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Training Methods in the Sport of Surfing: A Scoping Review

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Abstract

Surfing has grown significantly in the past decade as highlighted by its inclusion in the 2020 Olympic Games. This growth substantiates a need for training methods which improve surfing performance. The purpose of this review is to: a) identify training methods available to competitive and recreational surfers in peer-reviewed literature b) evaluate the effectiveness of these methods and c) highlight any limitations and potential areas for future research. Five electronic databases were searched and eight papers were identified that met the eligibility criteria. Five of these studies used a quasi-experimental design and one used a case study. The remaining two studies used field-based outcome measures specific to paddling; however, no study demonstrated improvement in wave riding performance. The main training methods identified were 1) resistance training, 2) unstable surface training, and 3) cardiovascular training. Maximal strength training of the upper-body and high-intensity and sprint-interval paddling demonstrated effectiveness for improving paddling performance; however, unstable surface training was ineffective. Although all interventions improved lab-based outcomes, there were no objective measures of wave-riding performance. The findings of this scoping review demonstrate a paucity and low level of evidence in peer-reviewed literature relating training methods to surfing performance.

Introduction

In the last decade there has been significant growth in both recreational and competitive surfing. In fact, in 2012 the International Surfing Association (ISA) reported a worldwide surfing population of 35 million people with a growth expected to exceed 50 million people by 2020 (3). This growth can be further highlighted by the sport’s inclusion into the 2020 Tokyo Olympic Games; a process requiring the sport to be practiced by men in at least 75 countries and four continents and women in at least 40 countries and three continents (7).

In its essence, surfing is a sport that is centred around standing on a board while riding an unbroken wave (44). In order to ride a wave, a surfer must first be able to position themself appropriately in the water and paddle both efficiently and expeditiously prior to explosively “popping up” onto their board to catch a wave. Based on time motion analysis of competitive surfers, roughly 50% of surfing is spent paddling while approximately 3% is spent riding a wave (45, 55). This time breakdown is mirrored in recreational surfing (6, 35). Once a wave is successfully caught, surfing performance can be subjectively based on five key elements established by the World Surfing League (WSL). These include: i) commitment and degree of difficulty, ii) innovative and progressive manoeuvres, iii) combination of major manoeuvres, iv) variety of manoeuvres, and v) speed, power and flow (36). While each of these elements are used to judge competitive surfers, recreational surfers may also aspire to improve their performance in each of these aspects to increase enjoyment and physical benefits through an enhanced ability to catch waves and perform manoeuvres. Regardless of the level of ability of the surfer, improving performance requires practice and training to develop the skills and fitness components necessary to excel. At the elite level, athletes spend a significant amount of time training for their respective sports. For example, Olympic athletes have been shown to spend up to 21 hours per week engaging in strength, conditioning, and mobility training leading up to competition (17, 29). In contrast to this, competitive adolescent surfers have been shown to spend less than five hours per week developing these same aspects (23).
The effects of training on sport specific outcomes have been well documented by research in various sports. For example, a 12-week strength and sprint protocol improved sprint time in masters road cyclists (16). Additionally, an eight and 15-week strength and power protocol was found to improve tackling ability in semi-professional rugby players (58, 59). However, while sports like cycling and rugby have outcomes such as sprint time and tackling ability that directly correlate to sport performance, the same cannot be said about surfing, which is subjectively scored. While this is true, in particular the WSL judging criteria of speed and power may be developed through land-based training. This has been demonstrated in an article by Secomb et al. (51) which found that surfers with more lower-body strength and power scored higher in competition compared to their weaker counterparts. While this observational study presents a correlation between lower-body strength and power and higher scores, the direct causation cannot be concluded and further experimental designs are needed to explore this relationship. With such a difference in the land-based training volume of competitive surfers compared to other Olympic athletes there is an opportunity to explore the potential effects of training on surfing performance.

In regard to surfing, one study found that more than half of a 20-30 minute-competition is spent in brief paddling efforts lasting between 1-20 seconds, with minimal rest time between exertions (21). It should be noted that these times may be affected by environmental conditions in the ocean. As such, surfers require a strong anaerobic system built on a highly developed aerobic foundation to meet these energy demands. On an individual level there are a plethora of studies outlining the physiological and physical characteristics of surfers. Competitive surfers have been shown to have greater anaerobic power (20, 28), maximal oxygen consumption (2, 38, 44), faster paddling velocities in aerobic and anaerobic events (14, 19, 49, 51, 56, 57, 61), and greater upper and lower-body strength (14, 24, 27, 48, 49, 51, 57) compared to recreational surfers. In addition, a positive relationship between competition scores in elite surfers and lower-body strength and power has been reported in the literature (51). Competitive surfers have also been shown to have increased postural control and balance (26, 30, 31, 47), ankle dorsiflexion (25, 27), lumbar extension, and hip and shoulder internal rotation (27). This last point is poignant given that the act of paddling requires a high degree of rotation around the shoulder for an efficient stroke (43). All these characteristics offer insight into areas in which surf performance can be improved through training.

However, to the authors’ knowledge there have been no studies that have examined the effects of a training intervention on any objective measures of wave-riding ability such as speed, acceleration and force output. While outcome measures such as force plates, global-positioning-system (GPS), and accelerometers have been shown to be a valid and reliable way to measure these variables on land (34, 46, 63), the aquatic environment challenges these concepts. This is likely a result of the fact that these measures are influenced by uncontrollable environmental factors such as swell period (the time between waves), wave height, wave shape, and current. However, recent advancements in wave pool technology may offer an ideal experimental paradigm, which allows for outcome variables associated with training interventions to be measured in a controllable wave-riding environment.

The purpose of this review is to thoroughly collate the peer-reviewed literature surrounding training methods in the sport of surfing, determine its quality and relevance, and highlight areas...
for future research. To the authors knowledge, there is currently a paucity of published data on this topic. Therefore, a scoping review was determined to be the optimal study design to address these questions, since it allows for both the examination and summarization of novel heterogeneous literature that has not previously been comprehensively reviewed (50).

**Objectives**
The objective of this scoping review was to 1) identify training methods available to surfers in the peer-reviewed literature 2) synthesize the findings and 3) highlight any limitations and potential areas for future research.

**Methods**

**Protocol and Registration**
An a priori protocol was developed using the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) Extension for Scoping Reviews: Checklist and Explanation (1). This final protocol was registered prospectively with the Open Science Framework osf.io/zyq4f.

**Eligibility Criteria**
The eligibility criteria were informed by the Population-Concept-Context framework recommended by the Joanna Briggs Institute (JBI) Reviewer’s Manual (32).

Population
Given the paucity of available research on this topic, no restrictions were imposed on surfing populations for this review. Competitive and recreational level surfers were included. For the purpose of this review a recreational surfer was defined as someone who participates in surfing recreationally only, whereas a competitive surfer was defined as someone who competes in the sport of surfing (42). Moreover, all genders of any age were suitable for inclusion.

Concept
The concept of this review was to identify and examine the different training methods for surfers available in the peer-reviewed literature. For the purpose of this review training methods were defined as any physiological training regime that was substantiated by a background of exercise science and had explicit or implicit effects on surfing performance.

Context
All periods of time, duration of intervention, follow up, training locations (land, water), age groups, and level of surfing ability were eligible for inclusion. The following types of studies were eligible for inclusion in the study: randomised control trials (RCTs), non-RCTs, quasi-experimental designs, and case studies. The following types of studies were excluded: cross-sectional research, qualitative research, expert opinion/theoretical perspective.

**Information Sources**
To identify pertinent peer-reviewed literature a layered search strategy was used. First, a basic preliminary search of scholarly articles was conducted via three databases: PubMed, SportDiscus, and CINAHL to optimize key words and mesh-terms. Next, a comprehensive search strategy was formulated and tested through consultation with the faculty librarian. Using this optimized search strategy, a literature search of electronic databases was conducted in:
PubMed, CINAHL, Embase, SportDiscus ProQuest, and Google Scholar. The databases were searched from their inception to 16/06/20.

The initial search strategy was formatted with syntax appropriate for PubMed can be found in Table 1. All search strategies for other databases were developed using a translated version of the initial search strategy using the Polyglot tool (11) and can be found in Appendix 1. Finally, the search was supplemented by scanning the reference lists of the included studies for other relevant articles.

Table 1: Search Strategy for PubMed and Google

Selection of Sources of Evidence
Screening was conducted concurrently in duplicate; whereby two reviewers (T.D & M.S) used separate EndNote libraries to individually screen all articles. Any disagreements were resolved immediately during the screening process. If consensus could not be attained a third reviewer (J.F) was brought in to resolve any difference of opinion.

The search results were exported into EndNote (EndNote X9, Clarivate Analytics) and duplicates were removed. Following removal of duplicates, articles captured by the search strategy were screened based on title and abstract for eligibility. Remaining articles were further screened by full text to confirm eligibility and sorted based on resource type. Reasons for full text articles that were excluded were provided. References of articles meeting full eligibility criteria were further examined for additional relevant data.

Critical Appraisal
Peer Reviewed Literature
A critical appraisal was conducted for individual articles included in this review to assess the quality and strength of the studies (T.D & M.S). The Checklist for Quasi-Experimental Studies by the JBI (32) was used and adapted to meet current research aims. This tool can be found in Appendix 2. The tool consisted of 10 questions and a binary grading was used to create a raw score, with a “yes” receiving a score of “1” and a “no” receiving a score of “0” for each question. In order to assess surfing performance one additional question was added, “were both field and lab-based measures used in the outcome?”. As per previous research by Kennelly (33) and McArthur, Jorgensen, Climstein and Furness (40), a quality grade was assigned to each study. A score equal to or greater than 74% was considered ‘good’ quality, a score between 55%–73.9% was considered ‘fair’ quality, and a score less than 54.9% was considered ‘poor’ quality. The finalized scores and associated quality grade can be found in Appendix 3.

Data Charting and Data Items
The JBI Methodology Guidance for Scoping Review was used to frame the data charting process (32). Key areas were identified such as study citation details (author, date, and study design), key study characteristics (outcome measures assessed, dose, intensity, duration of intervention, and results) and overall findings. This initial tool was used and applied to all included studies and adapted in order to ensure all measures were included. Additionally, the level of evidence was determined using the National Health and Medical Research Council template (NHMRC) (13).
A data extraction table was created to address the previously established research questions. This table was piloted on two studies initially and adapted in order to include all relevant measures. The data extraction process was completed by two researchers (T.D & M.S).

Data Synthesis
A descriptive narrative synthesis is associated with all tables and diagrams in order to address the research questions and objectives of the paper. Additionally, synthesis of the results was conducted by summarizing the literature according to the data items listed above.

Results
Selection of Sources of Evidence
Following the removal of duplicates, a total of 935 articles were identified from searches of the electronic peer-reviewed databases and the reference lists of included studies. Based on title and abstract screening, 877 articles were excluded, whereas 58 were retrieved and assessed for eligibility. Of these, 50 were excluded for the following reasons: five government documents, two books without an intervention focus, four expert opinions, eight magazines, five videos, 18 non-intervention-based studies, two articles without a surfing population, five with full text unavailable, and one article that was not relevant. An illustration of search results is presented by the PRISMA flow diagram below (Figure 1).

Figure 1. PRISMA flow diagram showing literature search, screening and eligible studies

Study Characteristics
Study aim and population are highlighted for each of the eight studies in this scoping review. Each study was assessed and graded for quality of study design according to the NHMRC (13). Two studies contained a control group (15, 53), two contained a comparison group (22, 62), and four lacked either a control or comparison group (4, 8, 54, 60). These four studies were categorized as level IV which is qualified as the lowest level of evidence as per the NHMRC. Of the eight studies, seven received a quality score ranging between 70-80% with an associated rating of “good” as per previous research (33, 40). One study received a quality score of 50% and an associated quality score of “fair” (8). One study (15) included recreational surfers in the study design whereas all other studies only examined competitive athletes. A summary of these findings can be found in Table 2 below and Appendix 4. Detailed descriptions of the tools used to assign quality grades can be found in Appendix 3.

Table 2: Key Study Characteristics of Included Studies (n=8)

Comparison of Study Outcome Measures and Interventions
Only two studies examined field-based surfing outcome measures, one study highlighted an improvement in 5m, 10m and 15m sprint paddling performance and 400m endurance paddle performance following a five week upper-body maximal strength training program (15). The other demonstrated an improvement in 15m repeat sprint paddle performance as well as 400m paddle endurance performance following five weeks of either high intensity interval paddle training (HIIT) or sprint interval padding training (SIT) (22). The remaining studies (4, 8, 53, 54, 60, 62) demonstrated improvements in countermovement jump (CMJ) and squat jump (SJ) variables.
such as peak force (PF), peak velocity (PV), as well as isometric mid-thigh pull (IMTP), time to stabilisation (TTS), and rotational acceleration following various resistance training interventions. Outcomes were measured using force plate technology and accelerometers. One study \(^{(53)}\) found that IMTP, CMJ PV, and SJ PV improved with no associated increase in jump height. These findings are summarized below in Figures 2 and 3 and within Table 3.

**Figure 2. Comparison of Study Outcome Measures**

**Figure 3. Comparison of Study Interventions**

**Table 3: Comparison of Study Interventions and Outcomes for Included Studies (n=8)**

**Discussion**

The primary purpose of this scoping review was to outline the literature available surrounding training methods for recreational and competitive surfers. The objectives were to: 1) identify training methods for these surfing populations in peer-reviewed literature 2) evaluate the effectiveness of these methods and 3) to highlight limitations with respect to the findings.

Of the 935 peer-reviewed articles identified, 58 (6%) were eligible for full-text review. Of these, eight (0.8%) met the inclusion criteria. These results were consistent with authors’ knowledge of the paucity of scientific literature regarding the topic. These findings highlight the limited literature in the field for surfers to access. Furthermore, four of the eight studies \(^{(4, 8, 54, 60)}\) were classified as the lowest level of evidence as per the NHMRC \(^{(13)}\) as they were lacking any form of comparator or control group. This contributes to the overall low level of evidence of the papers identified.

Six of the eight studies involved an adolescent surfing population \(^{(4, 8, 22, 53, 60, 62)}\). A single study included recreational surfers \(^{(15)}\). Additionally, only six of the 113 subjects among all studies in this review were female \(^{(8, 22)}\). This highlights a potential underrepresentation of mature, recreational, and female surfers in the published literature surrounding training methods in the sport of surfing. Furthermore, the application of the present research on male surfers to female surfers may be limited due to the inherent physical and physiological differences between the sexes.

Training methods identified included resistance training \(^{(4, 8, 15, 53, 54, 60, 62)}\) and cardiovascular training \(^{(22)}\). Coyne et al. \(^{(15)}\) found that strength training with 1-5 repetition maximum (RM) of the upper-body improved 5m, 10m, 15m and 400m paddling times in competitive and recreational male surfers. Although paddling is not judged in a surfing competition it is integral to tactical positioning and adjusting to ever-changing environmental conditions \(^{(21)}\).

For the lower-body, Secomb et al. \(^{(54)}\) found that a program of combined strength, plyometric, and gymnastics training improved IMTP variables as well as CMJ PV. A later study by Secomb et al. \(^{(53)}\) differentiated the effects of strength training against plyometric and gymnastics training independently and found that only resistance training improved IMTP variables and SJ PV with no associated increase in jump height. Conversely, plyometric and gymnastic training was found
to improve eccentric leg stiffness with no increase in IMTP variables or jump height. Previous research has shown that initial lower-body strength levels can greatly affect the improvements in jump height following a plyometric or power-based intervention (12, 52). The short training time-frame (two sessions a week for seven weeks) may not have allowed for adequate development of lower-body strength to maximize these adaptations, potentially explaining the lack of increase in jump height. The authors acknowledge the importance of developing lower-body eccentric stiffness in jumping performance as per previous research (10, 37). Based on the findings of these studies the authors recommend the implementation of a comprehensive upper-body strength-training program in the 1-5RM range to improve paddling speed and endurance. Additionally, plyometrics or gymnastics may be used as an adjunct to a lower-body strength-training program; however, more research is needed to substantiate the effect of these methods on surfing performance.

Additionally, one article examined the effect of unstable and stable surfaces on resistance training for improving strength (IMTP), power (CMJ), and sensorimotor abilities (TTS via drop and stick; DS) among 10 competitive adolescent surfers (62). All outcome measures were calculated using force plate technology. This article found similar improvements in strength and sensorimotor abilities between stable and unstable surfaces for resistance training. It should be highlighted that the participants of this study were inexperienced with respect to resistance training. This may explain the strength improvement in the unstable surface group as neuromuscular adaptation occurs in untrained individuals with minimal stimulus (9). However, lower-body power output was improved relative to baseline following the stable surface intervention and reduced from baseline for the unstable surface intervention. These findings are in line with other research demonstrating that unstable surface training interventions attenuate force and power development (5, 41). It is also important to note that balance training may be important for enhancing proprioception as competitive surfers have been shown to have increased postural control and balance compared to recreational surfers (26, 30, 31, 47). Given these findings, the use of unstable surfaces for the purpose of developing strength and power to improve surfing performance is not recommended; however, it may serve as an important adjunct to improve postural control and balance.

Two studies examined outcomes in the water; however, only one utilized a cardiovascular training intervention. Farley et al. (22) found that a twice per week five-week intervention of SIT paddling improved repeated 15m sprint paddle time while the HIIT paddling group decreased their 400-m endurance paddling time. Program variables for both interventions such as sets, reps and work to rest ratios (Table 4) mirrored paddling bouts reported by previous time motion analysis (21, 55). This study further delineated that HIIT paddling intervals enhanced aerobic capacity whereas repeated SIT paddling demonstrated more improvements in the anaerobic system. The findings of this study demonstrate the ability of SIT and HIIT training methods to enhance key cardiovascular aspects of the sport that should be included in a surf-training program.

Interestingly, none of the peer-reviewed articles examined mobility or flexibility training despite the finding that professional surfers have increased lumbar extension, trunk rotation, shoulder and hip internal rotation (27), and dorsiflexion (25, 39) compared to recreational surfers. These aspects may play a crucial factor in performing manoeuvres such as snapping and cutbacks.
which require a surfer to oppose the momentum of a wave and turn the surfboard rapidly (18). Furthermore, when positioning inside the airspace underneath the breaking part of the wave, colloquially known as a “barrel”, a surfer may need to crouch to accommodate their bodies into this space. Based upon qualitative analysis, successful completion of this high-scoring manoeuvre may require a high level of lower-body mobility (18). This may highlight the need for future studies to examine the effect of mobility and flexibility training on surfing performance.

Six out of the eight interventions had a positive effect on the outcome measures used (CMJ, IMTP, TTS, VJH, rotational trunk acceleration) (4, 15, 53, 54, 60, 62). Although these outcomes were measured in the lab, previous research has also identified a positive correlation between lower-body strength and power on turning manoeuvres (51). This study included subjective measures of wave-riding ability, and while wave-riding is judged subjectively, objective measures may be used to complement and inform our understanding of how these scores were derived.

Incorporating technology such as board-integrated accelerometers to measure acceleration, force plates to measure power output, GPS units to measure speed, and video-analysis software to quantify aerial height, will allow researchers to objectively measure surfing performance variables. These measures may correlate to the subjective judging criteria from the WSL, in particular, speed and power (36). With this information, causal relationships may be made between training methods and objective surfing performance variables, for example, how is aerial height and magnitude of turning manoeuvre performance affected by a six-week maximal lower-body strength program? Moreover, wave pool technology is becoming increasingly available. This allows for control of ever-changing environmental variables found in the ocean such as swell period, wave height, wave shape, as well as current. With this, consistent reproducible waves can be created, setting the stage for a well-controlled experiment. Collectively, these aforementioned factors will allow future studies to investigate potential complementary correlations and or causational relationships between training, objective riding variables and the subjective performance measures on which surfing is judged.

The findings of this scoping review demonstrate both a paucity and insufficiency in high quality peer reviewed literature surrounding training methods for the sport of surfing. One explanation for this may be the lack of valid and reliable tools available for researchers to objectively measure field-based outcomes such as speed, power, and acceleration while surfing waves. The authors believe that lower-body resistance training focused on building strength and power should be included in a surfing program, as a positive relationship has been identified between lower-body strength and power and surfing performance (51); however, further research is required to support this relationship.

To the authors knowledge this is the first scoping review that highlights the gap between training methods and wave riding performance. Other strengths of this review include the use of two reviewers to reduce bias and the inclusion of a broad eligibility criteria. This review was limited by only including sources published in English, which may have excluded key sources in other languages. To the authors knowledge, no confounding factors exist that may have impacted these study findings. The findings of this scoping review may influence future studies by highlighting the need to examine the direct relationship between training methods and wave riding performance for both competitive and recreational surfers.
Conclusion

The findings of this scoping review demonstrate a paucity in the peer reviewed literature with respect to training methods for improving surfing performance. Two of the eight studies found in this review demonstrated an improvement from either upper-body maximum strength training or SIT and HIIT on paddling performance (15, 22). The remaining six reported improvements in lab-based outcome measures following training input but demonstrated no improvement on wave-riding performance. Moreover, the quality of these studies was relatively low. A lack of available field-based technology and shortage of participants may explain the low number and lack of high-quality research in this context; however, with continued growth in the sport of surfing there is a need for proven training methods that have demonstrated improvements in performance as in other sports (16, 58, 59).

Based upon these findings the authors would recommend a surf training program that focuses on maximal strength training of the upper-body to improve sprint and aerobic paddling performance, HIIT and SIT paddling to improve aerobic capacity and repeat sprint paddle ability, and lower-body resistance training focused on building strength and power to potentially improve surfing performance. These suggestions are in line with previous research which has found that competitive surfers have greater upper-body strength (14, 27, 48, 57) and produce more power aerobically (14, 19, 49, 51, 56, 61) and anaerobically (20, 28) compared to recreational surfers. Furthermore, greater lower-body strength was found to be correlated to improved surfing performance (51). Gymnastics and plyometric training may also be considered an adjunct to a comprehensive strength training program. More research is required to examine the effects of mobility and balance training on surfing performance as these characteristics have also been found to be increased in competitive surfers (25-27, 31, 47). Additionally, more research is required to highlight the direct impact of physical training on objective markers of wave-riding ability. Future studies that implement the use of modern technology such as high-speed cameras, board integrated accelerometers and GPS units, and wave pool technology may serve to fill the gap in research between training and wave riding performance. This study is a call to action for future researchers to investigate objective, measurable outcomes specific to surfing performance and explore how different training methods affect them.

Appendix 1

Appendix 2

Appendix 3

Appendix 4

References
3. Association IS. International Surfing Association to Celebrate 50 Years of Success at the ISA 50th Anniversary World Surfing Games in Punta Rocas, Peru. 2012.


Table 1: Search Strategy for PubMed and Google Scholar

<table>
<thead>
<tr>
<th>Data Base</th>
<th>Search Strategy</th>
</tr>
</thead>
</table>
Figure 1. PRISMA flow diagram showing literature search, screening and eligible studies.
<table>
<thead>
<tr>
<th>Author</th>
<th>Aim</th>
<th>Level of Evidence (8)</th>
<th>Population</th>
<th>Control/ Comparison Group</th>
<th>Grade / Quality Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coyne et al., 2017</td>
<td>Report on effect of a five-week (2x per week) maximal upper-body strength training intervention on surfboard sprint (5m,10m,15m) and endurance (400m) paddling performance in competitive and recreational surfers.</td>
<td>III-2</td>
<td>six competitive and eleven recreational male surfers (29.7 +/- 7.7 years of age)</td>
<td>Y</td>
<td>80% / Good</td>
</tr>
<tr>
<td>Secomb et al., 2017</td>
<td>To compare training-specific adaptations in lower-body strength (IMTP), jumping performance (CMJ) and muscle structure (ultrasound) following a seven-week (2x per week) resistance training versus gymnastics and plyometric training and non-training interventions.</td>
<td>III-2</td>
<td>16 junior competitive surf athletes aged (14.8 +/- 1.8 years of age)</td>
<td>Y</td>
<td>80% / Good</td>
</tr>
<tr>
<td>Farley et al., 2016</td>
<td>Determine effect of a five-week (2x per week) sprint or high-intensity interval paddle training intervention on 400m and repeated 15m paddle performance.</td>
<td>III-2</td>
<td>24 competitive adolescent surfers (19 male, 5 female) (14+/-1.3 years of age)</td>
<td>Y</td>
<td>70% / Good</td>
</tr>
<tr>
<td>Tran et al., 2015</td>
<td>Report on effect of a seven-week (2x per week) unstable versus stable resistance training intervention on strength (IMTP), power (CMJ, SJ), and sensorimotor abilities (TTS) in adolescent surfers.</td>
<td>III-2</td>
<td>10 competitive male and female high school surfers (14 +/- 1.1 years of age)</td>
<td>Y</td>
<td>70% / Good</td>
</tr>
<tr>
<td>Axel et al., 2018</td>
<td>Report on an effect of an eight-week core strength training program (CSTP) on: CMJ, rotational acceleration and power, core strength and endurance) in junior competitive surfers</td>
<td>IV</td>
<td>19 junior competitive surf athletes (15.7±1.01 years of age)</td>
<td>N</td>
<td>70% / Good</td>
</tr>
<tr>
<td>Tran et al., 2016</td>
<td>Examine the effect of four weeks of detraining on strength (IMTP), power (SJ) and sensorimotor ability (TTS) of adolescent surfers following seven weeks of periodized resistance training.</td>
<td>IV</td>
<td>19 adolescent competitive surfers (13.8 +/- 1.7 years of age)</td>
<td>N</td>
<td>70% / Good</td>
</tr>
<tr>
<td>Secomb et al., 2015</td>
<td>Report on the training specific adaptations (CMJ, SJ, IMTP) following a short block (6 weeks/3 times per week) of combined strength, plyometric and gymnastic training</td>
<td>IV</td>
<td>seven international competitive male surfers aged (22.8 +/- 4.1 years of age)</td>
<td>N</td>
<td>70% / Good</td>
</tr>
<tr>
<td>Caballes et al., 2015</td>
<td>Report on effect of a seven month periodized ASCA youth resistance training program on a competitive female surfer’s strength and reported surfing ability.</td>
<td>IV</td>
<td>one elite junior female surfer (15 years of age)</td>
<td>N</td>
<td>50% / Fair</td>
</tr>
</tbody>
</table>
Figure 2. Comparison of Study Outcome Measures

- **Isometric Mid-Thigh Pull (IMTP)**
- **Countermovement Jump (CMJ)**
- **Squat Jump (SJ)**
- **Time to Stabilisation (TTS)**
- **Rotational Acceleration (RA)**
- **Ultrasound (US)**

Field-Based Outcomes 25% (2/8)

Lab-Based Outcomes 75% (6/8)

- **Sprint Paddle Time** (5m, 10m, 15m)
- **Endurance Paddle Time** (400m)
Figure 3. Comparison of Study Interventions

- Lab-Based Interventions: 88% (7/8)
- Field-based Interventions: 12% (1/8)
### Table 3: Comparison of Study Interventions and Outcomes for Included Studies (n=8)

<table>
<thead>
<tr>
<th>Author</th>
<th>Results</th>
<th>Field-Based Outcome</th>
<th>Lab-based Outcome</th>
<th>Translation to Surfboarding Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coyne et al., 2017</td>
<td>Five-week (3 x per week) maximal upper-body strength (1-5RM) training for pull-ups and dips demonstrated improvements in surfing paddling sprint (5m,10m,15m) and paddling endurance performance (400m).</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Farley et al., 2016</td>
<td>Five-week (2 x per week) HIIT paddle training intervention demonstrated significant improvement in aerobic (400m) paddle performance. SIT paddle training significantly improved 15m repeat-sprint paddle performance.</td>
<td>✔</td>
<td>✖</td>
<td>✔</td>
</tr>
<tr>
<td>Tran et al., 2015</td>
<td>Seven-week (2 X per week) unstable and stable periodized resistance training effective in developing strength but no significant effect on sensorimotor abilities for either intervention. However, unstable training found to be inferior for the development of lower body power.</td>
<td>✖</td>
<td>✔</td>
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</tr>
<tr>
<td>Axel et al., 2018</td>
<td>Eight-week (2x per week) of a periodized core strength training program demonstrated improvement in rotational power, time to peak acceleration, maximal CMJ height, estimated peak CMJ power, core strength, and rotational flexibility.</td>
<td>✖</td>
<td>✔</td>
<td>✖</td>
</tr>
<tr>
<td>Tran et al., 2016</td>
<td>Four weeks of detraining following seven weeks of resistance training demonstrated that absence of resistance training (detraining) is not a sufficient training stimulus to maintain physical abilities in CMJ, isometric strength, and sensorimotor abilities.</td>
<td>✖</td>
<td>✔</td>
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</tr>
<tr>
<td>Secomb et al., 2015</td>
<td>A six-week (3x per week) strength, plyometric, and gymnastics-based intervention demonstrated improvements in lower-body muscle structure (ultrasonography), strength (IMTP) and jumping performance (CMJ).</td>
<td>✖</td>
<td>✔</td>
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</tr>
<tr>
<td>Caballes, 2015</td>
<td>A nine-month periodized resistance training (calisthenics, free-weights, medicine balls, bands) as per the ASCA Child and Youth resistance training model demonstrated improvements in IMTP, CMJ and self-reported surfing ability in one single 15-year-old competitive female surfer.</td>
<td>✖</td>
<td>✔</td>
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</tr>
<tr>
<td>Secomb et al., 2017</td>
<td>Seven weeks (14 sessions) of resistance training demonstrated increases in IMTP Peak Force, DSD ration, SJ Peak Velocity and vastus lateralis (VL) fascicle length (FL). Gymnastics and plyometrics demonstrated increases in VLFL and eccentric leg stiffness.</td>
<td>✖</td>
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### Appendix 1

**Data Base Search Strategy**

<table>
<thead>
<tr>
<th>Data Base</th>
<th>Search Strategy</th>
<th>Total Hits</th>
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    training”[Title/Abstract] OR “aerobic”[Title/Abstract] OR development[Title/Abstract] OR repetitions[Title/Abstract]
    OR reps[Title/Abstract] OR sets[Title/Abstract] OR “drills”[Title/Abstract] OR “flexibility training”[Title/Abstract]
    OR proprioception[Title/Abstract] OR development[Title/Abstract] OR “training method”[Title/Abstract] OR “physical
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development”[Title/Abstract]))
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| Embase    | 

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development.ti,ab.))
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| Cinahl    | 

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    OR TI strengthening OR AB strengthening OR TI "weight lifting" OR AB "weight lifting" OR TI "functional training"
    OR AB "functional training" OR TI "balance training" OR AB "balance training" OR TI "functional balance"
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| CSTP: core strength training program, HIT: high intensity training, SIT: sprint interval training, IMTP: isometric mid-thigh pull, CMJ: counter-movement jump, RM: rep max, DSD: dynamic strength deficit, SJ: squat jump, ASCA: Australian Strength and Conditioning Association, ✗ = study did not have outcome, ✔ = study did have outcome | |

---

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<tr>
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## Modified JBI Critical Appraisal Checklist for Quasi-Experimental Studies

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<td>Is it clear in the study what is the ‘cause’ and what is the ‘effect’ (i.e. there is no confusion about which variable comes first)?</td>
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<td>Were the participants included in any comparisons similar?</td>
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<tr>
<td>Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?</td>
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<td>Were there multiple measurements of the outcome both pre and post the intervention/exposure?</td>
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<td>Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?</td>
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<td>Were the outcomes of participants included in any comparisons measured in the same way?</td>
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<td>Were both field and lab-based measures used in the outcome?*</td>
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<tr>
<td>Were outcomes measured in a reliable way?</td>
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Appendix 3

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## Appendix 4

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<tr>
<th><strong>Intervention</strong></th>
<th><strong>Outcome Measure</strong></th>
<th><strong>Study Design</strong></th>
<th><strong>Results/Main Findings</strong></th>
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<tbody>
<tr>
<td>Tran et al., 2015</td>
<td>1. Lower-body isometric strength using isometric mid-thigh pull (IMTP) measured in (N•kg⁻¹) */+ Using a force plate (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia) 2. Power measured by counter-movement vertical jump (CMJ) measured in meters using inverse dynamics to calculate peak force as well as peak velocity and jump height based on the impulse momentum Relationship */+ 3. Sensorimotor abilities measured through time to stabilization (TTS) in milliseconds using a drop and stick (DS) onto both feet from 0.5m box. Time to Stabilization between initial ground contact and stabilization within 5% of bodyweight taken as outcome score */+</td>
<td>Within-subject cross over study design (4-week washout between interventions)</td>
<td>(IMTP) Pre-Post percentage change Unstable +5.5% increase Stable +12.7% increase (CMJ) Pre-Post percentage change Unstable -6.5% Stable +5.7% TTS (ms) Pre-Post percentage change Unstable -14% Stable -34.2% Unstable and stable resistance training are both effective in developing strength in previously untrained competitive surfers, but with little significant effect on sensorimotor abilities. However, unstable training is inferior for the development of lower body power in this population</td>
</tr>
<tr>
<td>Axel et al., 2018</td>
<td>Maximal acceleration (dumbbell with attached accelerometer) (R.Accel/L.Accel)</td>
<td>Quasi-Experimental Pre-test/ Post-test</td>
<td>Eight-weeks of CSTP (2x per week) improved rotational power, time to peak</td>
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<tr>
<td>Program (CSTP) 2x per week</td>
<td>Rotational power (3kg dumbbell, 180° rotation measured w. TENDO Fitodyne) (R.TP R.RP/L.TP L.RP) (seconds / watts)</td>
<td>Time to peak acceleration (same as above) (TP – sec)</td>
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<tr>
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<td>Maximum counter-movement jump (Vertec mat) (CMJ – meters)</td>
<td>Estimated peak power (via counter movement jump) (PP – Watts)</td>
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<td></td>
<td>Core strength (cross body medicine ball rotational throw for distance) (CS – meters)</td>
<td>Core endurance (prone plank) (CE-sec)</td>
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<td></td>
<td>Core endurance (prone plank) (CE-sec)</td>
<td>Rotational flexibility (Bobo and Yarbrough flexibility test) (RF - # repetitions)</td>
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<table>
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<tr>
<th>Farley et al., 2016</th>
<th>Surfboard Sprint Interval Training</th>
<th>Repeat-Sprint Paddle Test 10 x 15m paddle bouts every 40s (fastest time, total time, peak paddling velocity, fatigue index)*</th>
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<tr>
<td></td>
<td>SIT: 10s work, 30s rest (1: 3), 2 min rest between sets</td>
<td>400m timed endurance test (20m up and back course measured in seconds)*</td>
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<td>W1 3x5</td>
<td>*Both conducted in outdoor, heated pools with no kicking of legs to assist paddle.</td>
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<tr>
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<td>W2 4x6</td>
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<td>W3 5x7</td>
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<td>W4 5x8</td>
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<tr>
<td></td>
<td>W5 6x8</td>
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</tr>
<tr>
<td></td>
<td>HIT: 30s work, 30s rest, 1:1. 2 min rest between sets</td>
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<tr>
<td></td>
<td>W1 2x5</td>
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<tr>
<td></td>
<td>W2 2x6</td>
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<td>W3 2x7</td>
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<td>W4 3x5</td>
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<td>W5 3x6</td>
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<table>
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<tr>
<th>Quasi-Experimental Pre-test/post-test</th>
<th>400m paddle test HIT – Pre 366.4sec +/- 22.1 Post 347.5sec +/- 19.5 Percent change -15.8 +/- 16.1 (range, 237.0 to +8 s) 0.03 / p=0.03</th>
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<tr>
<td></td>
<td>400m paddle test SIT -Pre 377.5sec +/- 26.6 Post 359sec +/- 42 Percent Change -13.5 +/- 21.2 (range, 251.0 to +13 s) 0.24 / p = 0.24</td>
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</table>

HIT and SIT effective and may be implemented to the training program of surfers to improve aerobic and repeat-sprint paddle ability, both of which are identified as key aspects of the sport.
<table>
<thead>
<tr>
<th>Study</th>
<th>Session Details</th>
<th>Measures</th>
<th>Design</th>
<th>Results</th>
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<tr>
<td>Caballes et al., 2015</td>
<td>Sessions performed twice per week for both interventions</td>
<td>Isometric Mid Thigh Pull (IMTP) measured in Force (N)</td>
<td>Case Study Pre-Test/post test</td>
<td>ASCA youth resistance training guidelines resulted in an increase in IMTP and CMJ scores in this single case study (15-year-old female athlete). The results also depict the clear strength advantage that this program has allowed the surfer to attain, in comparison to her elite and non-elite junior surfer teammates.</td>
</tr>
<tr>
<td>Coyne et al., 2017</td>
<td>Five weeks (2x per week) of max strength training (1-5RM) in the pull-up and dip exercises. 3 upper body strength sessions per week consisting of 2-4 sub-maximal warm-up sets followed by five working sets of 1-5RM for both the dip and pull-up</td>
<td>5m paddle sprint time 10m paddle sprint time 15m paddle sprint time 400m endurance paddle time</td>
<td>Repeated-measures parallel control study design</td>
<td>$5_{\text{meter}}$ Pre/Post/Change/Cohens effect size 4.32 +/- 0.97 / 4.19 +/- 0.53 / 2.95 $d=0.71$ $10_{\text{m}}$ 7.61 +/- 1.57 / 7.5 +/- 0.86 / 21.47 / $d=0.51$ $15_{\text{m}}$ 11 +/- 2.34 / 10.89 +/- 1.25 / 20.95 / $d=0.4$ $400_{\text{m}}$ 455.05 +/- 121.63 / 428.82 +/- 84.92 / $d=0.72$ Short-term exposure to maximal upper-body strength (1-5RM) training elicits improvements in surfing paddling sprint and endurance performance</td>
</tr>
<tr>
<td>Secomb et al., 2015</td>
<td>Six weeks (18 sessions) of a combined strength, gymnastics and plyometric training</td>
<td>Lower body strength and power as measured by CMJ, Squat Jump, IMTP and ultrasonography of vastus lateralis and lateral gastrocnemius.</td>
<td>Quasi-Experimental Pre-test/post-test</td>
<td>CMJ Pre Test / Post Test / Change 2.39 NBW^{-1} / 2.54 NBW^{-1} / 0.15 NBW^{-1} Squat Jump Pre Test / Post Test / Change 0.49m/ 0.50m / 0.01m IMTP Pre Test / Post Test / Change 2466N / 2947N / 482N</td>
</tr>
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| Tran et al., 2016 | Four weeks of detraining following seven weeks of resistance training | Countermovement Jump, Isometric Strength via Mid-thigh Pull (IMTP) and Sensorimotor ability during a drop and stick (ds)/time to stabilization (TTS) measure | Quasi-Experimental Pre-test/post-test | This study indicate that likely training-specific adaptations can be achieved in lower-body muscle structure, and strength and jumping performance, following a short block of combined strength, plyometric and gymnastics training.

Absence of resistance training (detraining) is not a sufficient training stimulus to maintain physical abilities in CMJ (height and velocity), isometric strength, and sensorimotor abilities.

VJ height – Decreased 5.26%
VJ peak velocity – Decreased 3.73%
IMTP strength – Decreased 5.5%
IMTP rel. strength – Decreased 7.27%
TTS increased 61.36% |

| Secomb et al., 2017 | Seven-week intervention followed by a three-week break prior to commencing alternate intervention (resistance training or gymnastics and plyometrics) | Countermovement Jump (CMJ) and Squat Jump (SJ) variables including peak force (PF), relative peak force (rPF), peak velocity (PV), relative peak velocity (rPV) Isometric Mid-Thigh Pull (IMTP) variables including PF, rPF, dynamic strength deficit DSD, and Ultrasonography of Vastus Lateralis (VL) and Lateral Gastrocnemius (LG) thickness, pennation angle and fascicle length (FL) | Within-subject cross over study design (3-week washout between interventions) | Resistance training intervention demonstrated significant changes in: IMTP rPF, DSD ratio, VL FL and a moderate effect in SJ rPV. Gymnastics and plyometrics intervention demonstrated large magnitude changes in structural change in vastus lateralis fascicle length and lateral gastrocnemius thickness and improved eccentric lower-body stiffness. Non-training group demonstrated no changes in strength, structure or jumping performance. |