletal and anthropometric characteristics seen in competitive surfers were increased postural control, increased ankle dorsiflexion, higher lean mass ratio, shorter stature, and greater arm span, respectively. Knowledge of these characteristics could lead to development of talent identification protocols as well as tailor programs to target specific characteristics the athlete is lacking in order to minimize the risk of these attributes inhibiting optimal performance.

KEY WORDS: Surf, aerobic, strength, skin folds, range of motion, screening protocol

INTRODUCTION

Surfing is the ability to ride a surf board along the unbroken section, wall or face of a wave, as it moves closer towards the shore (22). The popularity of surfing as both a recreational and competitive sport has grown globally at an exponential rate, with recent estimates showing

approximately 35 million surfers worldwide and an annual growth of 11.5% (29). This increase in popularity has captured the interest of the International Olympic Games and has led to the decision to include competitive surfing for the first time in the Tokyo 2021 Summer Olympic Games (38). Given this rise in popularity, the ability to analyse and identify performance characteristics has become increasingly important. Generally, Olympic sports have a higher degree of professional evidence-based research and performance development of athletes in their associated sports, taking sports to a higher level of athleticism (13). More pressure, therefore, has been placed upon surf coaches and health professionals to enhance the performance of surfers, ensuring that they can perform at an Olympic level. Thus, the demand for identifying physiological, anthropometric and musculoskeletal characteristics that can be attributed to performance and profiling of surfers with different abilities has become crucial.

Surfing is performed in a dynamic environment with ever-changing and challenging oceanic conditions that surfers need to constantly adapt to (10). Farley, Harris and Kilding (9) analyzed the physiological demands of surfing for national competitive surfers, reporting that approximately 54% of a 20-30-minute heat was spent paddling, followed by 28% spent stationary, 8% wave riding, 5% of miscellaneous activity and 4% paddling for a wave. Furthermore, 80% of the total paddling time described above lasted approximately 1-20-seconds and 64% of stationary time between paddling bouts lasted 1-10-seconds. The variation in paddling speeds, therefore, highlights the importance of utilizing both the anaerobic and aerobic energy systems in order for the surfer to 1) achieve tactical positioning during a competition (i.e. gaining priority for a wave), and 2) adapt to everchanging environmental conditions (i.e. crowd, swell and current).

However, within competitive surfing, only the "wave riding" stage is scored. Scoring is based on a criterion set in 2010 by the World Surfing League (WSL). The criterion consists of 5 main aspects as follows: 1) commitment and degree of difficulty, 2) innovative and progressive maneuvers, 3) combination of major maneuvers, 4) variety of maneuvers, and 5) speed, power and flow (43). However, the paddling aspect of the event is equally as important in order to determine the best take off position and have advantages over other competitors.

During competition, surfers can catch an unlimited number of waves, where each wave ridden is scored subjectively by a judging panel on a scale of one to ten, considering the above criteria. The two-highest scoring waves are combined for an overall total out of 20, where improvements of as little as ~0.5 points can alter the result of a competitor's performance (22). Both a high level of skill and combination of key physiological, musculoskeletal and anthropometric characteristics are needed by competitive surfers to score maximally against a judging criterion.

Studies by Farley, Harris and Kilding (8) & Furness, Hing, Sheppard, Newcomer, Schram and Climstein (16) identified that physiological characteristics such as peak anaerobic power were significantly greater in competitive surfers compared to those who surfed recreationally. Furthermore, a higher peak in maximal oxygen uptake (VO_2 peak) was identified by a group of researchers (1) in surfers who were competitive compared to those who surfed recreationally. A higher relative oxygen uptake normalised against body weight (i.e. ml/kg/min) was also identified in competitive surfers (1, 19, 23). Lactate threshold and the onset of blood lactate accumulation were both significantly higher in competitive surfers compared to recreational

surfers (1, 11, 14, 19, 23, 24, 37), indicating that higher level surfers have a greater ability to efficiently remove blood lactate and therefore perform better during anaerobic bouts.

Upper limb (6, 15, 27, 35) and lower limb strength (10, 28, 31) were also found to be favourable in competitive surfers compared to recreational surfers. Faster paddling velocity both anaerobically and aerobically were also noticeably higher in the competitive groups (6, 7, 28, 31, 34, 35, 40). Combining these physiological characteristics allows more force to be applied to each movement (i.e. paddling stroke, wave riding manoeuvres, etc.) and therefore creating more powerful and explosive movements, permitting an individual to react and respond quickly to the wave.

Furthermore, multiple studies identified a potential relationship between anthropometric measures and the level of surfing ability. Barlow, Findlay, Gresty and Cooke (2) & Fernández-López, Cámara, Maldonado and Rosique-Gracia (11) found that a mesomorphic dominant figure was more common in competitive groups of surfers than in recreational. Lean mass ratio from the sum of 6-, 7- and 8-site skinfold measures was found to be poorer in recreational surfers rather than competitive surfers (2, 10, 11, 28, 34, 35, 40).

Significant musculoskeletal characteristics in competitive surfers have been associated with having better postural control under certain conditions (14, 18, 26, 30) as well as increased ankle dorsiflexion (12, 15) trunk rotation, lumbar extension, shoulder and hip internal rotation (15). During wave riding, lower limb range of motion varies in different directions at high velocities, indicating the importance of having full pain free range of motion of the lower extremity joints. Competitive surfers need to produce a high level of force throughout this range in order to perform complex manoeuvres such as vertical turns, aerials and tube-rides, ensuring higher success rates in competition (20). Without optimal range of motion and control at the ankle and trunk, these complex tasks predispose other joints to excessive load and increases the risk of injury unless appropriate flexibility and mobility is maintained (21). Similarly, for the upper extremity, having full shoulder range of motion is vital when paddling. To achieve an efficient paddle stroke and prevent injury, the shoulder requires higher degree of rotation in order to pull the hands through the water and therefore produce optimal force (22).

With the increase in demand for this knowledge regarding characteristics associated with surfing performance, there has been a corresponding increase in the literature surrounding the identification of these characteristics. However, with the increase of literature comes an increase in conflicting findings between multiple studies. For example, Almeida, Reis, Beckert, Moreira and Alves (1) reported a statistically significant relationship with VO_2 peak between competitive and recreational surfers, whereas Farley, Harris and Kilding (8) found there to be no significant relationship. Having clear knowledge of favorable characteristics (physiological, musculoskeletal and anthropometric) related to surfing performance could possibly lead to the development of talent identification protocols and specific prescription of training modalities. Having a talent identification system may allow surf coaches to formulate a protocol and apply to amateur surfers in order to find the ideal characteristics best suited to high level surfing. Additionally, it may assist surf coaches to tailor programs to target specific characteristics the

athlete is lacking in order to minimize the risk of these attributes inhibiting optimal performance.

This lead to the development of the 3 aims of this scoping review: 1) identify and summarize the major characteristics that differentiate performance between surfing abilities; 2) provide a starting point to assist professional surfing coaches and teams to determine the most appropriate battery of physiological, musculoskeletal and anthropometric tests that could be used to evaluate training interventions and/or athlete screening based off of the results of this paper; and 3) highlight any limitations within the current literature as well as areas for future research. This review therefore aims to provide surfing coaches of all levels with a screening protocol to identify what is important in being a successful surfer.

The specific research questions are as follows:

1. What are the physiological, musculoskeletal and/or anthropometric characteristics that are able to provide specific information relative to performance characteristics within competitive and recreational surfers?
2. Based on the established profiles and relationship with performance, what characteristics could aid professional surfing coaches and teams to identify the most appropriate battery of physiological, musculoskeletal and/or anthropometric tests that could be used to evaluate training interventions and be used in athlete screening?
3. What are the limitations in the current literature and proposed areas for future research?

METHODS

Protocol and Registration: The protocol was developed using the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) Extension for Scoping Reviews. The final protocol was registered with the Open Science Framework (doi: 10.17605/OSF.IO/THQBR) on July 7, 2020. This review was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (25).

Eligibility Criteria: The eligibility criteria of this scoping review were created following the Population-Concept-Context framework recommended from the Joanna Briggs Institute (JBI) Reviewer's Manual (36).

Population: This scoping review included studies that discriminated between competitive and recreational surfers. No restrictions were imposed on surfing populations for this review, all ages, gender, country of origin and type of surfboard ridden (long or shortboarders) were eligible for inclusion.

Concept: The concept of this scoping review was the profiling of physiological, musculoskeletal and anthropometric characteristics related to surfing and their relationship to performance in surfing populations.

Context: All periods of time, type of characteristics (physiological, musculoskeletal and anthropometric), all training locations (land, water) all age groups, all levels of surfers were

eligible for inclusion. All peer-reviewed studies were considered for this scoping review, which included; reviews, scoping reviews, systematic reviews, meta-analysis, randomised controlled trials and observational studies.

Any comparator was relevant for inclusion, for example, a study comparing profiling characteristics between competitive and recreational surfing groups. Studies without a comparator were also eligible for inclusion, however, there must be some form of discriminating factor within the group; for example, a competitive cohort that were ranked by ability. Studies were excluded if they did not; distinguish between two groups of surfing abilities, did not identify physiological, musculoskeletal and anthropometric characteristics, were not related specifically to surfing, were from magazine articles, if they had no access to full text, and were non-English language.

Information Sources and Selection of Studies: To identify pertinent literature, a layered approach was used. Using articles specific to the topic, key terminology and concepts were identified and implemented into a draft search strategy. After consultation with the faculty librarian, an informed search strategy was tailored for the following electronic databases: PubMed, CINAHL, Embase, SPORTDiscus and Google Scholar.

When searching on databases such as Google Scholar, a modified search was used and the relevant references from the first 10 pages were chosen due to the large number of results that were produced as per the guidelines established by the Canadian Agency for Drugs and Technologies in Health (CADTH) (4).

Relevant articles gathered from the search were exported into EndNote (Clarivate Analytics, Ver X9) where duplicates were removed based on Title, Author and Year. Articles were then screened using title and abstract performed by two independent reviewers which was conducted concurrently in duplicate. Any discrepancies were resolved between the reviewers through structured discussion. Relevant papers were then equally divided between the two reviewers and further screened by full text independently to identify eligible articles to include in the review. Articles that met full eligibility and inclusion criteria were further used in the data extraction process.

The selection of articles was completed by the two reviewers according the PRISMA—ScR statement (41) utilizing the following process. In summary the selection process is outlined below: 1) systematic search of selected databases; 2) removal of duplicates; 3) title and abstracts screened for eligibility; 4) full text articles assessed for eligibility.

Search: A final search strategy for PubMed database can be found in Appendix 1 and was adapted for other databases through the Systematic Review Polyglot Search Translator (5).

Data Extraction: The JBI Methodology Guidance for Scoping Review was used to frame the data charting process. Articles meeting eligibility criteria were divided in half and relevant data was

extracted by two reviewers into an excel spread sheet. The data form was created by the research team and piloted with draft data items and it was updated through an iterative process.

Any key findings relevant to the scoping review questions were extracted into the following data items: author, year and title, country of origin, study design, sample size, participants/groups, characteristics (physiological, musculoskeletal and/or anthropometric), outcome measures, results (mean values), analysis of results (statistics) and main findings (descriptive) and can be seen in Appendix 2.

This initial process was used and applied to all included studies and adapted accordingly to ensure all measures were included. As per the Johanna Briggs Institute Reviewers' Manual – Methodology for JBI scoping reviews (36) the data extraction process in scoping reviews is an iterative process where the process can be continually updated as the reviewers become more familiar with the evidence.

Data Synthesis: Synthesis of the results was conducted by summarizing the literature according to the data items listed above. Studies were also categorized according to themes. The results were presented in a diagrammatic and/or tabular form and a descriptive narrative synthesis is associated with all tables and diagrams in order to address the research questions and aims of the paper.

RESULTS

Study Selection of Sources of Evidence: Following the removal of duplicates, a total of 985 articles were identified from searches of the electronic databases and the Google Scholar Gray Literature searching tool. On the basis of title and abstract screening, 905 articles were excluded, whereas 80 full-text articles were reviewed and assessed for eligibility. Of these, 52 articles were further excluded for the following reasons as outlined in Figure 1 below: 19 did not identify characteristics to distinguish between two groups, 17 did not compare findings between two or more surfing ability groups, 9 articles were not related to surfing, 4 articles were not peer reviewed, and 3 articles were integrated in a thesis that had already been included in the published articles.

Study Characteristics: As seen in Figure 2, 24 articles analyzed the physiological characteristic differences between competitive and recreational surfers (1, 3, 6-8, 10-12, 14-17, 19, 23, 24, 27, 28, 31-35, 37, 40), 12 articles analyzed the anthropometric characteristics (2, 6, 10, 11, 16, 18, 28, 33-35, 37, 40), and 6 articles looked at the musculoskeletal characteristics (12, 14, 15, 18, 26, 30).

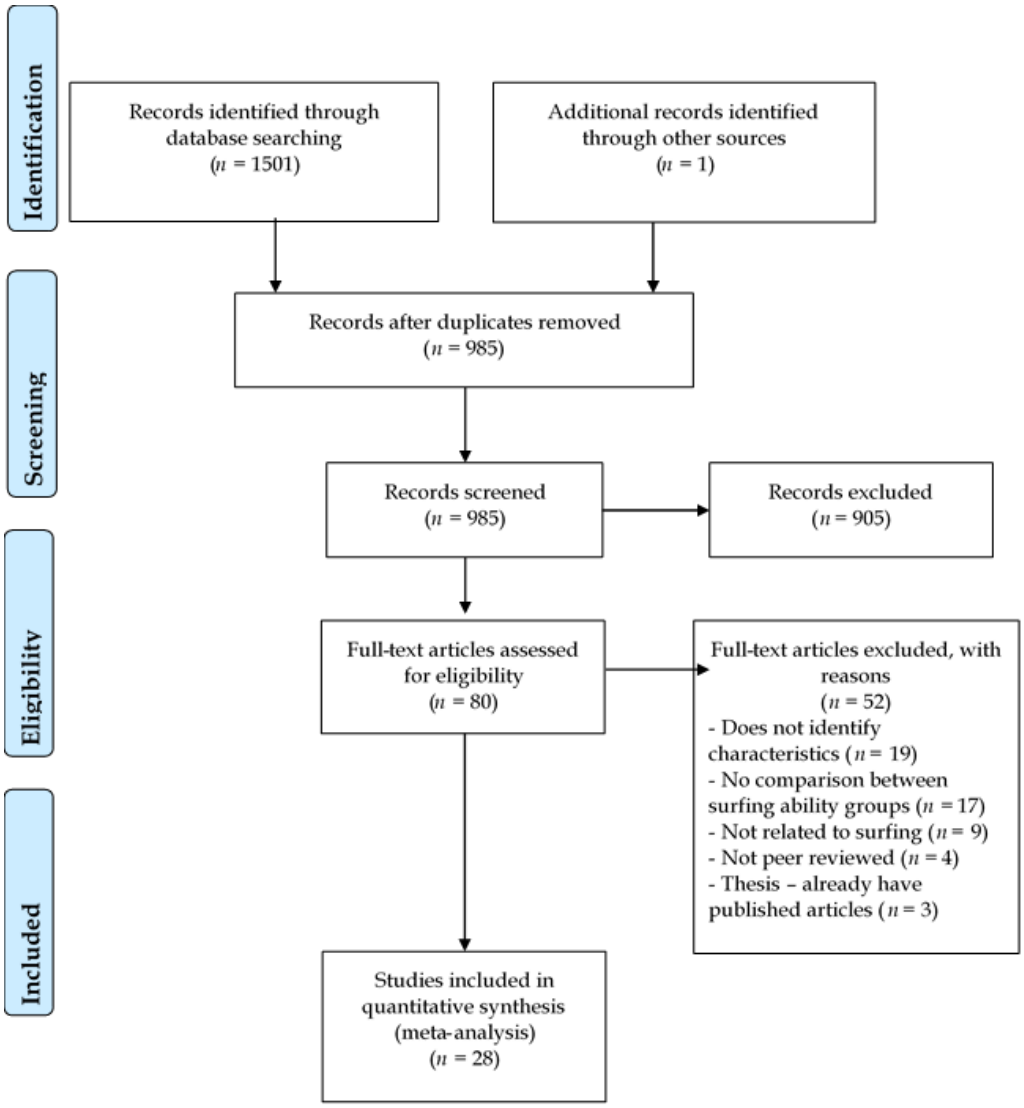

Figure 1. PRISMA (41) flow diagram presenting the results for study selection

The publication types most prevalent in the included studies were cross-sectional studies (21/28, 75%) (1-3, 6-8, 10, 11, 17, 19, 23, 24, 26-28, 30-35), followed by exploratory and quasi-experimental studies (3/28, 10.7%) (18, 37, 40), thesis (2/28, 7.1%) (15, 16), literature review (1/28, 3.6%) (14) and systematic reviews (1/28, 3.6%) (12). The years of publication identified in the literature search ranged from 2005 to 2019, with the years 2010 to 2018 producing the majority of publications (24/28, 85.7%) (1-3, 6-8, 10, 11, 14-16, 19, 24, 26-28, 30-35, 37, 40). The countries of origin varied across 9 countries represented by 5 continents: Australia and Oceania (17/28, 60.7%) (6-8, 12, 14-16, 19, 24, 27, 28, 31-35, 40), Europe (8/28, 28.6%) (1-3, 10, 11, 23, 26, 30), North America (2/28, 7.1%) (16, 17), South America (1/28, 3.6%) (37) and Africa (1/28, 3.6%) (18). Among the 9 countries, Australia produced the majority of the relevant literature (16/28, 57.1%) (6, 7, 12, 14-16, 19, 24, 27, 28, 31-35, 40). Further details are represented in Appendix 2.1 (Table 1). Figure 3 illustrates the physiological, anthropometric and musculoskeletal characteristics found within the scoping review and highlights their interrelationship to different aspects of surfing performance.

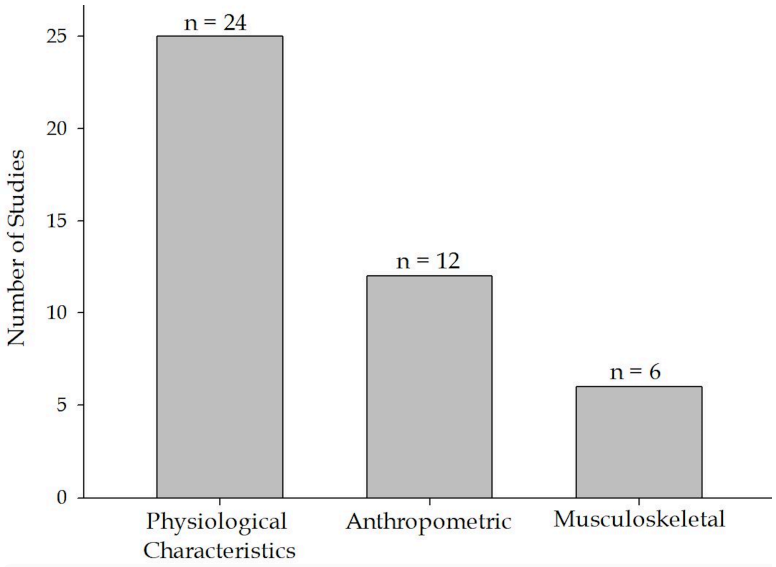

Figure 2. Number of studies analyzing anthropometric, physiological and musculoskeletal characteristics related to competitive vs recreational surfers.

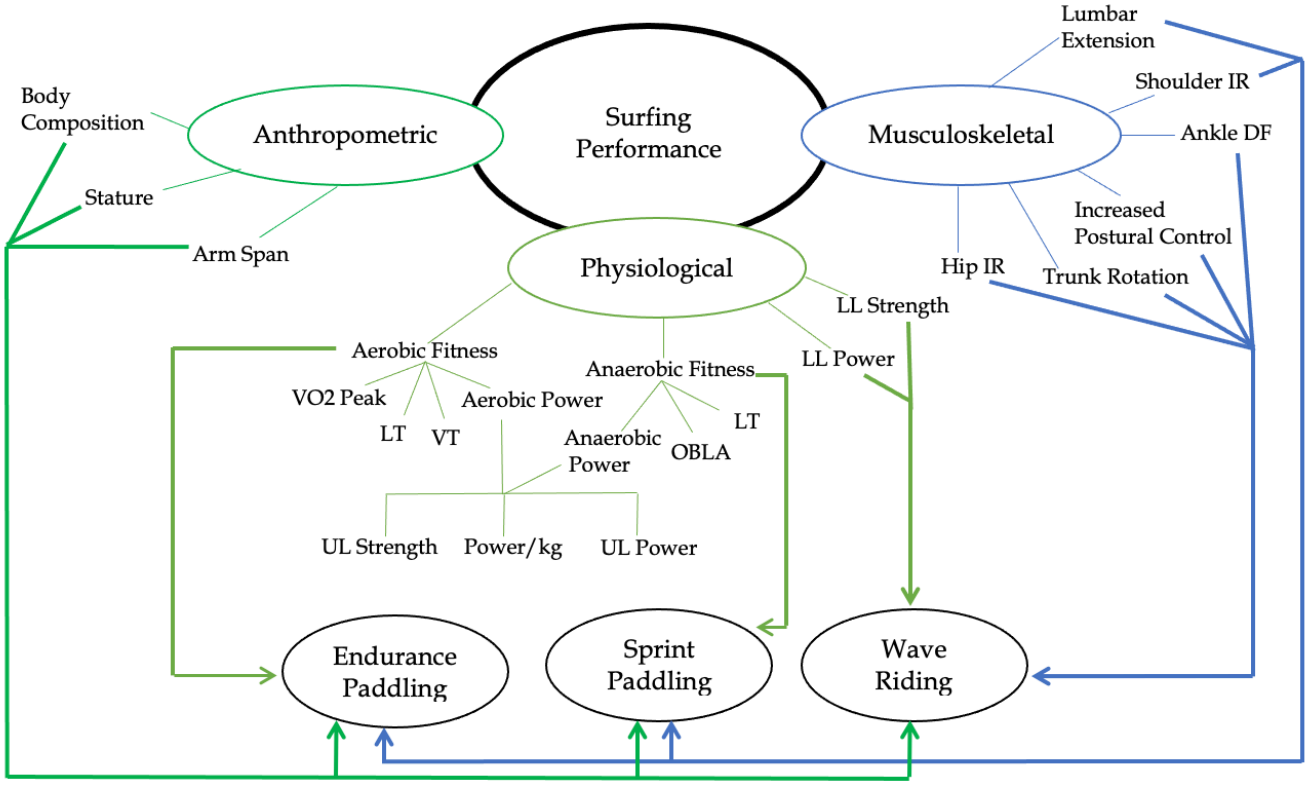

Figure 3. Schematic Diagram of the physiological, anthropometric and musculoskeletal characteristics and their interrelationship to different aspects of surfing performance. VO_2peak = peak volume of maximal rate of oxygen consumption during exertion; *LT* = lactate threshold; *kg* = kilogram; *OBLA* = onset of blood lactate accumulation; *VT* = ventilatory threshold; *UL* = Upper Limb; *LL* = Lower Limb; *IR* = Internal Rotation; *DF* = Dorsiflexion

Physiological Characteristics: Of the 24 articles looking at physiological characteristics, 6 articles found that competitive surfers have a higher VO_2 peak (1, 14, 16, 17, 23, 37) and 1 article found

higher ventilation threshold (VT) (1). Competitive surfers were also found to have a higher power output at VO_2 peak in 2 articles (3, 23). Anaerobic power was found to be significantly higher in competitive surfers by 7 articles (3, 8, 14, 16, 17, 23, 24) and 4 articles showed greater aerobic power (8, 16, 17, 24). Power output per kilogram (kg) (7, 16, 40), power per kg at onset of blood lactate accumulation (11, 19, 37) and at lactate threshold (LT) (11, 23, 37) was found to be higher in competitive surfers in 3 articles each. Five articles found LT threshold as a raw value to be higher in competitive surfers (1, 14, 19, 23, 24). Seven articles identified that competitive surfers have faster sprint paddling velocity (6, 16, 28, 31, 34, 35, 40), while 5 also identified faster endurance paddling velocity in competitive surfers (6, 7, 28, 34, 40). Competitive surfers having better lower limb power was found in 6 articles (10, 12, 28, 31, 32, 40) and lower limb strength in 5 articles (28, 31, 32, 34, 40). Better upper limb power (12, 27) and strength (6, 15, 27, 33) was found in 2 and 4 articles respectively. Vertical jump height was also found by 3 articles to be higher in competitive surfers (10, 31, 40). The number of each significant physiological characteristics in competitive surfers can be seen in Figure 4. Details regarding mean values, statistical values and descriptive results can all be seen in Appendix 2.2 Table 2.

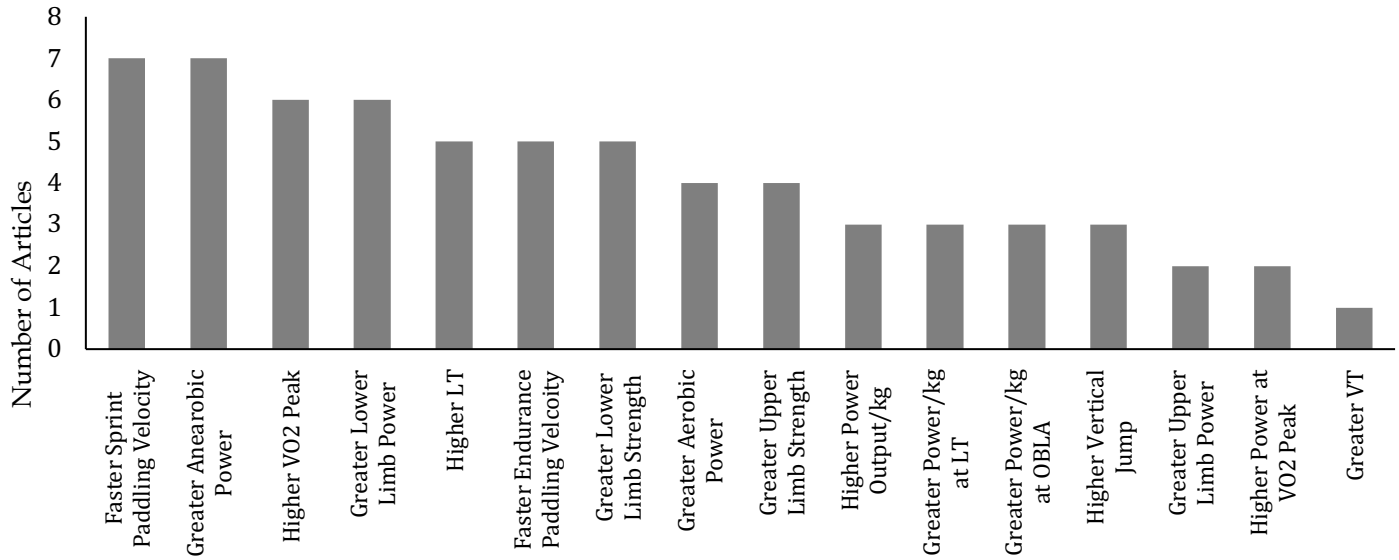

Figure 4. Significant Physiological Characteristics Between Competitive & Recreational Surfers. Number of articles identifying physiological characteristics that were statistically different between competitive and recreational surfers. *VO_2peak* = peak volume of maximal rate of oxygen consumption during exertion; *LT* = lactate threshold; *kg* = kilogram; *OBLA* = onset of blood lactate accumulation; *VT* = ventilatory threshold

Anthropometric Characteristics: There were 12 articles analyzing anthropometric characteristics. A higher lean mass ratio (2, 11, 34, 35, 40) and a shorter stature (2, 18, 28, 35, 40) in competitive surfers were each identified in 5 articles, respectively. A total of 4 articles found competitive surfers to have greater arm span (6, 16, 33, 35). Two articles found that competitive surfers tend to have a mesomorphic dominant figure compared to recreational surfers (2, 11). In addition, competitive surfers were reported to have lower sums of skin folds in 6- (2, 11), 7- (28, 40) and 8-site (10) skin fold measures. The number of articles that found each significant anthropometric characteristic in competitive surfers is represented in Figure 5 below. Details regarding mean values, statistical values and descriptive results can all be seen in Appendix 2.2 Table 2.

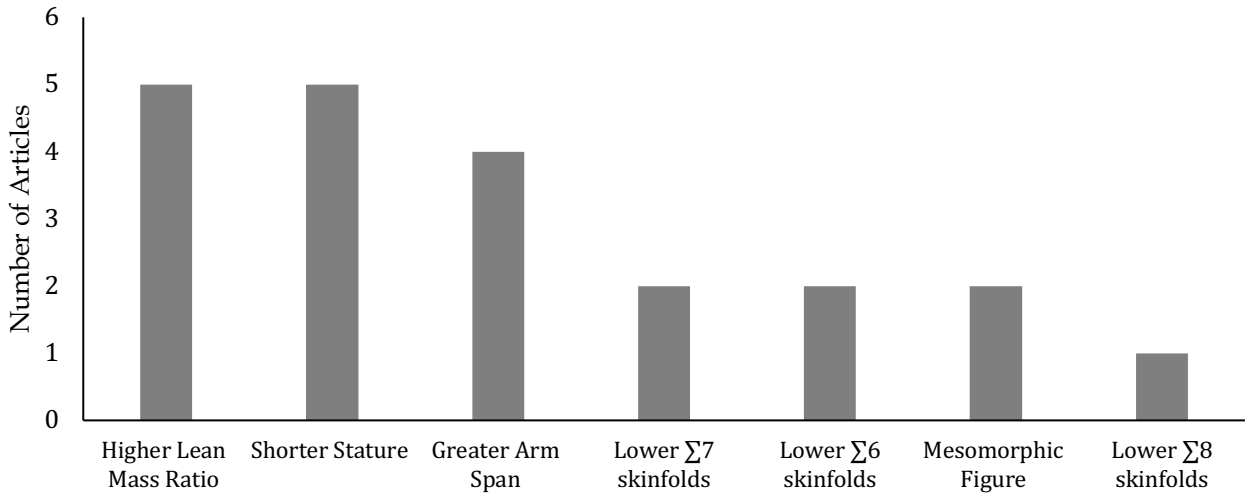

Figure 5. Significant Anthropometric Characteristics Between Competitive & Recreational Surfers
Number of articles identifying the anthropometric characteristics that were significantly different in competitive and recreational surfers. ∑*6 skinfolds* = sum of 6 skinfolds; ∑*7 skinfolds* = sum of 7 skinfolds; ∑*8 skinfolds* = sum of 8 skinfolds

Musculoskeletal Characteristics: Of the 6 articles which focused on musculoskeletal characteristics, 4 articles identified that competitive surfers have greater postural control and balance (14, 18, 26, 30). There were 2 articles that identified greater dorsiflexion range of motion in competitive surfers (12, 15). Also greater shoulder internal rotation range of motion, greater trunk rotation, greater lumbar extension and greater hip internal range of motion was identified by 1 article (15). The number of articles that found each significant musculoskeletal characteristic in competitive surfers are represented in Figure 6. Details regarding mean values, statistical values and descriptive results can all be seen in Appendix 2.2 Table 2.

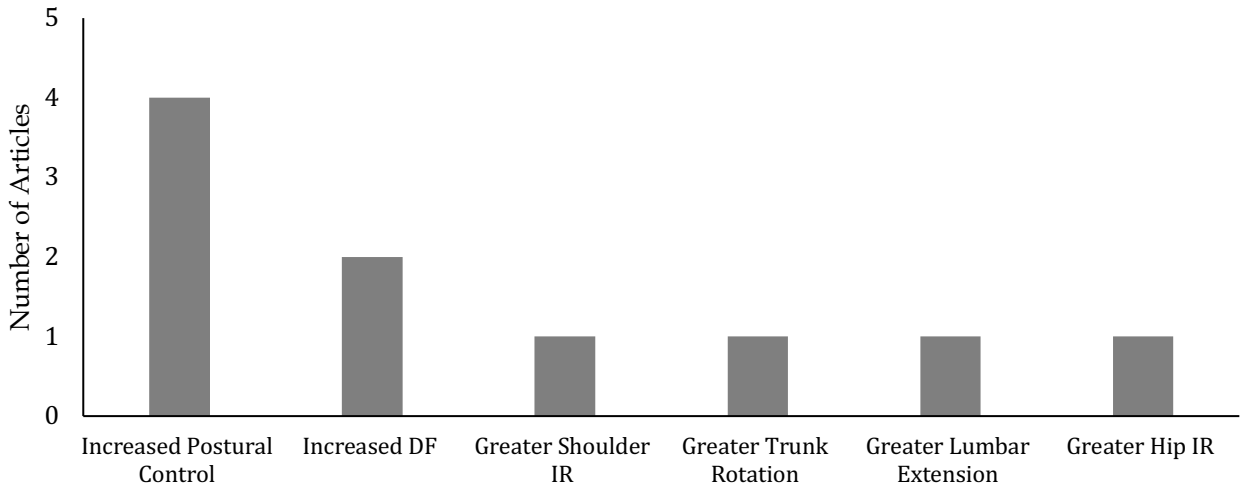

Figure 6. Significant Musculoskeletal Characteristics Between Competitive and Recreational Surfers**.** Number of articles identifying the musculoskeletal characteristics that were significantly different between competitive and recreational surfers. *DF* = ankle dorsiflexion; *IR* = internal rotation

DISCUSSION

The aims of this scoping review were to identify major physiological, anthropometric and musculoskeletal characteristics that differentiate performance between different surfing abilities, with the intentions of assisting surf coaches to develop appropriate test batteries to evaluate training interventions and/or athlete screening. In doing so, this review also aimed to highlight any limitations within the current literature as well as areas for future research. This review found that majority of the research papers identified physiological characteristics of surfers (n = 24), whereas anthropometric (n = 12) and musculoskeletal (n = 6) features were less investigated. The publication type most prevalent in the included studies were cross sectional studies (75%). The year of publication ranged from 2005 to 2019 for all included literature. Additionally, the country of origin varied across a number of countries (n = 9), with the most relevant literature being identified from Australia (16/28 papers, 57.1%).

Physiological Characteristics: The first domain of this review investigated physiological characteristics that were found to be statistically significant in differentiating between competitive and recreational surfing populations, encompassing 86% (n = 24) of the total studies included. Surfing is an intermittent sport that incorporates bouts of both maximal-intensity anaerobic sprint paddling and longer bouts of aerobic paddling. Anaerobic paddling bouts made up the majority of total paddle time during a competitive surfing heat with the aim to catch a wave and encourage tactical positioning to maximize wave riding ability and thus increasing the scoring potential (8).

Anaerobic measures found to be statistically significant between competitive and recreational surfers within this review were sprint paddling velocity, anaerobic power, lactate threshold, and power output (relative to onset of blood lactate accumulation [OBLA], lactate threshold [LT] and VO_2 peak). Although 80% of the paddling in a competitive surfing heat is utilizing the anaerobic energy system, competitive heats typically last between 20-30 minutes, supporting the importance of also optimizing aerobic characteristics. Aerobic measures found to be statistically significant within this review were VO_2 peak, endurance paddling velocity, aerobic power and ventilatory threshold. However, it must be noted that there were many discrepancies between multiple studies. Some studies stated VO_2peak discriminates between two different surfing abilities (1, 14, 16, 17, 23, 37), while others found that it does not (8, 19). However, due to competitive surfing populations possibly having a high VO_2 capacity from intense competitive training regimes and programs, it can be speculated that other factors contribute greater to rank and performance. This area of aerobic conditioning must still be incorporated and prioritized into assessment and specific training prescriptions as it allows athletes to perform at higher intensities for longer periods of time, and therefore enhance recovery time between anaerobic bouts (39).

Other characteristics that were identified to be significantly different between competitive and recreational surfers that contribute to both the anaerobic and aerobic systems were; UL strength, UL power and overall power output (absolute and relative).

Anthropometric Characteristics: Anthropometric characteristics encompassed 12 of the total studies included within this review. Having a shorter stature/body height, higher lean mass ratio and lower sum of skinfolds were found to be statistically significant in comparing competitive surfers and recreational surfers with surfing performance and rank. Having a higher lean mass ratio in competitive surfers denotes that these surfers have a lower percentage of adipose tissue (body fat) and a higher percentage of lean mass, indicating the likelihood of competitive surfers having a better power-to-weight ratio (2). Combining these characteristics allows the surfer to achieve a lower center of gravity, which ultimately helps to maintain stability and balance whilst wave riding. For example, a lower center of gravity can help to keep a surfers' weight evenly distributed over the board, allowing them to extend their legs through the turn and executing maximal power. Furthermore, smaller surfers were able to execute barrel riding more frequently as there is an increased likelihood of surfing in overhead wave heights. Barrel riding is a surfing term that involves the surfer riding inside the curve or "barrel" of a breaking wave and is scored highly in a competitive heat and therefore improves the surfer's rank.

Currently, five out of the top six ranked surfers in the World Surf League are below 1.82m (6 feet) and below 80kg (176lbs) (42), supporting the findings of the articles included within this review. Other anthropometric characteristics found to be significantly different between competitive and recreational surfers were having a mesomorphic body type, with typical traits including having a naturally athletic physique (large bone structure and large muscle size) (11), which could possibly coincide with the frequency and intensity of training competitive surfers undertake as opposed to recreational surfers. Lastly, competitive surfers having greater arm span significantly correlated with sprint paddle performance in 4 studies (6, 16, 33, 35), which could further suggest that surfers with greater arm span are predisposed to being able to paddle more efficiently and at a greater velocity (33).

Musculoskeletal Characteristics: Musculoskeletal characteristics were the least observed outcome measures within this review and was included in 6 of the total articles. A total of 4 articles reported a statistically significant difference in postural control and balance between competitive and recreational surfers. These characteristics allows surfers to perform a higher degree of maneuvers with more speed, power and flow whilst increasing the probability of the surfer successfully completing complex maneuvers. Furthermore, Furness (15) discovered that competitive surfers displayed greater ROM in the ankle, hip, shoulder and trunk, allowing them to optimally position their body so that there are reduced forces and stain on these joints, potentially reducing the risk for injury. Incorporating exercises aimed to improve ROM in training protocols could therefore allow surfers to have a greater advantage over their opponents and gain priority for waves.

Gaps and discrepancies in the literature: As identified throughout this review, the majority of the articles published focused on physiological aspects of surfing, leaving anthropometric and musculoskeletal aspects of surfing to be largely underrepresented (n = 24; 12; 6, respectively). Further research needs to be focused on these two domains to completely understand their contribution to surfing ability and performance.

Throughout data extraction and synthesis within this review, large discrepancies were found in defining competitive surfers versus recreational surfers. Some of the literature considered the competitive population only to be those surfers who competed on the professional circuit (World Surfing League or Qualifying Series Tour), others considered those competing at a national level or even at a local level to be included in the competitive population (some still regarded this as recreational). Furthermore, there were large variations in testing protocols (field and laboratory based) used in the literature included to assess all characteristics identified, for example, multiple studies investigated upper limb strength and power using 1RM pull up tests whereas others used 1RM push up strength. These discrepancies within the literature have led to some variations in findings such as those identified within the physiological characteristics. A common definition for both competitive and recreational surfers along with standardized testing protocols would further validate future literature.

Limitations of the literature review: This review was limited to literature published in English which may have excluded other key studies published in other languages. This review focused solely on physical factors inclusive of the physiological, anthropometric and musculoskeletal characteristics associated with surfing and did not consider the impacts of psychological skills, tactical skills, equipment, experience and or conditions to assess the differences between competitive and recreational surfers.

Additionally, the search protocol, data extraction and data synthesis of this review were completed by two student reviewers. Although all stages were cross checked by each reviewer, the experience of the reviewers could elicit the possibility of errors in these stages of the review. This review only extracted and included data from the literature that was found to be statistically significant reducing the likelihood that all characteristics related to surfing performance were included. Uncertainty of which characteristics fell under the title of musculoskeletal rather than physiological (for example, muscle power and strength) may have led to the number of musculoskeletal articles to be underrepresented.

Comparisons with Previous Work: To the authors' knowledge, this scoping review is the first to analyze the literature surrounding the 3 main characteristics associated with athletic performance in the surfing population – physiological, anthropometric and musculoskeletal. The inclusion criteria for this review focused on the comparison between competitive and recreational surfers, or between two different surfing abilities, whereas many other articles did not compare their findings to performance ability or focused on populations where there were no differences in surfing performance. Only two reviews were similar in profiling surfers (Farley, Harris and Kilding (8) and Secomb, Nimphius, Farley, Lundgren, Tran and Sheppard (32)), however the authors limited their research to one or two of the above characteristics only. Although the findings within both reviews identified similar results to that of the current review, identifying all features of surfing performance is essential in profiling surfers as it incorporates a holistic view on all domains of surfing.

Future Directions: The purpose of developing this scoping review was to identify physiological, anthropometric and musculoskeletal characteristics that differentiate between surfing abilities and directly correlate to improved surfing performance. This current synthesis of knowledge could lead to the development of a screening protocol that surfing coaches could implement for 2 purposes: 1) as a talent identification tool to identify surf athletes that possess optimal characteristics and therefore have an increased likelihood to perform at a higher standard of surfing, or 2) assist surf and strength and conditioning coaches to identify characteristics that surf athlete's may be lacking and therefore create or adapt their specific training prescriptions in order to optimize performance of current athletes or those athletes identified by the talent identification process.

By extrapolating the most significant characteristics within this review that relate to greater surfing performance, future developments could include this screening protocol and administering it to high performance surf clubs or coaches in order to refine their drafting process or improve current athlete's profile and therefore improve performance and therefore rank.

The purpose of this review was to collate the relevant literature and identify the statistically significant physiological, anthropometric and musculoskeletal characteristics that are able to differentiate between competitive and recreational surfers. Overall, competitive surfers were found to have greater physiological capacities such as anaerobic and aerobic paddling velocity, VO_2 peak, LT, VT, lower limb power and strength, upper limb power and strength, power output relative to weight at LT, OBLA and at VO_2 peak. Shorter stature, a higher lean mass ratio, larger arm span, and a greater tendency to have a mesomorphic figure were statistically significant in studies reviewing anthropometric measures. Furthermore, greater postural control, balance and shoulder, hip, ankle and trunk range of motion were found to correlate with greater surfing performance in studies reviewing musculoskeletal characteristics.

However, there still remains significant gaps in the literature, with the majority of the articles published focusing on physiological characteristics rather than anthropometric and musculoskeletal characteristics of surfing. Variations within what defines a surfer as competitive compared to recreational exists, and variations within testing protocols when assessing characteristics also exist within the literature. These gaps will need to be addressed to further validate future research.

The collation of characteristics found within this review creates a summary of what differentiates between the ability of competitive surfers and that of recreational surfers. This review potentially could be used by coaches and talent scouts within the surfing industry as a talent identification tool and to help develop specific strength and conditioning programs for all abilities of surfers.

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