2015

Evaluation and training of sensorimotor abilities in competitive surfers

Tai T. Tran
Edith Cowan University

2015

Evaluation and training of sensorimotor abilities in competitive surfers

Tai T. Tran
Edith Cowan University

USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

Evaluation And Training Of Sensorimotor Abilities In Competitive Surfers

Tai T. Tran, MS, CSCS*D

Submitted to

Edith Cowan University

In fulfilment of the requirements for the degree of

Doctorate of Philosophy

March 2015

Centre for Exercise and Sport Science Research

Edith Cowan University, Western Australia

Supervisors:

Dr. Jeremy M. Sheppard

Dr. Sophia Nimphius

Professor Robert U. Newton

Dedication

This thesis is dedicated to my parents and siblings for their continuous support and unconditional love.

Declaration

I certify that this thesis does not, to the best of my knowledge and belief:

(1) Incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;

(2) Contain any material previously published or written by another person except where due reference is made in the text; or

(3) Contain any defamatory material. I also grant permission for the Library at Edith Cowan University to make duplicate copies of my thesis as required

Tai T. Tran March 20, 2015

Abstracts

Study 1: Development of a comprehensive performance testing protocol for competitive surfers

Purpose: Appropriate and valid testing protocols for evaluating the physical performances of surfing athletes is not well refined. The purpose of this project was to develop, refine, and evaluate a testing protocol for use with elite surfers, including measures of anthropometry, strength and power, and endurance. *Methods:* After pilot testing and consultation with athletes, coaches and sport scientists, a specific suite of tests was developed. Forty-four competitive junior surfers (16.2±1.3 years, 166.3±7.3 cm, 57.9±8.5 kg) participated in this study involving a within-day repeated measures analysis, using an Elite Junior Group of 22 international competitors (EJG), to establish reliability of the measures. To reflect validity of the testing measures, a comparison of performance results was then undertaken between the EJG and an age-matched Competitive Junior Group of 22 nationally competitive surfers (CJG). *Results:* Percent Typical Error of Measurement (%TEM) for primary variables gained from the assessments ranged from 1.1-3.0%, with intra-class correlation coefficients ranging from 0.96- 0.99. One-way analysis of variance revealed that the EJG had lower skinfolds ($p=0.005$, $d=0.9$) compared to the CJG, despite no difference in stature ($p=0.102$) or body mass ($p=0.827$). The EJG were faster in 15 m sprint-paddle velocity ($p<0.001$, $d=1.3$), had higher lower-body isometric peak force ($p=0.04$, $d=0.7$), and superior endurance paddling velocity ($p=0.008$, $d=0.9$). *Conclusions:* The relatively low %TEM of these tests in this population allows for high sensitivity to detect change. The results of this study suggest that competitively superior junior surfers are leaner, and possess superior strength, paddling power, and paddling endurance.

Study 2: Comparison of physical capacities between non-selected and selected elite male competitive surfers for the national team

Purpose: The purpose of this study was to determine whether a previously validated performance testing protocol for competitive surfers was able to differentiate between Australian elite junior

surfers selected (S) to the national team, and those not selected (NS). *Methods:* Thirty-two elite male competitive junior surfers were divided into two groups (S=16; NS=16). The mean age, stature, body mass, sum of 7 skinfolds and lean body mass ratio (mean ± SD) were 16.17 ± 1.26 y, 173.40 ± 5.30 cm, 62.35 ± 7.40 kg, 41.74 ± 10.82 mm, 1.54 ± 0.35 for the S athletes and 16.13 ± 1.02 y, 170.56 ± 6.6 cm; 61.46 ± 10.10 kg; 49.25 ± 13.04 mm; 1.31 ± 0.30 for the NS athletes. Power (countermovement jump; CMJ), strength (isometric mid-thigh pull), 15 m sprint paddling, and 400 m endurance paddling was measured. *Results:* There were significant ($p \leq 0.05$) differences between the S and NS athletes for relative vertical jump peak force ($p=0.01$, $d=0.9$), CMJ height ($p=0.01$, $d=0.9$), time to 5, 10, and 15 m sprint paddle, sprint paddle peak velocity ($p=0.03$, $d=0.8$; PV), time to 400 m ($p=0.04$, $d=0.7$) and endurance paddling velocity ($p=0.05$, $d=0.7$). *Conclusions:* All performance variables, particularly CMJ height, time to 5, 10, and 15 m sprint paddle, sprint paddle PV, time to 400 m and endurance paddling velocity can effectively discriminate between S and NS competitive surfers and this may be important for athlete profiling and training program design.

Study 3: The development and evaluation of a drop and stick method to assess landing skills in various levels of competitive surfers

The purpose of this study was to develop and evaluate a drop and stick (DS) test method and to assess dynamic postural control in senior elite (SE), junior elite (JE), and junior development (JD) surfers. Nine SE, 22 JE, and 17 JD competitive surfers participated in the study. The athletes completed five drop and stick trials barefoot from a pre-determined box height (0.5 m). The lowest and highest time to stabilisation (TTS) trials were discarded, and the average of the remaining trials were used for analysis. The SE group demonstrated excellent single measures repeatability (ICC=0.90) for TTS, whereas the JE and JD demonstrated good single measures repeatability (ICC 0.82 and 0.88, respectively). In regards to relative peak landing force (rPLF), SE demonstrated poor single measures reliability compared to JE and JD groups. TTS for SE (0.69 ± 0.13 s) group was significantly ($p=0.04$) lower than the JD (0.85 ± 0.25 s). There were no significant ($p=0.41$)

differences in the TTS between SE (0.69 ± 0.13 s) and JE (0.75 ± 0.16 s) groups or between the JE and JD groups (p=0.09). rPLF for SE (2.7 ± 0.4 body mass; BM) group was significantly lower than the JE (3.8 ± 1.3 BM) and JD (4.0 ± 1.1 BM), with no significant (p=0.63) difference among the JE and JD groups. A possible benchmark approach for practitioners would be to use TTS and rPLF as a qualitative measure of dynamic postural control using a reference scale to discriminate amongst groups.

Study 4: Effects of stable and unstable resistance training on strength, power, and sensorimotor abilities in adolescent surfers

The purpose of this study was to investigate two different resistance-training interventions (unstable or stable) on strength, power, and sensorimotor abilities in adolescent surfers. Ten competitive female and male high school surfers were assessed before and after each of 2 x 7-week training intervention, using a within-subjects cross-over study design. Results for strength revealed no condition by time interaction or main effect for condition. However, there was a significant main effect for time, with significant strength gains post-training. There was a significant condition by time interaction for power exhibited as a significant decrease from pre- to post-training in the unstable condition, while the stable condition approached significant improvement. These results suggest that unstable and stable resistance training are equally effective in developing strength in previously untrained competitive surfers, but with little effect on sensorimotor abilities. However, unstable training is inferior for the development of lower body power in this population.

Study 5: Effect of four weeks detraining on power, strength, and sensorimotor ability of adolescent surfers

The purpose of this study was to investigate the effect of four weeks of detraining on power, strength, and sensorimotor ability in adolescent surfers. Nineteen adolescent surfers with an overall mean age, mass, and stature (mean ± SD) of 14.1 ± 1.6 y, 54.0 ± 10.8 kg and 165.1 ± 9.0 cm, respectively, volunteered to participate in four weeks of detraining (surfing participation maintained but resistance training ceased) following seven weeks of periodized resistance training. Power

(vertical jump height; VJH), maximal isometric strength (isometric mid-thigh pull; IMTP), and sensorimotor ability (time to stabilization during a drop and stick (DS); TTS) pre-test results were determined from the conclusion (post-test) of the first seven-week training block while post-test results were measured at the start (pre-test) of a second seven-week training block. Four weeks of detraining significantly decreased the following variables: VJH by -5.26%, ($p = 0.037$, $d = -0.40$), vertical jump peak velocity by -3.73% ($p = 0.001$, $d = -0.51$), maximal isometric strength by -5.5%, ($p = 0.012$, $d = -0.21$), and relative maximal isometric strength by -7.27% ($p = 0.003$, $d = -0.47$). Furthermore, sensorimotor ability worsened, as assessed by TTS, with a significant increase of 61.36% ($p = 0.004$, $d = 0.99$), indicating athletes took longer to stabilize from a dynamic landing task. This demonstrates that surfing, in the absence of resistance training, is not a sufficient training stimulus to maintain physical characteristics. Adolescent surfers with a relatively low training age should avoid cessation of resistance training and strive to maintain consistent resistance training in conjunction with surf training in order to avoid negative decrements in physical characteristics that are associated with surfing performance.

Acknowledgements

It is truly a blessing and honour to have received this unique opportunity to pursue my PhD at Edith Cowan University in collaboration with Surfing Australia. This once in a lifetime opportunity and experience in Australia was amazing and at times challenging. However, when I look back at this amazing experience, I have to thank all the people that have helped me along my journey and contribution to completing this thesis.

Dr. Lee Brown, you were not just my former advisor, but also a friend who believed in me and always committed to assist in any possible way. I am truly grateful of you for getting me started with research and making your strength lab my second home in graduate school. I am very honoured to have worked with you and be one of your former graduate students. Your words of wisdom and continuous support throughout the years have been inspirational. You are "The Man" and a "Strength Legend". This unique opportunity would not have been possible without you. A special thanks to Greg and Erin Haff, you guys are awesome. You guys understood the difficult transition and made it easier each day in the weight room. It was an honour and pleasure to learn and lift with the both of you during my time at ECU. Laurent (Frenchie), I can't thank you enough for being such a great friend. Thanks for all your help during my time in Australia and your hospitality when I visited ECU. Josh and Olly, thanks for waking up early to help out with data collection. Data collection would not have been possible without your assistance. Lina, I can't thank you enough for your friendship and contribution to this thesis. You are an awesome and caring individual and go out of your way to help other people succeed. This thesis would not have been possible without you.

I would also like to express my gratitude to my supervisors. Thank you Dr. Sophia Nimphius for your tremendous help throughout my journey in Australia and accomplishing this unthinkable task. You are full of energy and always fun to be around. I will never forget all the surf

sessions we had, which we spent majority of the time paddling to get pass the breaking waves. It was worth the paddle! I couldn't have asked for a better co-supervisor and friend. You Rock!!! Thank you Professor Robert Newton for getting me settled and started at ECU. Although we didn't see much of one another, you always made the time to meet and see how things were going when I visited ECU. Many thanks for your time and contributions to this thesis. I like to express my deepest appreciation and thanks to Dr. Jeremy Sheppard. I can't thank you enough for taking the risk bringing me over to Australia and providing the amazing opportunity to work for you and Surfing Australia. Watching you coach on a daily basis was inspirational. I have learned so much from you and my ability to coaching athletes improved because of your passion and knowledge. Thank you for your guidance throughout the years and believing in me.

To my amazing and loving family, this thesis is dedicated to you guys. Thank you for all your support throughout this journey. Mom and dad, I admire and appreciate the fact that you left Vietnam and your love ones to give us a better life in America. You both have worked countless hours and made many sacrifices to raise eight children. Thank you with much love! Finally, I could not have completed this thesis without my brothers and sisters. You guys were always encouraging and supportive of my passion. When times were challenging, you told me to stay strong and never give up. Love you all!

List of publications and presentations related to thesis

Original Research

Sheppard, J. M., Nimphius, S., Haff, G. G., **Tran, T. T**., Spiteri, T., Brooks, H., Slater, G., Newton, R. U. Development of a comprehensive performance testing protocol for competitive surfers. *Int J Sports Physiol Perform* 8;490-495, 2013. (Appendix 3)

Tran, T. T., Lundgren, L., Secomb, J., Farley, O. R. L., Haff, G. G., Seitz, L. B., Newton, R. U., Nimphius, S., Sheppard, J. M. Comparison of physical capacities between non-selected and selected elite male competitive surfers for the national junior team. *Int J Sports Physiol Perform* 10, 178-182, 2015). (Appendix 4)

Tran, T. T., Lundgren, L., Secomb, J., Farley, O. R. L., Haff, G. G., Newton, R. U., Nimphius, S., Sheppard, J. M. The development and evaluation of a drop and stick method to assess landing skills in various levels of competitive surfers. *Int J Sports Physiol Perform*. 10, 396-400, 2015. (Appendix 5)

Tran, T. T., Nimphius, S., Lundgren, L., Secomb, J., Farley, O. R. L., Haff, G. G., Newton, R. U., Brown, L. E., Sheppard, J. M. Effects of stable and unstable resistance training on strength, power, and sensorimotor abilities in adolescent surfers. *Int J Sports Sci Coach.* (Accepted, Ahead of Print).

Tran, T. T., Nimphius, S., Lundgren, L., Secomb, J., Farley, O. R. L., Haff, G. G., Newton, R. U., Brown, L. E., Sheppard, J. M. Effect of four weeks detraining on power, strength, and sensorimotor ability of adolescent surfers. *J Strength Cond Res.* (In Review).

Conference Presentations

Tran, T. T., Lundgren, L., Secomb, J., Farley, O., Raymond, E., Nimphius, S., Newton, R. U., Sheppard, J. M. Reliability of an alternative method to assess landing skills in adolescent surfers. Australian Strength and Conditioning Association Conference, Melbourne, VIC, Australia, 2013. Poster Presentation: (Appendix 6).

Tran, T. T., Lundgren, L., Secomb, J., Farley, O., Haff, G. G., Nimphius, S., Newton, R. U., Brown, L. E., Sheppard, J. M. Effects of detraining on strength, power, and sensorimotor abilities in adolescent surfers. National Strength and Conditioning Association Conference, Las Vegas, NV, United States, 2014. Poster Presentation: (Appendix 7).

Use of thesis

Table of Contents

List of Tables

List of Figures

List of Abbreviations

1RM	one repetition maximum
ANOVA	analysis of variance
APSI	anterior-posterior stability index
ASP	Association of Surfing Professional
AUS	Australia
BOSU	BOth Sides Up
BRA	Brasil
BM	body mass
CI	confidence intervals
CL	confidence limits
CJG	domestic competitors
cm	centimetre
CMJ	countermovement jump
CSA	cross sectional area
CT	Championship Tour
CV	coefficient of variation
CV%	coefficient of variation percentage
d	Cohen's effect size
DEU	Germany
DPSI	dynamic postural stability index
DS	drop and stick
EJG	international competitors
ES	effect size

EUK	Basque Country
FRA	France
GRF	ground reaction force
HAW	Hawaii
ICC	intraclass correlation coefficient
IMTP	isometric mid-thigh pull
IPF	isometric peak force
ISA	International Surfing Association
ISAK	International Society for the Advancement of Kinanthropometry
JD	junior development
JE	junior elite
JS	jump squat
kg	kilogram
L	light
LB	lower body
LMI	lean mass index
m	metre
ms	millisecond
M	moderate
ML	moderately light
MLSI	medial-lateral stability index
mm	millimetre
$m \cdot s^{-1}$	metre per second
N	newton
$N \cdot kg^{-1}$	newton per kilogram
NZL	New Zealand

PER	Peru
PRT	Portugal
PYF	French Polynesia
r	pearson product moment correlation
rIMTP	relative isometric mid-thigh pull peak force
rIPF	relative isometric peak force
rPLF	relative peak landing force
rVJPF	relative vertical jump peak force
s	second
S	selected
SC	selection camp
SE	senior elite
SEM	standard error of the mean
SD	standard deviation
TE	typical error
TEM	typical error of measurement
%TEM	percentage typical error of measurement
TTS	time to stabilisation
UB	upper body
USA	United States
VJ	vertical jump
VJH	vertical jump height
VJPV	vertical jump peak velocity
VL	very light
VO_{2peak}	peak oxygen uptake
VSI	vertical stability index

WSL	World Surf League
WQS	World Qualification Series
y	year
ZAF	South Africa

Chapter 1

Introduction and General Overview

Surfing is an intermittent sport that involves bouts of explosive manoeuvres followed by less intensive activities (Meir et al., 1991; Mendez-Villanueva et al., 2006; and Farley et al., 2012a). The sport of surfing requires a combination of strength, power, coordination, dynamic balance, and the ability to react to critical situations during wave riding (Mendez-Villanueva, 2005). Furthermore, surfing is considered a skill-based sport that demands a high physical capacity level to paddle past the breaking waves, sprint paddle to catch a wave, followed by an explosive pop-up (to go from prone to standing) on the surfboard. The surfer then performs numerous combinations of manoeuvres such as bottom turns, top turns and re-entries, or uses the face of the wave as a ramp to launch themself for an aerial and then land, all while maintaining balance or regaining stability (Everline, 2007; Metcalfe and Kelly, 2012).

The level of surfing sophistication has increased each year with surfers expected to perform more innovative manoeuvres such as aerials to maximize scoring potential. Recently, Lundgren et al. (2014) reported surfing athletes that successfully complete more difficult manoeuvres such as aerials or tube-rides were awarded higher wave scores compared to waves ridden without successful aerial or tube-ride manoeuvres. This is confirmed by the 2014 World Surf League (WSL) rulebook (Article 134: Judging Criteria), formally known as the Association of Surfing Professional (ASP); surfers that complete successful high-risk manoeuvres with speed, power, and flow under control in the most critical section of the wave will maximize scoring potential. Therefore, the ability to perform and complete these radical manoeuvres successfully requires surfers to have high levels of physical qualities (Metcalfe and Kelly, 2012). With this in mind, there

has been an increased awareness of physical preparation for the demand of surfing over the years. Not only will these qualities likely contribute to more forceful high velocity manoeuvres; they are also essential for injury prevention and can extend the longevity of a surfers' career (Mendez-Villanueva and Bishop, 2005).

Researchers have previously reported that paddling represents a majority of the activity time during an hour of competitive surfing and highlights the importance of relative high aerobic capacity (Meir et al., 1991; Mendez-Villanueva et al., 2006; Farley et al., 2012b). However, it is important to note that high aerobic capacity is not associated with season ranking, whereas anaerobic peak power during land-based surf paddling ergometer testing has been reported to have a strong correlation to season ranking ($r = -0.67$, $p = 0.01$ and $r = -0.55$, $p= 0.02$; Mendez-Villanueva et al., 2005; and Farley et al., 2012b, respectively). Additionally, surfing is judged on wave riding, which has been shown to represent 3.8%-8% of time during an hour of either competitive surfing (Mendez-Villanueva et al., 2006; Farley et al., 2012a) or recreational free surf session (Meir et al., 1991). Therefore, additional physical capability measures are essential to provide practitioners with a better understanding in regards to training adaptations. However, developing and evaluating performance-testing protocols with practical reliability and validity which are relevant to surfing has not yet been established. For example, one important aspect of surfing performance is sprint paddle ability. A surfing athlete with superior sprint paddle ability compared to their opposition in a two to four-person heat may have the advantage of sitting deeper on the peak of the wave, thereby controlling the line up. Most importantly, possessing greater sprint paddle ability may enable the surfing athlete to enter the wave with greater speed, thus allowing them to generate speed more quickly, and execute manoeuvres in the most critical section of the wave to maximise scoring potential (Sheppard et al., 2012). Therefore, an established protocol that is reliable and valid will enable practitioners to determine if the test is sensitive to detect differences amongst various levels of surfing ability or whether performance changes are due to training.

Although surfing is popular with a rich history in Australia, there is limited research on physical capabilities of Australian competitive junior surfing athletes. Each year the best junior competitive surfing athletes are selected to represent their country at the World Junior Surfing Championship competition. Performance measures using a cohort of elite juniors competing to represent the international team may further validate performance-testing protocols. One approach to evaluating physical capabilities, is comparing non-selected versus selected junior competitive surfing athletes representing Australia at the International Surfing Association World Junior Surfing Championship. This approach may support whether physical performance tests reflect selection for international competition. Previous studies have demonstrated that physical performance variables discriminate between playing levels (juniors vs. seniors) and selection levels (starters vs. non-starters) (Gabbett, 2002; Gabbett, 2009; Gabbett, et al., 2009; Till et al., 2011). These studies highlight that physical qualities reflect athletes being selected to a team or a starting role. In addition, physical characteristics such as strength and power may be used to establish normative data or reference scales for progressive standards as an athlete ages. However, an important physical characteristic that lacks research is dynamic postural control for surfing athletes.

Previous studies have investigated postural control, however, the tasks may not be ideal in re-creating athletic activities, as being motionless may not challenge the neuromuscular system (Colby et al., 1999). Examining a novel dynamic postural control task such as drop and stick via time to stabilisation (TTS) may be more relevant for the sport of surfing, as this task would challenge the neuromuscular system. Time to stabilisation (TTS) measurement has been used to examine dynamic postural control ability in jump landing sports. TTS measures the competency of an individual to transition from a dynamic to a motionless posture (Wikstrom et al., 2005). A common method used to quantify TTS is a jump-landing task. Although several studies have reported that reliability of TTS measures varied from fair to moderate (Wikstrom et al., 2005; Flanagan et al., 2008; Ebben et al., 2010); it is important to note that methodology will influence

these results. There are no studies that have investigated TTS from a drop and stick task to determine dynamic postural control ability in competitive surfing athletes.

A proposed test such as the drop and stick would require the athlete to stand on top of a 0.5 m box, step off the box and land on a force plate, then stabilise as quickly as possible. This test may be suitable for all ages and levels of athletes as it may be more relevant for surfing athletes because it involves high demands on the neuromuscular system without high risk of injury. Based on pilot testing, a possible approach that may be more practical is developing a reference scale (e.g., <0.6s, excellent; 0.60-0.75s, good; >0.75s, poor) to measure and track an athletes' progression. Another worthwhile variable to measure and track would be relative landing impact force. Landing impact force may provide valuable information regarding whether the athletes can use their muscles to attenuate the landing force and spare their joints. Similar to the TTS reference scale, developing a relative landing impact force reference scale (e.g., <3.0 BM, excellent; 3.0-4.0 BM, good; >4.0 BM, poor) for surfing athletes may help determine whether the athletes need to incorporate a landing intervention program in their training. Evaluating quantitative measures using both TTS and relative landing force may discriminate amongst surfing athletes. It is expected the findings would differ as a result of age and ability levels. Furthermore, it is also expected senior level surfing athletes with greater strength would be able to use their muscles to attenuate the landing force compared to developmental surfing athletes with lower strength.

Strength and power are important characteristics and significantly influence athletic performance. Numerous studies have demonstrated that traditional resistance training improves sprint speed, vertical jump height, change of direction and throwing velocity (Baker, 1996; DeRenne, Kwok, and Murphy, 2001; Nimphius, McGuigan, and Newton, 2010). Given that surfing is performed in a dynamic environment, there are some in the surfing community that believe training on unstable devices is specific to surfing (Everline, 2007). It is important to note that the faster the speed of the surfboard as it travels along the face of the wave, the more stable the supporting surface (Metcalfe and Kelly, 2012). Despite considerable research investigating the

effects of unstable surface training on strength, power, and balance, this method of training may seem logical to improve balance, however, training on unstable devices may not provide an adequate stimulus to elicit positive strength or power adaptations (Bruhn et al., 2004; Cressey et al., 2007; Taube et al., 2007; Kibele and Behm, 2009; Oberacker et al., 2012). Furthermore, acute (non-training) studies have reported reductions of 45.6-70.5% in maximal voluntary contraction force and 40.5% in rate of force development, with unstable training (Behm et al., 2002; Anderson and Behm, 2004; and McBride et al., 2006). In contrast, other studies have reported that training on unstable devices improved vertical jump height, rate of force development, or postural control in a cohort of physically active high school students and healthy men and women (Gruber and Gollhofer, 2004; Yaggie and Campbell, 2006; Myer et al., 2006; Gruber et al., 2007; Granacher et al., 2010). However, it might be safe to argue that untrained or less advanced athletes respond differently to training stimuli when compared to more advanced athletes. In addition, training on unstable devices for more advanced or non-injured athletes may not be the ideal method to challenge their neuromuscular system (Cressey et al., 2007). Despite these findings, a more detailed investigation of unstable versus stable training adaptations in a cohort of competitive surfing athletes will provide further insight as to which training method is superior.

With the vast amount of research investigating the effects of resistance training on athletic performance measures, it is also worthwhile to investigate the impact of detraining. Previous evidence clearly supports that when a training stimulus is completely removed, athletic performance measures significantly decline. Therefore, to get a better understanding of detraining, several studies have investigated and confirmed that cessation of resistance training while continuing sport practice alone does not contribute to significantly greater physical capacity compared to those that participate in their sport in conjunction with resistance training (Christou et al., 2006; Meylan and Malatesta, 2009; Harries et al., 2012). For instance, Faigenbaum et al. (1996) using a cohort of boys and girls demonstrated that eight weeks of detraining following eight weeks of resistance training significantly decreased upper and lower body strength. Izquierdo et al. (2007)

reported four weeks of detraining led to a significant loss of strength and power in strength-trained athletes. However, inconsistencies in the magnitude of effect that detraining has on athletic performance may be influenced by cessation duration, training age, prior training intensity and physical activity during the detraining phase. Currently, there is no evidence that supports that surfing alone, in the absence of resistance training, will increase or maintain the physical capacity of surfing athletes. It is commonly accepted in the surfing culture, that to enhance surf performance, one needs to spend more time surfing in a variety of surf conditions. It has been reported that recreational and competitive surfing athletes spend between 6.6 ± 4.4 and 12.3 ± 2.8 hours each week surfing (Loveless and Minahan, 2010), and current practise suggests that surfers believe that they can maintain physical capabilities for an extended period (gained from prior training periods) from surfing alone. Considering that from middle-school years through to professional touring, competitive surfers generally engage in a 10 month/year competitive calendar, with only short blocks of uninterrupted training, it is imperative to investigate the magnitude of performance changes following cessation of resistance training on strength, power, and sensorimotor ability.

1.1 Purpose of Research

The main purposes of this thesis were to investigate performance characteristics of competitive surfing athletes and the effects of various training interventions on their strength, power, and sensorimotor ability. This thesis is comprised of five studies.

- Study 1: Develop and evaluate a testing protocol with practical reliability and context validity, and measure surfers' anthropometry, strength, power, sprint and endurance qualities.
- Study 2: Compare physical characteristics between selected and non-selected junior competitive surfers and determine if performance tests of their physical qualities reflect selection for international competition.

- Study 3: Develop and evaluate a sensorimotor ability testing protocol to assess dynamic postural control, and determine whether testing measures are sensitive to discriminate athletic ability.
- Study 4: Determine whether land-based unstable surface training provides greater adaptations than traditional resistance training, and the effects of unstable versus stable resistance training on strength, power, and sensorimotor ability.
- Study 5: Determine the magnitude of changes in physical qualities following a short-term (four weeks) training cessation, and explore whether surfing, in the absence of resistance training, provides sufficient stimulus to maintain performance measures.

1.2 Significance of Research

With increased popularity of the sport of surfing and a pool of elite competitive surfing athletes striving to qualify and compete at the highest level of surfing competition, the Championship Tour (CT) of WSL, coaches and athletes are continuously searching for the winning edge. The majority of knowledge on surfing performance stems from parents or coaches, who were former surfers. In the past, a lack of equipment and understanding of the physical demands of surfing has made it challenging to improve the physical qualities of these athletes. Currently, there is limited research regarding the physical qualities and the resistance training adaptations of competitive surfing athletes. To gain further insight into these qualities and how athletes respond and adapt to resistance training, testing protocols must first be developed and evaluated. This research has established reliable and contextually valid testing protocols that can be implemented into a developmental pathway and national curriculum. Additionally, it is important to understand which training intervention elicits the greatest adaptations and prepares the athletes for the demands of the sport. Over the years, unstable surface training has been increasingly implemented by surfing athletes in a belief that it will promote greater strength and power gains, balance, and overall surf

performance. However, there is little or no evidence-based research to support this practice. Furthermore, with a very busy competition and travel schedule, surfing athletes' training primarily consists of surfing alone. The findings of this thesis provide additional insight as to whether surfing in the absence of resistance training provides sufficient stimuli to maintain adaptations from a previous short-term resistance-training program.

1.3 Research Questions

1. Are testing protocols of anthropometry, strength, and power, and sprint and endurance testing a practical reliability and context validity method investigating in competitive surfing athletes?
2. Are testing protocols for anthropometry, strength, and power, and sprint and endurance able to discriminate between competitive levels?
3. Does performance tests of physical qualities in a cohort of elite junior competitive surfing athletes reflect selection for international competition?
4. Does the novel drop and stick testing protocol demonstrate practical reliability and context validity to assess dynamic postural control?
5. Is the drop and stick testing protocol able to discriminate time to stabilisation and landing impact force between junior development, junior elite, and senior elite surfing athletes?
6. Does resistance training on unstable device provide greater adaptations compared to traditional resistance training on stable surface?
7. Does four weeks of surfing in the absence of resistance training provide enough stimulus to maintain or increase physical capabilities?

1.4 Research Hypotheses

Study 1, testing protocols of anthropometry, strength, and power, and sprint and endurance testing will provide practical reliability and context validity in competitive surfing athletes.

Study 2, performance tests of physical qualities in a cohort of elite junior competitive surfing athletes will reflect selection for international competition.

Study 3, the novel drop and stick testing protocols will provide practical reliability and context validity to assess dynamic postural control.

Study 4, resistance training on unstable device will not provide greater adaptations compared to traditional resistance training on stable surface.

Study 5, four weeks of surfing in the absence of resistance training will negatively affect strength, power, and sensorimotor abilities.

1.5 General Overview

Surfing may be considered a 'skilled-based' sport that is embraced worldwide by a broad age population. Physical demands of surfing has been well established with paddling representing 44-54% (Farley et al., 2012a; Mendez-Villanueva, Bishop and Hamer, 2006) of the activity during an hour of competitive or free surfing (Meir, Lowdon, and Davie, 1991). Currently there is no performance testing protocols to assess surfing athletes or track physical performance. Furthermore there is little understanding of the impact of any resistance training in competitive surfing, let alone resistance training on dynamic postural control (not standing in place doing nothing on unstable devices).

This thesis consists of a series of five studies to evaluate the training of sensorimotor abilities in competitive surfing athletes. To develop a better understanding of the sport of surfing and surfing athletes' physical capabilities, comprehensive performance testing protocols must be established. The first study developed testing protocols to determine whether the chosen performance tests demonstrate practical reliability and context validity. In addition, this study provides information whether these tests are able to discriminate between different levels of surfing ability. The second study was designed to further validate testing protocols from study 1 using Australian most promising elite junior surfing athletes during selection camp for the International

Surfing Association World Junior Surfing Championship. With a pool of elite junior surfing athletes, the performance tests may assist with talent identification. Although studies 1 and 2 demonstrated performance-testing protocols used in these studies to discriminate between different levels, establishing a dynamic postural control protocol to assess landing force and the ability to regain postural control as quickly as possible is of great importance. Therefore, developing and evaluating a novel drop and stick test protocol using time to stabilisation may be useful to assess dynamic postural control across various levels (e.g., development, elite juniors, and elite seniors) of competitive surfing athletes. Furthermore, this novel test may provide information on landing force across three different levels of surfing abilities. Based on the results of studies 1, 2, and 3, with established performance testing protocols, the fourth study was designed to examine the effects of short-term resistance training on strength, power and sensorimotor abilities. Furthermore, this study provides valuable insight to which resistance-training intervention provides greater adaptations (unstable vs. stable surface) over a period of 2 seven weeks training blocks. The fifth study provides information regard to detraining in a cohort of competitive surfing athletes. This final study outlines the importance of incorporating resistant training in conjunction with surf training. Overall, this thesis contributed to the establishment of performance testing protocols for competitive surfing athletes, and determined whether using unstable training devices provide greater adaptations compared to stable surface training. In addition, this thesis provided valuable insight regard to short-term detraining in surfing athletes. Future training studies investigating whether resistance training positively transfers to surfing performance is warranted.

Chapter 2

Review of Literature

2.1 Introduction

The popularity of surfing continues to increase throughout the world and appears to be drawing younger participants of school age (5-12), which has been shown in recent registrations of surfing schools that have increased from 70 to over 100 schools in just three years (Harper, 2012). Surfing is one of the most popular sports in Australia and over the past 10 years, Australia's men and women surfers have the greatest representation (Table 2.1 and 2.2) on the CT of WSL. Remarkably, Australia's men and women have claimed 4 and 7 World Champion titles, respectively, over the past 10 years. Additionally, Australia's men and women have the highest percentage of surfers ranked in the top 10 and top 5 (Table 2.1 and 2.2) over the past 10 years. Mendez-Villanueva and Bishop (2003) reported the country with the most representation on the WSL was Australia with 24 and 9 for men and women surfers, respectively. Moreover, the 2002 Women's World Qualifying Series (feeder system for the WSL) consisted of 34.4% Australian female surfers. These statistics confirm and reflect the evidence that Australians are the highest group represented on the CT.

The pathway to the highest level of surfing, the CT demands countless hours of extensive practise and training to excel. Junior surfers begin their pathway by competing in local, state, and national events to accumulate points, which contributes to higher ranking and seeding benefits at the next level of competition (e.g., Pro Juniors, World Qualification Series; WQS, WSL). The ultimate goal and dream for every young surfer is to compete on the CT, which is comprised of the top 32 male and top 17 female surfers in the world. Since 2010, the CT has become more challenging for male surfers to qualify due to the

WSL narrowing the field from 44, to only the top 32 in the world. In order for male and female surfers to continue competing on the WSL, they must finish in the top 22 and 10, respectively, at the end of the WSL season. The bottom ranked 10 male and 6 female surfers from the WSL rankings are dropped and must re-qualify via WQS events to continue their journey to compete at the highest level of surfing. This gives the top 10 ranked male and 6 female surfers on the WQS ranking (those who are not already qualified for the WSL) an opportunity to qualify and compete the following year. At the conclusion of each season, the surfer from the men's and women's field with the most total points accumulated from each of the WSL events is crowned the ultimate WSL World Champion. This highlights the importance of a developmental pathway program for the future of surfing. Implementing a development pathway program is necessary to ensure young aspiring surfing athletes follow age-appropriate guidelines. Furthermore, a development pathway program provides valuable guidelines for surf and strength coaches to continuously support and develops young surfing athletes to their full potential (Surfing Australia, National Curriculum Book; Overview, 2012). More specifically, evaluating and developing testing protocols to assess and track performance parameter throughout the pathway needs to be established.

WSL Men's Championship Tour (2004-2013)

Table 2.1. Presents the countries and the numbers and percentages of male athletes representing the Men's Championship Tour (CT) of World Surf League (WSL). Based on the final ranking from 2004-2013, this table also presents the numbers and percentages of male athletes from their respective country finishing in the top 10 and top 5 rankings. The following countries that represented the ASP Men's WSL the past 10 years are: *Australia (AUS), United States (USA), Hawaii (HAW), Brasil (BRA), South Africa (ZAF), France (FRA), French Polynesia (PYF), Portugal (PRT), Basque Country (EUK), amd Germany (DEU)*. *Indicates surfer from their respective country winning the CT of WSL.

2004

Country	Top 44	%	Top 10	%	Top 5	%
AUS	23	52.3	4	9.1	2	4.5
USA	8	18.2	3	6.8	2	4.5
HAW*	4	9.1	2	4.5	1	2.3
BRA	8	18.2	1	2.3	0	0.0
ZAF	1	2.3	0	0.0	0	0.0
FRA	0	0.0	0	0.0	0	0.0
PYF	0	0.0	0	0.0	0	0.0
PRT	0	0.0	0	0.0	0	0.0
EUK	0	0.0	0	0.0	0	0.0
DEU	0	0.0	0	0.0	0	0.0

2005

Country	Top 44	%	Top 10	%	Top 5	%
AUS	21	47.7	5	11.4	2	4.5
USA*	10	22.7	3	6.8	2	4.5
HAW	5	11.4	2	4.5	1	2.3
BRA	6	13.6	0	0.0	0	0.0
ZAF	2	4.5	0	0.0	0	0.0
FRA	0	0.0	0	0.0	0	0.0
PYF	0	0.0	0	0.0	0	0.0
PRT	0	0.0	0	0.0	0	0.0
EUK	0	0.0	0	0.0	0	0.0
DEU	0	0.0	0	0.0	0	0.0

2006

Country	Top 44	%	Top 10	%	Top 5	%
AUS	20	44.4	5	11.1	2	4.4
USA*	8	17.8	4	8.9	2	4.4
HAW	5	11.1	1	2.2	1	2.2
BRA	8	17.8	0	0.0	0	0.0
ZAF	3	6.7	0	0.0	0	0.0
FRA	1	2.2	0	0.0	0	0.0
PYF	0	0.0	0	0.0	0	0.0
PRT	0	0.0	0	0.0	0	0.0
EUK	0	0.0	0	0.0	0	0.0
DEU	0	0.0	0	0.0	0	0.0

2007

Country	Top 44	%	Top 10	%	Top 5	%
AUS*	20	45.5	5	11.4	4	9.1
USA	8	18.2	2	4.5	1	2.3
HAW	4	9.1	2	4.5	0	0.0
BRA	7	15.9	0	0.0	0	0.0
ZAF	4	9.1	0	0.0	0	0.0
FRA	1	2.3	1	2.3	0	0.0
PYF	0	0.0	0	0.0	0	0.0
PRT	0	0.0	0	0.0	0	0.0
EUK	0	0.0	0	0.0	0	0.0
DEU	0	0.0	0	0.0	0	0.0

2008

Country	Top 44	%	Top 10	%	Top 5	%
AUS	17	38.6	5	11.4	3	6.8
USA*	9	20.5	3	6.8	2	4.5
HAW	5	11.4	0	0.0	0	0.0
BRA	6	13.6	1	2.3	0	0.0
ZAF	3	6.8	0	0.0	0	0.0
FRA	2	4.5	1	2.3	0	0.0
PYF	0	0.0	0	0.0	0	0.0
PRT	1	2.3	0	0.0	0	0.0
EUK	1	2.3	0	0.0	0	0.0
DEU	0	0.0	0	0.0	0	0.0

2009

Country	Top 44	%	Top 10	%	Top 5	%
AUS*	18	40.9	4	9.1	4	9.1
USA	9	20.5	5	11.4	0	0.0
HAW	4	9.1	0	0.0	0	0.0
BRA	3	6.8	1	2.3	1	2.3
ZAF	3	6.8	0	0.0	0	0.0
FRA	3	6.8	0	0.0	0	0.0
PYF	1	2.3	0	0.0	0	0.0
PRT	1	2.3	0	0.0	0	0.0
EUK	1	2.3	0	0.0	0	0.0
DEU	1	2.3	0	0.0	0	0.0

2010

Country	Top 32	%	Top 10	%	Top 5	%
AUS	14	43.8	5	15.6	2	6.3
USA*	8	25.0	2	6.3	2	6.3
HAW	3	9.4	0	0.0	0	0.0
BRA	2	6.3	1	3.1	0	0.0
ZAF	2	6.3	1	3.1	1	3.1
FRA	1	3.1	1	3.1	0	0.0
PYF	1	3.1	0	0.0	0	0.0
PRT	1	3.1	0	0.0	0	0.0
EUK	0	0.0	0	0.0	0	0.0
DEU	0	0.0	0	0.0	0	0.0

2011

Country	Top 32	%	Top 10	%	Top 5	%
AUS	14	43.8	5	15.6	3	9.4
USA*	5	15.6	1	3.1	1	3.1
HAW	2	6.3	0	0.0	0	0.0
BRA	6	18.8	2	6.3	1	3.1
ZAF	2	6.3	1	3.1	0	0.0
FRA	1	3.1	0	0.0	0	0.0
PYF	1	3.1	1	3.1	0	0.0
PRT	1	3.1	0	0.0	0	0.0
EUK	0	0.0	0	0.0	0	0.0
DEU	0	0.0	0	0.0	0	0.0

	2012							2013					
Country	Top 32	%	Top 10	%	Top 5	%	Country	Top 32	%	Top 10	%	Top 5	%
AUS*	13	37.1	6	17.1	2	5.7	AUS*	12	37.5	6	18.8	3	9.4
USA	7	20.0	1	2.9	1	2.9	USA	7	21.9	2	6.3	1	3.1
HAW	3	8.6	1	2.9	1	2.9	HAW	4	12.5	1	3.1	0	0.0
BRA	7	20.0	2	5.7	1	2.9	BRA	5	15.6	0	0.0	0	0.0
ZAF	2	5.7	0	0.0	0	0.0	ZAF	2	6.3	1	3.1	1	3.1
FRA	1	2.9	0	0.0	0	0.0	FRA	1	3.1	0	0.0	0	0.0
PYF	1	2.9	0	0.0	0	0.0	PYF	1	3.1	0	0.0	0	0.0
PRT	1	2.9	0	0.0	0	0.0	PRT	0	0.0	0	0.0	0	0.0
EUK	0	0.0	0	0.0	0	0.0	EUK	0	0.0	0	0.0	0	0.0
DEU	0	0.0	0	0.0	0	0.0	DEU	0	0.0	0	0.0	0	0.0

WSL Women's Championship Tour (2004-2013)

Table 2.2. Presents the countries, the numbers and percentages of female surfers representing the Championship Tour (CT) of World Surf League (WSL). Based on the final ranking from 2004-2013, this table also presents the numbers and percentages of female surfers from their respective country finishing in the top 10 and top 5 rankings. The following countries that represented the ASP Women's WSL the past 10 years are: *Australia (AUS), United States (USA), Hawaii (HAW), Brasil (BRA), France (FRA), Peru (PER), New Zealand (NZL), and South Africa (ZAF).* *Indicates surfer from their respective country winning the CT of WSL.

2004

Country	Top 17	%	Top 10	%	Top 5	%
AUS	9	52.9	4	23.5	2	11.8
USA	0	0.0	0	0.0	0	0.0
HAW	4	23.5	3	17.6	1	5.9
BRA	2	11.8	2	11.8	1	5.9
FRA	0	0.0	0	0.0	0	0.0
PER*	1	5.9	1	5.9	1	5.9
NZL	0	0.0	0	0.0	0	0.0
ZAF	1	5.9	0	0.0	0	0.0

2005

Country	Top 17	%	Top 10	%	Top 5	%
AUS*	9	52.9	6	35.3	3	17.6
USA	0	0.0	0	0.0	0	0.0
HAW	4	23.5	3	17.6	1	5.9
BRA	2	11.8	0	0.0	0	0.0
FRA	0	0.0	0	0.0	0	0.0
PER	1	5.9	1	5.9	1	5.9
NZL	0	0.0	0	0.0	0	0.0
ZAF	1	5.9	0	0.0	0	0.0

2006

Country	Top 17	%	Top 10	%	Top 5	%
AUS*	9	52.9	6	35.3	4	23.5
USA	1	5.9	0	0.0	0	0.0
HAW	3	17.6	2	11.8	0	0.0
BRA	2	11.8	1	5.9	0	0.0
FRA	0	0.0	0	0.0	0	0.0
PER	1	5.9	1	5.9	1	5.9
NZL	0	0.0	0	0.0	0	0.0
ZAF	1	5.9	0	0.0	0	0.0

2007

Country	Top 17	%	Top 10	%	Top 5	%
AUS*	9	52.9	7	41.2	3	17.6
USA	0	0.0	0	0.0	0	0.0
HAW	3	17.6	1	5.9	0	0.0
BRA	2	11.8	1	5.9	1	5.9
FRA	1	5.9	0	0.0	0	0.0
PER	1	5.9	1	5.9	1	5.9
NZL	0	0.0	0	0.0	0	0.0
ZAF	1	5.9	0	0.0	0	0.0

2008

Country	Top 17	%	Top 10	%	Top 5	%
AUS*	9	41.2	6	35.3	3	17.6
USA	1	5.9	0	0.0	0	0.0
HAW	2	11.8	1	5.9	0	0.0
BRA	2	11.8	2	11.8	1	5.9
FRA	0	0.0	0	0.0	0	0.0
PER	2	11.8	1	5.9	1	5.9
NZL	0	0.0	0	0.0	0	0.0
ZAF	1	5.9	0	0.0	0	0.0

2009

Country	Top 17	%	Top 10	%	Top 5	%
AUS*	7	41.2	4	23.5	2	11.8
USA	0	0.0	0	0.0	0	0.0
HAW	4	23.5	2	11.8	1	5.9
BRA	3	17.6	1	5.9	0	0.0
FRA	0	0.0	0	0.0	0	0.0
PER	1	5.9	1	5.9	1	5.9
NZL	1	5.9	1	5.9	0	0.0
ZAF	1	5.9	1	5.9	0	0.0

2010

Country	Top 17	%	Top 10	%	Top 5	%
AUS*	7	41.2	4	23.5	2	11.8
USA	0	0.0	0	0.0	0	0.0
HAW	3	17.6	3	17.6	1	5.9
BRA	2	11.8	1	5.9	1	5.9
FRA	1	5.9	0	0.0	0	0.0
PER	1	5.9	1	5.9	1	5.9
NZL	1	5.9	1	5.9	0	0.0
ZAF	2	11.8	0	0.0	0	0.0

2011

Country	Top 17	%	Top 10	%	Top 5	%
AUS	7	41.2	4	23.5	3	17.6
USA	1	5.9	1	5.9	0	0.0
HAW*	4	23.5	2	11.8	1	5.9
BRA	2	11.8	1	5.9	1	5.9
FRA	1	5.9	1	5.9	0	0.0
PER	1	5.9	1	5.9	0	0.0
NZL	1	5.9	0	0.0	0	0.0
ZAF	0	0.0	0	0.0	0	0.0

2012							2013						
Country	**Top 17**	**%**	**Top 10**	**%**	**Top 5**	**%**	**Country**	**Top 17**	**%**	**Top 10**	**%**	**Top 5**	**%**
AUS*	**5**	**29.4**	**4**	**23.5**	**3**	**17.7**	**AUS**	**5**	**29.4**	**4**	**23.5**	**3**	**17.7**
USA	**3**	**17.7**	**2**	**11.8**	**1**	**5.9**	**USA**	**3**	**17.7**	**2**	**11.7**	**1**	**5.9**
HAW	**3**	**17.7**	**3**	**17.7**	**1**	**5.9**	**HAW***	**4**	**23.5**	**3**	**17.7**	**1**	**5.9**
BRA	**1**	**5.9**	**0**	**0.0**	**0**	**0.0**	**BRA**	**1**	**5.9**	**0**	**0**	**0**	**0.0**
FRA	**2**	**11.8**	**0**	**0.0**	**0**	**0.0**	**FRA**	**1**	**5.9**	**1**	**5.9**	**0**	**0.0**
PER	**1**	**5.9**	**0**	**0.0**	**0**	**0.0**	**PER**	**1**	**5.9**	**0**	**0**	**0**	**0.0**
NZL	**2**	**11.8**	**1**	**5.9**	**0**	**0.0**	**NZL**	**1**	**5.9**	**0**	**0**	**0**	**0.0**
ZAF	**0**	**0.0**	**0**	**0.0**	**0**	**0.0**	**ZAF**	**1**	**5.9**	**1**	**5.9**	**0**	**0.0**

2.1.1 Format of competitive surfing

Surfing is an individual sport that is characterised by intermittent high intensity activities, coupled with low-moderate level activities. The duration of the knock-out format event for competitive surfing heats ranges from 20 to 40 minutes with each varying from two to four surfers (Mendez-Villanueva et al., 2006). The surfer with the two highest combined wave scores is the winner of the heat and advances to the next round till a winner from the final round is determined. According to the ASP judging criteria, surfers can maximize their scoring potential by performing major elements such as innovative and progressive manoeuvres, a combination of major manoeuvres, and a commitment and degree of difficulty to various manoeuvres with speed, power and flow in the most critical section of the wave. Depending on the event (e.g., WQS, WSL), each surfer receives individual scores from a panel consisting of a minimum of five judges. The lowest and highest wave scores are discarded and the remaining three scores are then averaged for the wave ride. Each wave ride is subjectively scored by the judges on a range from 0.1 to 10 with a reference scale to describe each wave ride: *Poor: 0-1.9; Fair: 2.0-3.9; Average: 4.0-5.9; Good: 6.0-7.9; and Excellent: 8.0-10.0* (WSL Rule Book 2014, Article 134: Judging Criteria).

2.1.2 Activity profile of competitive surfing

Surfing is a challenging sport due to the variety of ocean conditions (e.g., wind, sand bar, current, swell). Therefore, when the surf conditions are favourable, competitive surfing athletes take advantage and train in the water. For example, Loveless and Minahan (2010) reported that competitive surfers train on average 12.3 ± 2.8 hours surfing per week. Lowdon et al. (1983), reported that surfers of various levels (beginners, recreational, and competitive) average 4.0 ± 1.6 hours surfing a day, 2.7 ± 1.4 days per week. In another study, investigating international surfers, Lowdon et al. (1987) reported surfers averaged 5.2 ± 1.3 hours a day, 3.7 ± 1.1 days per week. Collectively, surfers, regardless whether they are recreational or competitive, appear to average similar hours surfing throughout the week. This similarity in surf hours might be explained by them engaging in surfing for the enjoyment rather than for purposeful competition training. Given the amount of hours spent per week in the water, many surfers have traditionally believed that surfing alone is sufficient to maintain or improve their physical fitness.

Recent manuscripts have stressed the importance of possessing high aerobic fitness for paddling during surfing (Everline, 2007; Loveless and Minahan, 2010). The four main categories for this intermittent sport consist of paddling, stationary sitting, wave riding, and miscellaneous activities such as ducking under broken waves or retrieving the board (Mendez-Villanueva et al., 2006). Several studies have examined physiological profiles (aerobic and anaerobic) of surfers via modified paddling kayak ergometry (Farley et al., 2012b; Mendez-Villanueva et al., 2005), swim bench ergometry (Loveless and Minahan, 2010), and the relationship of these assessments to surfing performance. Time-motion analyses during an hour of surfing have reported 44-54% of surfing activity being devoted to paddling, while stationary represented 28-42.5%, wave riding at 5-8%, and miscellaneous activities at 2.2-16% (Meir et al., 1991; Mendez-Villanueva et al., 2006; Farley et al., 2012a). This might imply that surfers require a high level of aerobic physical conditioning to be successful at paddling during competition. However, Farley et al. (2012b) found

no significant ($r = -0.02$, $p = 0.97$) relationship between VO_{2peak} and season rank, whereas anaerobic power was significantly ($r = -0.55$, $p = 0.05$) correlated to season rank. However, the evidence shows that the majority of surfing activity is spent paddling; it is important to note that completing high-risk manoeuvres successfully with speed, power, and flow under control during wave riding influences scoring, and this is the only feature that is judged.

Collectively these studies have provided baseline measures of physical fitness and an insightful profile of surfing activities; however, other measures such as sprint paddle ability (e.g., 5, 10, 15 m) may be more relevant for surfing athletes. For example, sprint paddling is important for greater entry speed into the wave, sitting deeper on the peak, and paddling against an opponent to gain priority (Sheppard et al., 2012). Currently, there are no comprehensive testing protocols for sprint paddle ability in competitive surfing athletes. As a result, study 1 developed and evaluated testing protocols to assess a sprint paddle task, as it is a critical performance factor of surfing. Additionally, a sprint paddle test may provide coaches a reference scale to distinguish amongst various ability levels. Furthermore, study 2 further validated these comprehensive-testing protocols between selected and non-selective junior competitive surfers' physical characteristics to determine if performance tests of their physical qualities reflect selection for international competition.

2.2 Sensorimotor ability

Over the years, "proprioception" has received a great deal of attention when prescribing training methods to reduce injury or improve balance. When describing mechanisms involved with regulating postural control, sensorimotor ability is defined as an "integration of sensory, motor, and central integration and processing information involved in maintaining posture and joint stability" (Lephart et al., 2000). In other words, an integration of vestibular, visual, and proprioceptive feedback to control movement (Cardinale et al., 2011). For example, in tube riding (riding in the barrel of a wave) for an elite surfer, greater sensorimotor ability will allow the athlete to ride through the tube, absorbing the wave's perturbations whilst using well-developed pattern

recognition and dynamic visual acuity to spot the tip of the wave barrelling over top of them and will get in a position that will generate greater speed to ride out of the tube, an integration of context-specific visual, vestibular, and proprioceptive expertise. A recreational surfer experiencing the same situation may panic and react differently due to a lack of 'tube awareness'. It is possible that elite surfers, with hours of deliberate surfing practice and experience, gain the ability to perform dual-tasks while diverting unnecessary attention away from the main task, and yet, common belief is that simply by performing unstable, stationary proprioceptive training will advance surfing performance in contexts such as riding the barrel.

2.2.1 Measurement of sensorimotor ability

The dynamic environment of surfing due to wind, current, and swell makes it challenging to replicate surf performance testing in a land-based setting. One high-risk manoeuvre that would require dynamic postural control during wave riding is an aerial. This requires surfers to launch themselves off the breaking wave and rotate their body and board in mid-air then land back on the surface of the water while maintaining balance and regaining stability. The success of landing may depend on the strength and the integration of the sensorimotor system. Therefore, it is likely worthwhile to develop and evaluate sensorimotor ability in such a manner where control must be regained after a drop from a height.

The ability to transition from a dynamic to static environment requires integration of sensory, vestibular, and visual information (Wikstrom et al., 2005). Drop landings from a pre-determined height on a force plate, followed by attaining a static and motionless position is a method used to analyse dynamic postural control. Dynamic postural control assessments using time to stabilisation (TTS) from a drop landing have been used to evaluate plyometric exercises (Ebben et al., 2010; Flanagan et al., 2008), postural control (Wikstrom et al., 2005; Webster and Gribble, 2010), and functional fatigue (Wikstrom et al., 2004). Vertical ground reaction force from drop landings to time at stabilisation within 5% of bodyweight is a method used to calculate TTS

(Wikstrom et al., 2005; Ebben et al., 2010; Flanagan et al., 2008). Using a force plate to measure TTS has been reported to have fair to moderate reliability (Wikstrom et al., 2005; Ebben et al., 2010; Flanagan et al., 2008). Flanagan et al. (2008) with average ICC measures of 0.69 for TTS, whereas Ebben et al. (2010) and Wikstrom et al. (2005) found ICC values of 0.51 to 0.86 and 0.78, respectively.

Although TTS studies have reported reliable measures of postural stability, they have not reported Typical Error (TE), which would allow for detection or interpretation of the smallest worthwhile change of stabilisation in athletes. Another measures used in previous research is dynamic postural stability index (DPSI) which is a combination of medial-lateral stability index (MLSI), anterior-posterior stability index (APSI), and vertical stability index (VSI) and is sensitive to changes in all three directions (Wikstrom et al., 2005). Wikstrom found a small standard error of measurement for DPSI (SEM=0.03) and excellent reliability for APSI (ICC=0.90), VSI (ICC=0.97), and overall excellent reliability for DSPI (ICC=0.96). The greater the reliability, the more likely it will be sensitive to change as it has a direct relationship with SEM. Dynamic postural stability index includes mean square deviation and ground reaction force; therefore it may be more accurate and precise than the time to stabilisation method (Wikstrom et al., 2005). Thus, using DPSI may be more practical to detect precision and small worthwhile changes of surfer's strength and dynamic postural abilities over time. However, a limitation to using this method is the ability of widely available (portable force-plates usable in a field setting) force plates to collect measurements in three dimensions whereas TTS can be collected using single dimensional (vertical) force plates. Although DPSI have been shown to be more sensitive to changes, all TTS data in this study was collected in the vertical axis of the force plate.

Surfing is different from other sports, as countermovement jumps do not precede landing. Often times, surfers experience large eccentric forces in the lower extremities from getting forced into the bottom of the wave or drop landing from the height of a wave. Therefore, drop landings from a box onto a force plate may be more relevant to measure postural control and eccentric

landing forces. It is imperative to measure how well surfers receive and attenuate landing forces and whether ground reaction force (GRF) declines following a resistance training intervention. A decline in GRF following resistance training will suggest that the muscles are effectively attenuating the force rather than allowing force transmission through the joints. Absorbing force using muscular contraction may spare excess force at the joints, therefore reducing the risk of joint injury allowing the surfer to make a softer and easier transition from air to wave landings, which is most important for performance.

Using a force plate, dynamic postural control from a 'drop and stick' may be a relevant test to standardise dynamic postural control measures for surfers. The proposed drop and stick test will require an athlete to start in an upright position on top of a 0.5m box, then step forward barefoot off the box with their preferred leg, land soft on both feet on a force plate and maintain their balance for three seconds. Wikstrom et al. (2005) was one of the first to address the reliability and precision of dynamic postural stability index (DPSI) on a force plate. Other studies have used single leg jump and stick to measure dynamic postural, sensorimotor training on athletic performance or for rehabilitation purposes (Wikstrom et al., 2005; Webster and Gribble, 2010; Ross et al., 2005). The single leg jump and stick method may not be a functional measure of sensorimotor control for surfers as they are required to drop from an aerial and land on their board with both feet while maintaining or regaining their posture. Therefore, landing with both feet simultaneously on the force plate may be more suitable for surfers.

In order to gain insight into the physical preparation and postural control of surfers, a comprehensive test protocol is needed, one that is robustly able to detect sensorimotor changes over time. Currently there is no standardised test to evaluate sensorimotor ability of surfers. Therefore study 3 developed and evaluated a novel drop and stick test to assess landing skills in various levels of competitive surfing.

2.3 Training interventions

Unlike other jump sports (e.g., basketball, volleyball), where athletes produce and absorb forces throughout the countermovement vertical jump, surfing requires athletes to produce and absorb forces while riding across the face of a wave. During wave riding, surfing athletes are awarded higher scores for speed, power, and flow (WSL 2014 rulebook, Article 134: Judging Criteria). Recently, Lundgren et al. (2014) reported high-risk manoeuvres such as aerials and tube rides are awarded higher scores compared to less risk manoeuvres. Furthermore, Secomb et al. (In Press), demonstrated a significant relationship between lower-body strength and power with higher scoring potential for turning manoeuvres. The finding of Secomb et al. (In Press) further validates the importance of incorporating resistance training in conjunction with surf training. Therefore, traditional resistance training such as Olympic lifts, squats, push and pull exercises are suggested and should be the foundation of land-based training (Everline, 2007; Metcalfe and Kelly, 2012) to tolerate the demands of the sport. Although most traditional resistance training methods produce movements in the sagittal plane, and surfing requires a lot of upper body rotation, it is important to note that traditional resistance training movements such as squats, single leg squats, pull ups, and push ups are relevant for the sport of surfing. Furthermore, these movements are general and appropriate for the cohort of surfing athletes that participated in this study.

There is a strong belief in the surf communities that surfers may mimic surf training in land-based interventions to improve performance via basic training, including resistance training on unstable devices. However, over the years, unstable training has transitioned from physical therapy purposes; aiming to rehabilitate injuries, to a view to enhance athletic performance. The premise of unstable training to improve core stabilisation to enhance athletic performance has been much debated, but no scientific evidence-based studies support the hypothesis that unstable training enhances athletic performance (Anderson and Behm, 2005). With the growing body of non-empirical information and young athletes seeing their idols train, it is easy to deviate from scientific evidence-based findings. For example, the latest custom balance surfboard trainer promotes surfing

athletes may receive the same physical benefits, feeling and physical demands of surfing without the ocean. These training devices (RipSurfer X, IndoBoard, or BOSU (Figure 2.1), might be appropriate for lower-limb rehabilitation purposes due to the proprioceptive overload they provide (Cressey et al., 2007; Chapman et al., 2008; Paillard et al., 2011). However, they may not provide an adequate stimulus to un-injured athletes, and are thought to be ineffective in developing strength qualities (Anderson and Behm, 2005).

Resistance training has been extensively researched and reported to improve athletic performance (Wilson, Murphy, and Walshe, 1996; Newton et al., 2002; McBride et al., 2002; Christou et al., 2006; Faigenbaum et al., 2009; Sheppard et al., 2009; Nimphius, McGuigan, and Newton, 2010). Sports scientists and practitioners are continuously searching for training interventions to increase the transfer of gains in maximal strength and power to an athlete's sport. Utilizing heavy loads equal to or greater than 80% of 1RM have been recommended and reported to maximize strength gains (Baechle et al., 2000; McBride et al., 2002; Peterson et al., 2004; Rhea et al., 2003) whereas lighter loads have demonstrated greater increases in power output (Baker et al., 2001; Harris et al., 2000; McBride et al., 2002). Furthermore, Peterson et al., (2004) reported that a training intensity of 50-70% elicits minimal gains in strength. In light of these findings, caution should be used when resistance training on an unstable device, as utilizing intensities greater than 80% of 1RM for major lifts would be challenging or impossible to complete with proper form.

Behm et al. (2002) reported that lower limb force output in an unstable condition was 70.5% less when compared to a stable condition. Similarly, Anderson and Behm (2005) also reported 59.6% less force output in the upper limb in an unstable condition. Although both studies were not training studies, their findings may support that resistance training on unstable devices provides no advantage over stable conditions when the objective is to gain strength. Two other studies (Gruber and Gollhofer, 2004; Kibele and Behm, 2009) also have reported that resistance training on an unstable device provided no advantages over a stable surface in terms of strength gains. An explanation of the decreased forces associated with unstable devices might be attributed to the

combination of the musculature stabilising the joint and force production when performing the task under unstable conditions (Anderson and Behm, 2004).

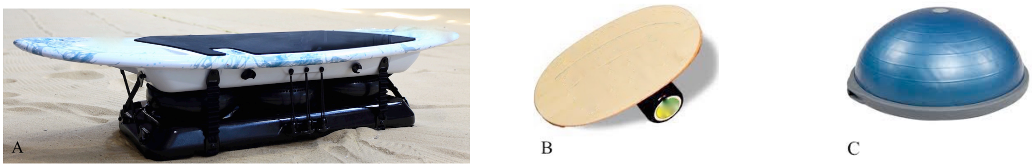


Figure 2.1 (A) Rip Surfer X Board, (B) Indo Board, and (C) BOSU Trainer

Investigating the possibility of sensorimotor changes due to specific tasks or training interventions and whether it is associated with performance enhancement is of great importance. Furthermore, the effectiveness of sensorimotor training (e.g., unstable surface) compared to traditional resistance training (strength-power) interventions may provide additional support to the principle of specificity training. For example, four weeks of static postural control training in untrained subjects has been shown to increase explosive strength (Gruber and Gollhofer, 2004; Gruber et al., (2007), When investigating the effect of sensorimotor training in elite youth athletes, Taube et al. (2007) demonstrated that six weeks of sensorimotor training did not improve rate of force development. It is important to note that in untrained subjects, any training stimulus may positively affect explosive strength in the early phases of training and these positive adaptations are attributed to improved neuromuscular coordination (Sale, 2003). Furthermore, in elite athletes, the training stimulus must be properly designed to elicit further changes in explosive strength since they have a smaller window of adaptation. The training program used by Taube et al. (2007) was not properly programed to enhance either maximal strength or explosive strength due to the use of low relative percentages of maximum strength. Instead they prescribed a common load that would be considered a very low percentage of maximal load.

Furthermore, the majority of work with active and trained participants has demonstrated that unstable training attenuates most athletic performance characteristics (Bruhn et al., 2004; Cressey et al., 2007; Eisen et al., 2010; Kibele et al., 2009; Oberacker et al., 2012). Following 10 weeks of resistance training, Cressey et al. (2007) demonstrated that an unstable condition showed no

significant changes in power; whereas, a stable condition significantly improved bounce drop jump and vertical jump height.

It is important to consider that maintaining basic postural control (i.e., standing on these devices) whilst under a high proprioceptive demand is likely to only develop proprioceptive abilities in that specific context, and it is unknown whether this transfers to increased performance in able-bodied (i.e., uninjured) surfers or to such a specific and variable task such as surfing. Although some static postural control tasks have been reported to discriminate between surfers and non-surfers (Chapman et al., 2008), this was only observed when a surf-specific pattern recognition task was included as part of the test, perhaps highlighting the importance of dual-task abilities rather than an actual physical superiority. Furthermore, a static postural control task discriminating between surfing ability does not indicate that further development of static postural control through proprioceptive overload will influence dynamic sensorimotor ability, as has been indicated previously (Chapman et al., 2008; Paillard et al., 2011).

Recently, Mohammadi et al., (2012) concluded that six weeks of strength training increased dynamic balance of young male athletes. In agreement, Salehzadeh et al., (2011) demonstrated that eight weeks of strength training enhanced dynamic balance, with similar gains observed with a combination of plyometric and strength training programs. Salehzadeh et al. (2011) postulated that the improvements in dynamic balance might be due to increased lower body strength, recruitment of fast twitch muscle fibres and activation of sensory receptors. Collectively, these studies demonstrate that traditional resistance training on stable surfaces also contributed to improvement in dynamic balance without compromising strength. To further support these findings, study 4 investigated whether land-based unstable surface training provides greater adaptations than traditional resistance training, and the effects of unstable versus stable resistance training on strength, power, and sensorimotor ability

2.4 Detraining

Detraining is defined as a reduction or complete cessation of training, which may have negative implications for anatomical and physiological adaptations as well as athletic performance (Faigenbaum et al., 1996). While resistance training with sufficient stimulus induces positive physiological and athletic performance adaptations, these adaptations have been shown to diminish within a short period (4-8 weeks) when the stimulus is completely removed (Faigenbaum et al., 1996; Taaffe and Marcus, 1997; Kraemer et al., 2002; Izquierdo et al., 2007; Gharahdaghi et al., 2014). For example, Faigenbaum et al. (1996), reported that both upper (-19.3%) and lower (-28.1%) body strength significantly decreased following 8 weeks of detraining in a cohort of active boys and girls. Recently, Gharahdaghi et al. (2014) reported that collegiate male wrestlers' peak and mean anaerobic power significantly declined following three weeks of detraining. There has been further evidence demonstrating that detraining induces a decrease in strength and power in non-athletes (Kraemer et al. 2002; Izquierdo et al. 2007; Pereira et al. 2012). In physically active men, Izquierdo et al. (2007) demonstrated significant decreased upper and lower body strength (-9% and -6%, respectively) and power (-17% and -14%, respectively), following four weeks of physical inactivity. An interesting finding in this study was that four weeks of detraining negatively impacted power more than strength. In a cohort of healthy men, Kraemer et al. (2002) also reported that detraining had a greater affect on power than strength. It is unclear what mediates greater power loss compared to strength in the early phases of detraining. A possibility may be that neural mal-adaptations in power occur at a faster rate with advancing age. This might also support the high incidence of falls in the elderly. Collectively, the findings of these studies demonstrate the possible deleterious implications of detraining on strength and power across various populations.

In contrast, some previous studies have reported that short-term detraining (2-3 weeks) did not elicit any decline in performance measures (Hortobágyi et al., 1993; Kraemer et al., 2002). For instance, Hortobágyi et al. (1993) reported that power athletes were able to maintain upper (-1.7%) and lower body strength (-0.9%), and vertical jump height (1.7%) following 14 days of detraining.

Interestingly, they showed the percent and cross-sectional area of slow twitch fibres were not altered, however, fast twitch fibre area significantly decreased by -6.4%. Although cross-sectional area plays a large role in muscular strength gains, muscular atrophy of fast twitch fibres did not contribute to any significant decline in strength. The athletes under investigation had an average of eight years of extensive weightlifting experience, performing major lifts such as power snatch, clean and jerk, back squat, bench press, and shoulder press three times per week. Therefore, it may be speculated that 14 days of detraining is not sufficient to induce negative implications in athletic performance in highly trained individuals. Further, one may speculate that in these highly trained individuals this short detraining period allowed for attenuation of cumulative fatigue of training allowing the athlete to effectively express high neuromuscular demand performance measures such as strength and power.

However, discrepancy in results between these studies may be explained by the high-speed power training that athletes participated in prior to the detraining phase. Therefore, it may be suggested that athletes incorporate high-speed power training in their programs to prevent rapid declines or to maintain performance measures. Furthermore, it is important to note that the rate of diminished performance due to detraining varies according to training intensity, volume, and frequency used in the prior training program. In addition, other factors such as training age, performance level of athletes, or duration of detraining should be taken in to account when investigating retention of strength and power (Izquierdo et al., 2007; Gharahdaghi et al., 2014).

With the vast amount of competitive surfing events along with the demands of traveling and limited access to a land-based training facility, it may be challenging for surfing athletes to maintain a resistance-training program on the road. Furthermore, this is seen more with athletes at the lower levels due to their need to compete in more events to acquire the necessary points to qualify for the higher levels, and ultimately the WSL. However, it is important for surfing athletes to be aware that a loss of strength and power during the season may negatively affect their surf performance. Nonetheless, the effects of detraining on strength, power, and sensorimotor ability in

competitive surfing athletes have not been investigated and remain unclear. Therefore, study 5 investigated competitive surfing athletes responses to detraining and the magnitude of strength, power, and postural control changes. Furthermore, it is of great importance to determine whether surfing alone provides sufficient stimulus to maintain performance measures.

Overall, this review highlights the importance of a developmental pathway for competitive surfing and provided a basic understanding of sensorimotor ability. Previous studies have made significant contribution to assessing sensorimotor abilities to reduce injury or improve balance, however, there are no relevant protocols that assess sensorimotor abilities in a way where surfing athletes must regain postural control following a drop from a pre-determine height. Furthermore, little is known regard to training of sensorimotor abilities in competitive surfing athletes. In order to progress the sport of surfing and how surfing athletes responses and adapts to resistance training and detraining, testing protocols must be developed and established.

Chapter 3

Study 1: Development of a comprehensive performance testing protocol for competitive surfers

(*Int J Sport Physiol Perform*, 8:490-495, 2013)

3.1 Introduction

Surfing (wave-riding) is a mass participation sport worldwide, enjoyed by both sexes and a broad age demographic. Waves are being surfed on every continent, with 69 countries having a national federation membership of the International Surfing Association (ISA), and between 30-35 of these federations contesting ISA World Junior Championships and World Surfing Games each year, as well hundreds of elite athletes contesting the professional contests of the World Tour of the Association of Surfing Professionals.

Competitive surfing involves grouping 2-4 surfers in each 20-40 minute competitive heat, dependent on the format of the competition, and surf conditions. Competitive success is determined by judging criteria applied to the act of wave-riding only (the point the athlete moves from prone to standing on the breaking wave to the completion of the wave being ridden). The criteria examine the athlete’s ability to ride the best waves and performing complex maneuvers under control. Generally, the athlete’s highest scoring 2 waves in each heat are used to determine the heat outcome. In other words, success is judged by their ability to obtain and ride the best waves during a competition, and ride them better than their opposition. Like any tournament style competition, the successful surfers from each round of competitive heats progress through the competition until quarter-, semi-, and final rounds are completed, and placing is determined.

Surfing competition takes places under a variety of conditions that have a large effect on activity patterns such as duration of wave-riding and time spent paddling (Meir, Lowdon, and

Davie, 1991; Mendez-Villanueva and Hamer, 2006). The type of wave-break, and changing conditions such as wind, swell, and tide conditions greatly influence the nature of the surfing activity. In a competition, wave riding duration was found to be 3.8% of total time, with paddling accounting for 51.4% of time, and no activity (i.e. stationary sitting on board) representing 42.5% of total time (miscellaneous activities 2.2%) (Mendez-Villanueva and Hamer, 2006). Although the mean paddling bout in a surfing competition was found to be ~30 seconds, the majority (~60%) of these paddling bouts were only 1-20 seconds (~25% <10 seconds, ~35% 10-20 seconds), highlighting the importance of shorter bouts of intense paddling (Mendez-Villanueva and Hamer, 2006; Mendez-Villanueva and Bishop, 2005). As such, analysis of both competitive and recreational surfing suggest that surfing can be characterized as a sport requiring multiple short duration intermittent paddle efforts (Meir, Lowdon, and Davie, 1991; Mendez-Villanueva and Hamer, 2006).

Sprint paddling appears to be a key feature of competition in order to catch waves and to gain a position advantage over their competitors during a heat, as well as to ensure fast entry speed into waves to optimize position on the wave face for the execution of maneuvers that will maximize the judges' score (Mendez-Villanueva, 2005; Lovelles and Minahan, 2010; Mendez-Villanueva et al., 2005). Indeed, adult competitive surfers are superior in sprint paddling to junior competitive surfers, highlighting this physical quality as an important development consideration (Sheppard et al., 2012). When you also consider the repeated bouts and extensive nature of surfing activity (Meir, Lowdon, and Davie, 1991; Mendez-Villanueva and Hamer, 2006), endurance paddling ability is also likely to be a highly relevant physical quality (Mendez-Villanueva et al., 2005). As such assessments of both sprint and endurance paddle ability in surfers is likely an important component of a comprehensive testing protocol for competitive surfers.

Surfboard paddling is considered a closed-kinetic chain task, as the surfer ‘pulls’ their body over the water surface, as opposed to pulling the water surface toward them. Previous examinations have used stationary paddle ergometry to determine sprint and endurance paddle performance,

therefore being an open-kinetic chain task, with conflicting results in discriminating between higher and lower performing surfers (Meir et al., 1991; Loveless and Minahan, 2010; Mendez-Villanueva et al., 2005). It would seem more appropriate, and indeed more practical, to evaluate paddling ability in the water with surfers, to provide greater context validity.

Surfing a wave requires a continual and relatively rapid production and arresting of force, particularly in the lower body, to execute the maneuvers required to maximize scores under the judging criteria. Despite this, there have been no studies involving surfers that have examined strength and power measures of the lower body, despite its likely importance to performance (Mendez-Villanueva and Bishop, 2005). As such, currently there exist no established protocol for the assessment of strength and power from which to implement measures into a comprehensive protocol.

In order to advance the understanding of the physical capabilities of surfers, and to pursue further research into the responses and adaptations of these qualities with training, valid test measures must first be established. Therefore the purpose of this study was to develop and evaluate a testing protocol with practical reliability and context validity, such that the testing protocols assess physical qualities that relate to performance within the sport, including measures of anthropometry, strength and power, and sprint and endurance qualities.

3.2 Methods

3.2.1 Participants

Forty-four competitive junior surfers (16.2±1.3 years, 166.3±7.3 cm, 57.9±8.5 kg) participated in this study, which involved two groups: an Elite Junior Group of 22 international competitors (EJG) and an aged matched group of 22 domestic competitors (CJG). The EJG were both nationally and internationally competitive surfers at junior competitions (e.g. World Junior Championships), and were included in national-team programs, whilst the CJG competed in national competitions (e.g. State and National titles) but were not a part of the national program.

All subjects received a clear written and verbal explanation of the study and all risks and benefits, with written informed consent obtained by the subjects and their parent or guardian. The study procedures were approved by the Human Ethics Committee at Edith Cowan University, and procedures conformed to the Code of Ethics of the World Medical Association (Declaration of Helsinki).

3.2.2 Study Design

Following a development and refinement process, subjects were familiarised with the testing procedure and conducted practice trials. Following this, a repeated measures analysis was conducted within the same day with the subjects from the EJG, to establish reliability of the measures. To assess the validity of the testing measures to discriminate athlete ability, a comparison of performance results was then performed between the EJG and the CJG.

3.2.3 Anthropometry

Subjects were assessed for stature, body mass, and the sum of seven skin-folds. The sum of seven skin-folds was determined following measurement of the triceps, sub scapulae, biceps, supra-spinale, abdominale, thigh, and calf skin-fold using a Harpenden skinfold caliper (British Indicator, Hertfordshire, UK). A composite ratio of body-mass divided by the sum of seven skin-folds was then determined to reflect the amount of mass that is made up of lean tissue, termed the Lean Mass Index (LMI) (Sheppard et al., 2009), modified by original methods (Slater et al., 2006). All tests were conducted in accordance with the International Society for the Advancement of Kinanthropometry (ISAK) guidelines, with a practitioner whose %Typical Error of Measurement (%TEM) for skinfold measurements was 1.12-1.70%, and 0.10% for all other measures.

3.2.4 Lower-Body Strength and Power

With a light-weight wooden bar across the shoulders, subjects conducted 3-4 trials of a jump squat (JS) from a self selected depth (Sheppard et al., 2008). Subjects then performed 2 trials of a maximal isometric mid-thigh pull (IMTP), using a 130° knee angle and corresponding hip angle of

155-165°, as described in previous research (Sheppard and Chapman, 2011; Nuzzo et al., 2008; Haff et al., 1997) with the hip and knee angles determined using a hand held goniometer. If the trials differed by >250 N a third trial was performed (Kraska et al., 2009). The best trials as determined by maximum force (IMTP) and maximum jump height (JS) were retained for analysis.

All movements were conducted with the subjects standing on a commercially available force plate sampling at 600 Hz (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia). The force plate was interfaced with computer software (Ballistic Measurement System, Fitness Technology, Adelaide, Australia) that allowed for direct measurement of force-time characteristics (force plate) and then analysed using the Ballistic Measurement System software (Fitness Technology, Adelaide, Australia). Force-time data recorded from the jumps was processed using the impulse-momentum method to determine velocity and displacement data. Peak force and jump height determined as the peak in displacement were used as the representative performance measures. Prior to all data collection procedures, the force plate was calibrated using a spectrum of known loads spanning the likely measurement range (20 and 200 kg), and then assessed against three criterion masses (of 40, 100 and 200 kg).

3.2.5 Sprint and Endurance Paddling

Sprint paddle testing was conducted in an outdoor 25 m swimming pool. This allowed for easy outline of distances for the subjects, and control for the potential effect of tides and currents. Each subject used their own surfboard for the testing (the one they use in competition) to provide context validity. All subjects wore surfing boardshorts.

Before the paddling test and in addition to the general warm-up, subjects performed a progressive paddling warm-up consisting of 200 m of low-intensity paddling, followed by a specific sprint paddling warm-up of 4 x 15 m sprint paddling efforts at 60, 70, 80, and 90% volitional effort on ~two minute time intervals. After two minutes rest, the subjects then performed two maximal effort sprint-paddling time-trials (i.e. 2 x 15 m) to determine maximum sprint

paddling performance. The sprint paddle efforts were initiated from a stationary, prone lying position.

Using a purpose-built horizontal position transducer (I-REX, Southport, Australia) attached to the back of each subject's shorts, kinematic data was obtained and stored for analysis on a personal computer. The position transducer recorded a time-stamp for each 0.02 m of displacement, thereby allowing determination of sprint time from the start to 5 m, 10m, and 15 m, and by differentiation to determine peak sprint paddle velocity, a procedure that has been validated previously with surfboarding paddling in a pool (Loveless and Minahan, 2010).

The timed endurance paddle test was conducted over a 20 m up and back course in the same pool, utilizing 2 pool lane widths, so that continuous paddling to a total of 400 m could be accomplished. The paddling test was conducted with small buoy markers at both ends of the 20 m segment. As such, the subjects paddled 20 m and completed a turn at each end around the buoy, until the 400 m was completed. The subjects paddled up to and around the buoy completing a 180 degree turn whist remaining prone on their surfboard. The time to complete the endurance paddle test allowed for determination of each subjects' maximum aerobic speed, which was intended to reflect their endurance capabilities in the specific context of surfboard paddling.

3.2.6 Statistical Analyses

Reliability data was calculated by determining the Intra-Class Correlation co-efficient (ICC), Typical Error of Measurement, and Percentage Typical Error of Measurement (as co-variance, %TEM). Comparisons of the difference between higher (EJG) and lower performers (CJG) was determined by ANOVA, with Cohen's effect size (*d)* applied to determine the magnitude of any differences observed. For all means-based testing, minimum significance was considered to be achieved when $p<0.05$, with a 90% confidence interval (CI).

3.3 Results

Table 1 outlines the reliability of experimental measures used in this study.

The EJG had lower total skinfold values (p=0.005, *d*=0.9), despite no difference in stature (p=0.102, *d*=0.5) or mass (p=0.827, *d*=0.1)(Figure 1), consequently resulting in a higher LMI (p=0.001, *d*=1.1).

The EJG had a higher peak force (1802 ± 351 N) compared to the CJG (1531 ± 308 N) in the IMTP (p=0.041, *d*=0.7). In regards to peak jump height, there were no clear differences observed between the EJG (0.40 ± 0.07 m) and the CJG (0.38 ± 0.09 m) (p=0.505, *d*=0.3), or for the peak velocity (p=0.521, *d*=0.2), or peak force (p=0.787, *d*=0.1) in the jump squat (Figure 2).

EJG produced superior sprint paddle times to 5 (p=0.000, *d*=1.4), 10 (p=0.000, *d*=1.3), and 15 m (p=0.000, *d*=1.2), and a higher sprint paddle velocity (p=0.000, *d*=1.3), which was achieved between the 5-14 m interval. The EJG also had a lower endurance paddle time (p=0.008, *d*=0.9), and consequently a higher endurance paddling velocity (p=0.000, *d*=0.9) (Table 2).

Table 3.1: Reliability (90% Confidence Intervals) of Measures on the Tests in Elite Junior Competitive Surfers

Measure	Intraclass Correlation	Typical Error of Measurement (TEM)	%TEM
Jump Squat			
Height (m)	0.98 (.094-0.99)	0.01 m (0.01-0.02)	2.67% (2.00-4.30)
Peak Force (N)	0.97 (0.91-0.99)	37.3 N (27.3-58.8)	2.99% (2.20-4.80)
Isometric midthigh-pull peak force (N)	0.99 (0.97-0.99)	42.5 N (32.9-60.1)	2.25% (1.80-3.20)
15 m sprint paddle (s)	0.97 (0.93-0.99	0.11 s (0.09-0.16)	1.13% (0.90-1.60)

Table 3.2: Mean (±SD) Sprint- and Endurance-Paddle Results Comparing an Elite Junior Group (EJG, n: 22) and an Age-Matched Group of Competitive Junior surfers (n = 22).

Measure	Elite Junior Group	Competitive Junior Group	*P*	Effect Size
Sprint Paddle				
5 m (s)	3.96 ± 0.30	4.35 ± 0.25	p=0.000	1.4
10 m (s)	7.08 ± 0.49	7.69 ± 0.44	p=0.000	1.3
15 m (s)	10.23 ± 0.68	11.04 ± 0.63	p=0.000	1.2
Peak Velocity (m/s)	1.66 ± 0.11	1.53 ± 0.09	p=0.000	1.3
400-m endurance-paddle time (s)	324 ± 25	360 ± 18	p=0.008	0.9
Endurance Velocity (m/s)	1.17 ± 0.08	1.11 ± 0.05	P=0.006	0.9

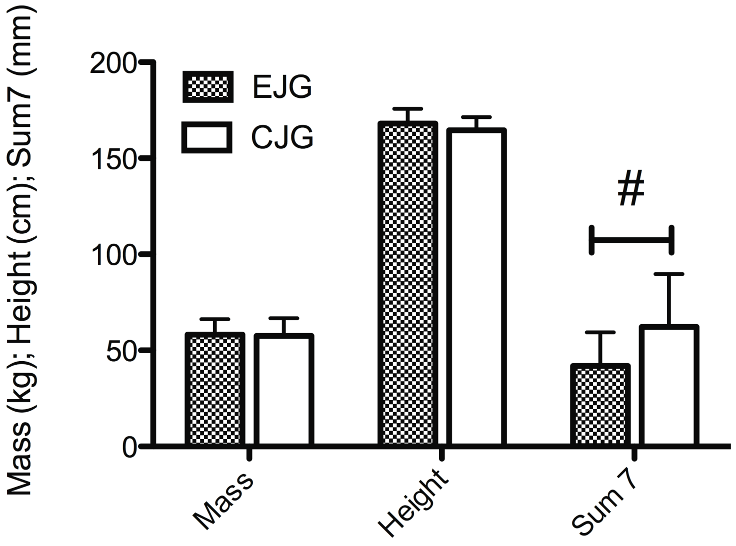


Figure 3.1: The mean (±SD) mass (kg), height (cm), and sum of 7 site skinfolds (mm) of an Elite Junior Group (EJG, n: 22) and an aged-matched group of Competitive Junior surfers (CJG, n: 22). #Indicates significant difference (p=0.005).

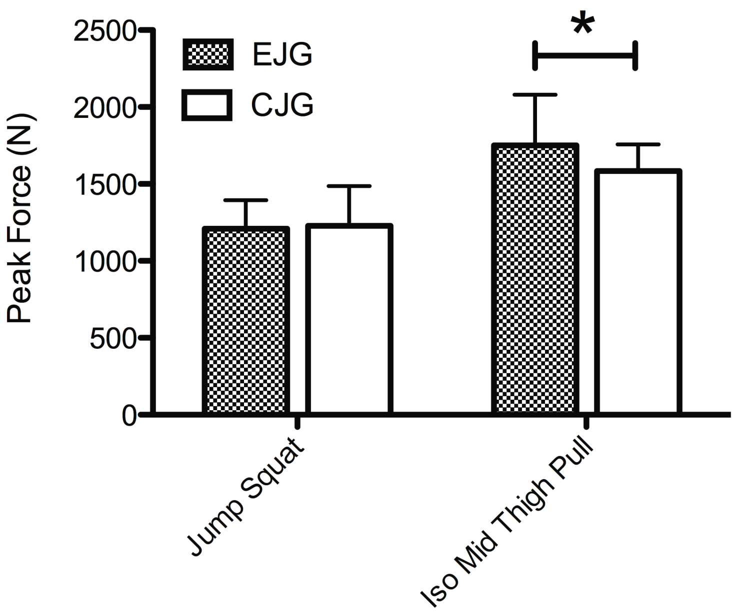


Figure 3.2: The mean (±SD) peak force (N) of a body-weight Jump Squat (JS) and Isometric Mid-thigh Pull (IMTP) of an Elite Junior Group (EJG, n: 22) and an aged-matched group of Competitive Junior surfers (CJG, n: 22). * Indicates significant difference (p=0.04).

3.4 Discussion

To advance sport science knowledge of the physical capabilities of competitive surfers, and to advance further research into the responses and adaptations of these qualities, valid test measures must first be established for use with this population. The first purpose of this study was to develop and evaluate a testing protocol that demonstrated practical reliability such that the practitioner can be confident that small training induced changes can be detected by the tests, and not attributed to biological and measurement noise. The second purpose was to evaluate the protocol for its ability to discriminate between competitive levels, thereby reflecting the validity of the measurements.

The relatively low TEM values for the variables obtained in this study demonstrate considerable practical use for the coach and sport-scientist, as a high TEM makes interpreting small changes in performance difficult, as unless the change measured is larger than the TEM, the practitioner cannot be confident that the change is due to training or de-training, or simply due to measurement and biological noise associated with the testing protocol. Previously, favorable reliability has been found with a 10 s paddling time trial with surfers (Loveless and Minahan, 2010), and we have previously found high reliability using the JS and IMTP protocols in other sports (Sheppard et al., 2008; Sheppard and Chapman, 2011). However, this is the first study to comprehensively evaluate the repeatability of measures usable in an entire suite of tests to evaluate the physical qualities of surfers. The low TEM observed across the entire protocol indicates that comparably small magnitudes of change can be detected in the test scores, likely providing a sensitive protocol for the practitioner working with surfing athletes.

Although the EJG and the CJG did not differ in terms of stature or mass, the EJG had lower total skinfold sum, and a higher LMI (Figure 1), as well as superior lower-body maximal strength (Figure 2). Surprisingly, the importance of low fat mass in surfers has not been previously supported by empirical evidence (Barlow et al., 2012).Lower fat mass and greater strength would seem a logical advantage in a sport such as surfing, where the act of wave-riding involves a sequence of force production and absorption to complete whole-body maneuvers, thereby making

physical capabilities relative to body-mass of high importance. This has been found in numerous other contexts (Sheppard et al., 2009; Gore, 2000) and speculated upon previously in regards to competitive surfing (Mendez-Villanueva and Bishop, 2005). Although our previous work identified superior upper-body strength relative to body-mass in senior competitive surfers compared to junior surfers, this was easily accounted for by maturation (Sheppard et al., 2012). Our current findings are novel as the subjects in this study were age-matched, and so the differences observed offer strong support for the importance of strength in higher performing surfers. These results suggest that maximum strength is an important aspect of physical preparation for surfers. It could be speculated that traditional strength exercises (pull-ups, squats, presses, and Olympic lifts) have an important role to play in the physical preparation of surfers, but generally and as yet, this is not a common training practice of the majority of elite competitors.

A 10 s sprint paddle assessment has previously been demonstrated to offer a reliable method to evaluate paddling ability in surfers (Loveless and Minahan, 2010), and sprint paddling ability has been shown to be a relevant quality to assess in competitive surfers (Sheppard et al., 2012). The results of this study demonstrate the relatively large difference in peak sprint paddling velocity (d=1.3) between the higher performing EJG compared to the CJG, further highlighting the importance of sprint paddling ability. Considering that competitive heats comprise many relatively short duration paddling bouts, interspersed by some inactive periods (sitting on the surfboard) (Mendez-Villanueva, Bishop, and Hamer, 2006), it stands to reason that sprint paddling ability is a critical consideration for performance in obtaining and to maintain positional dominance in the water during a heat over fellow competitors. Furthermore, well developed sprint paddling ability is an important component of achieving early and efficient entry, and a high entry speed into waves, so that the competitor can initiate their first combination of maneuvers (e.g. bottom turn and re-entry) as soon as possible, to maximize the scoring potential of the wave.

The ability of lab based endurance paddling ergometer assessments to discriminate between higher and lower performing surfers has not been well established, with some studies suggesting

that superior aerobic qualities can be determined with paddling ergometers (Mendez-Villanueva et al., 2005), whilst other studies have not been able to detect maximal aerobic differences between groups (Loveless and Minahan, 2010). The present research is novel in that the endurance paddle time trial was performed in the water, in a closed-kinetic chain environment, and clearly delineates capacity between higher and lower performers (Table 2). Based on the present findings, if practitioners are examining paddling endurance in surfers, a paddling time trial may be most effective to achieve context validity. Furthermore, the time trial can be used for decision-making training needs, as the velocity achieved in the sprint paddle can be directly compared to that of the endurance paddle time trial (a ratio of sprint paddle to endurance paddle velocity), to assert the relative performance of each quality (and thereby set training priorities). Further research and analysis should include a cross-sectional analysis of the sprint and endurance paddling velocities of a range of competitors at varying levels, to assist with creating guidelines that may help practitioners determine training emphasis needs on sprint paddling and endurance paddling ability.

There are several limitations to this current data set that require future research focus. Due to the exhausting nature of the 400 m endurance paddle time trial, we were unable to obtain reliability data from this population for the endurance assessment. Despite the large differences observed between groups (Table 2), this current limitation prevents us from calculating reliability statistics that allow for a determination of the smallest worthwhile change.

In addition, although the low TEM, and indeed the large differences observed between performance groups, suggests that the tests involved in this protocol will be sensitive to detect training induced changes, this has not been assessed specifically in this study. To evaluate this, future research should assess the ability of the testing protocol to detect potential training and de-training effects in the endurance qualities of surfers.

3.5 Practical Applications

Appropriate and valid testing protocols evaluating the physical performances of surfing athletes has not been well refined. This project developed and evaluated a comprehensive sport-science testing protocol for use with surfers, including measures of anthropometry, lower-body strength and power, and sprint and endurance ability. The outcomes from this study resulted in the creation of a national sport-science testing protocol for competitive surfers, that can be adopted wholly, or in part, or expanded upon, by other training programs and for use with future research.

Higher performing competitive junior surfers are leaner, stronger, and have superior sprint and endurance paddling ability in comparison to lower performing competitive surfers. As such, practitioners can place an emphasis on developing these capabilities, and utilize assessments of anthropometry, strength and power, and sprint and endurance paddling ability to evaluate the physical qualities of competitive surfers.

Chapter 4

Study 2: Comparison of physical capacities between non-selected and selected elite male competitive surfers for the national junior team

(*Int J Sports Physiol Perform*, 10:178-182, 2015)

4.1 Introduction

The level of competition in surfing has increased exponentially over the last decade. Surf coaches and surfers are beginning to realise the importance of physical preparation in enhancing performance to perform high-risk manoeuvres, as well as tolerate the physical demands of participation. For instance, surfing is performed in a dynamic environment with challenging conditions and situations (Mendez-Villanueva and Bishop 2005), therefore the surfing athletes must adapt to the conditions and situations all while maintaining a high level of performance (Eurich et al., 2010). In other words, high levels of strength, power, endurance power, dynamic postural control, and the ability to respond to the challenging situations during competition or free surfing are important for the sport of surfing (Mendez-Villanueva and Bishop 2005). Having these qualities will assist the surfing athletes to paddle past the breaking point, sprint paddle to catch a wave followed by an explosive pop-up (transition from a prone position to standing) on the surfboard, and then perform radical manoeuvres such as bottom turns, top turns, and re-entries, or land from aerials. And so, whole-body strength and power characteristics are likely important parameters that are needed to produce and attenuate force during high-risk manoeuvres and landings.

Previous research has shown that 44-54% of surfing activity is devoted to paddling (Farley et al., 2012a; Meir, Lowdon, and Davie, 1991; Mendez-Villanueva, Bishop, and Hamer, 2006), and paddling performance has been shown to highlight performance differences in surfing populations (Mendez-Villanueva et al., 2005; Farley et al., 2012). While wave riding only represents 3.8-8% (Farley et al., 2012a; Meir, Lowdon, andDavie, 1991; Mendez-Villanueva, Bishop, and Hamer, 2006) of time spent in a surfing competition, surfers are awarded points for their ability to perform high-risk manoeuvres such as turns, aerials, barrels and floaters under control in the most critical parts of the wave (ISA, 2012). Although paddling is a major physical requirement to perform in the sport, the surfer is judged only on the wave riding itself. This is not to say the coaches or athletes should dismiss on the relevance of monitoring or improving the physical quality of sprint paddling. Having the physicality to out paddle your opposition will give the surfing athlete the advantage to sit deeper on the peak, control the line up, first choice of wave section, and the ability for faster entry speed (Sheppard et al., 2013), thus increasing the opportunity to maximizing judging criteria.

Surfing is an individual sport, however every year national federations select their best junior surfers to represent their country and compete with the most promising elite junior surfers at the International Surfing Association (ISA) World Junior Surfing Championship. Each year, 16 young elite competitive male surfers are selected to attend an Australian Team Selection Camp (SC) and compete against each other to earn one of eight spots to represent the Australian Team at the ISA World Junior Surfing Championship. Of the 16 elite competitive surfers, eight compete in the under 18 (U18) age group and the remainder in the under 16 (U16) age group (vying for 4 spots in each age category). The selection criteria are based on surfing performance during the SC and previous competition results for making the Surfing Australia National Junior Surfing Team, as evaluated by a panel of national coaches.

Surfing can be considered a ‘skill-based’ sport. As such, when applying fundamental tests of physical performance, it is important to justify the inclusion of each test, particularly if they may be considered to partly influence selection, talent identification, and performance improvement.

Although recent studies have shown differences between competitive and recreational surfers' physical capacities (Barlow et al., 2012; Loveless and Minahan, 2010), there are no studies to our knowledge that distinguish physical capacities between closely matched groups of elite surfers'. Therefore, the purpose of this study was to determine whether tests of physical performance reflect selection for international competition from a pool of elite competitive junior surfers.

4.2 Methods

4.2.1 Participants

Thirty-two Australian elite competitive male junior surfers from 2012 (Under 18: n=8, Under 16: n=8) and 2013 (Under 18: n=8, and Under 16: n=8, table 1) SC participated in this study. A summary of the athletes' characteristics are presented in Table 1. Elite junior surfers are defined as competitive surfers who have competed in the Australian Nationals or World Junior Championships (Sheppard et al., 2013). Data collection was part of the athletes' participation in the SC and all testing and data management was conducted according to the Declaration of Helsinki and approved by the institutional human ethics committee.

4.2.2 Study Design

The present study required the participants to complete one testing session consisting of anthropometric (stature, body mass, and sum of 7 skinfolds), muscular power (vertical jump), lower body strength (isometric mid-thigh pull), 15 m sprint paddle, and 400 m endurance paddle measurements. Data from the SC 2012 and 2013 were combined for comparison between the athletes who were selected for the ISA Junior World Championships (Selected Group, S), and the Non-Selected Group (NS).

The testing procedures began with anthropometry, followed by a standardized dynamic warm-up, and following this, the four performance tests. Participants were measured for body mass, stature, and sum of 7 skinfolds (Sum7: triceps, biceps, subscapulae, supraspinale, abdominal,

quadriceps, and calf) via a Harpenden skinfold calliper (British Indicator, United Kingdom). Body mass was measured on a scale with resolution to the nearest 0.1 kg with the participant barefoot and wearing board shorts only. Stature was measured on a stadiometer to the nearest 0.5 cm with the participant barefoot, feet together, and head level. A single researcher certified by the International Society for the Advancement of Kinanthropometry (ISAK), in accordance with the ISAK guidelines, performed all skinfold measures. Lean body mass ratio was then calculated by dividing body mass by the sum of 7 skinfolds (Sheppard et al., 2013).

4.2.3 Countermovement Jump

The CMJ was used to assess lower body dynamic strength. Athletes were instructed to complete three trials dipping to a self-selected depth while maintaining a light wooden dowel in contact with the back of the shoulders and then jumping vertically for maximum height (Amonette et al., 2012). During each jump, if the wooden dowel lost contact with the shoulders, then the jump was discarded and repeated. Sixty seconds of rest was provided between jumps. Athletes were encouraged to jump as high as possible and the best jump height was used for further analysis. The athletes were instructed to start in an upright position while standing still on a portable force plate (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia), which utilized a built in amplifier and four load cells that measures vertical components for ground reaction force. Prior to data collection, calibration of the force plate was performed as per manufacturer's instructions. The force data was collected at sampling frequency of 600 Hz and inverse dynamics calculations were used to calculate displacement, velocity and acceleration data as per manufacturer software previously used in this population (Sheppard et al., 2013) (Ballistic Measurement System, Innervations, Perth, Australia). Data was filtered using a 4th order Butterworth filter with cutoff frequencies set at 16 and 10 Hz, for velocity, and acceleration data respectively was applied. Displacement and force were not filtered.

4.2.4 *Maximum Isometric Strength*

Maximum isometric strength was measured on a customized mid-thigh pull system with adjustable straps to accommodate individual height differences. Athletes completed three isometric mid-thigh pulls with two minutes rest between pulls. Prior to the initial pull, the athletes stood still on the force plate with the shoulders in line with the bar and hands slightly wider than shoulder width apart. The athletes were placed in a position similar to the second pull of the power clean and snatch, which have been reported to maximize force and power production (Garhammer, 1993). In other words, the position of the bar was relative to the mid thigh for each athlete. Athletes were instructed and verbally encouraged to push against the force plate as hard as possible (Haff et al., 1997) while holding the bar across their mid-thigh with maximal effort for five seconds. The same force plate, personal computer and software was used to measure vertical jump performance recorded and analysed the vertical ground reaction force and to derive peak force and force-time characteristics.

4.2.5 15 m Sprint Paddle

The 15 m sprint paddle test previously described by Sheppard et al. (2013, 2016) was performed in an outdoor 25 m swimming pool reserved specifically for paddle testing, which has been reported to have 1.13% typical error of measurement (Sheppard et al., 2013). This testing environment enabled the researchers to control and avoid variable environment factors such as wind and wave currents. Athletes performed the paddle test with their competition surfboard due to individual differences in stature and body mass. Prior to testing, the athletes performed a 200 m warm up paddle at an easy pace followed by a specific sprint paddle of 4x15 m (60, 70, 80, and 90 % of one's own deliberate effort) separated by two minutes of rest between sprint paddle trials. A rest period of 3-4 minutes was allowed before performing 2 x15 m maximum sprint paddle trials with two minutes of rest between each sprint. The athletes started in a stationary prone position on their surfboard with a horizontal position transducer (I-REX, Southport, Australia) attached to the rear waistline of their shorts to measure sprint paddle split time and velocity. The position

transducer recorded a time-stamp for each 0.02 m of displacement, thereby allowing determination of sprint time from the start to 5, 10, and 15 m, and by differentiation to determine peak sprint paddle velocity (Sheppard et al., 2012).

4.2.6 400 m Endurance Paddle

After 10 minutes of recovery, the athletes performed the 400 m endurance paddle test (Sheppard el al., 2013, Sheppard et al., 2012). Athletes were in a stationary prone position on their surfboard and started on a "ready, set, go" command. The athletes were instructed to paddle around two weighted buoys positioned 20 m apart and completing a total of 10 laps. Endurance average velocity was determined from the time to complete the endurance paddle test (Sheppard et al., 2013).

4.2.7 Statistical Analyses

To determine if there were any significant differences between the groups of selected and non-selected athletes, all statistical analyses were analysed using magnitude-based inferences (Hopkins, 2003). Magnitude-based inferences scale was applied as positive, trivial or negative based on the likelihoods that the true (population) values of the differences represented substantial change. The likelihoods that the true (population) differences were substantial were assessed using 0.2 standardised units (change in mean divided by the between subject SD) and expressed as both percentages and qualitatively, using practical inferences with the certainty of difference classified as: 50-74%, possibly; 75-95%, likely; 95-99%, very likely; >99% almost certainly (Humberstone-Gough et al., 2013). Furthermore, the effect was considered "trivial" if the confidence interval overlapped the true (population) values for both positive and negative change. Magnitude-based inferences scale approach has been suggested for practical importance to detect small effects in elite athletes (Hopkins et al., 2009). In addition, Independent t-tests with (± 90% confidence limits (CL) and alpha $P \leq 0.05$) were used to compare anthropometry and performance test results. Cohen's *(d)* effect sizes (ES) was calculated as ES=mean change divided by the standard deviation of the

sample scores (Cohen, 1988). The magnitudes of the ES's were considered: trivial < 0.2; small 0.2-0.5; moderate 0.5-0.8; large > 0.8 (Cohen, 1988).

4.3 Results

4.3.1 Performance Measurements

There were no significant differences between groups for age, stature, body mass, or sum of 7-skinfolds, but there was a significant difference in lean mass ratio between both groups. Paddling performance variables showed significant, highly probable, and large differences between the groups (P=0.01-0.03, 95-98%, *d*=0.8-0.9,) for time to 5, 10, and 15 m sprint paddle, and peak velocity in sprint paddling. Significant, highly probable, and moderate differences were observed for 400 m time (P=0.04, 93%, *d*=0.7) and endurance paddling velocity (P=0.05, 92%, *d*=0.7)(Table 4.2).

When normalised to body-mass, the selected athletes relative vertical jump peak force was significantly greater (P=0.01, 98%, *d*=0.9) in comparison to the non-selected athletes. Although there was no significant difference between the two groups for vertical jump peak velocity (P=0.06), the selected athletes demonstrated significantly greater vertical jump height compared to the non-selected athletes, with high probability and a large magnitude of difference (P=0.01, 98%, *d*=0.9)(Table 4.3). With respect to strength, there was no significant difference found between the two groups for absolute isometric strength, however, when normalised to body-mass, relative isometric strength was significantly greater for the selected athletes, with high probability and a moderate magnitude (P=0.05, 92%, *d*=0.7) (Table 4.3).

Table 4.1. Physical characteristics mean (± SD) between selected and non-selected elite competitive junior surfers.

Descriptive	Selected	Non-selected	P value	Effect size *(d)*	Magnitude Inference
Age (yr)	16.18 ±1.26	16.13 ±1.02	0.91	0.0	42% possibly, may (not)
Mass (kg)	62.36 ± 7.40	61.46 ± 10.10	0.78	0.1	40% possibly, may (not)
Stature (cm)	173.41 ± 5.35	170.57 ± 6.60	0.19	0.5	77% likely, probable
Sum7 (mm)	41.74 ± 10.83	49.25 ± 13.04	0.09	0.6	88% likely, probable
Ratio	1.56 ± 0.34[a]	1.31 ± 0.31	0.04	0.7	94% likely, probable

[a]Significantly different to non-selected athletes ($p \leq 0.05$)

Table 4.2. Sprint and endurance paddle performance mean (± SD)

Measure	Selected	Non-selected	P value	Effect size *(d)*	Magnitude Inference
Sprint Paddle					
5 m (s)	3.67 ± 0.15[a]	3.86 ± 0.23	0.01	0.9	98% very likely
10 m (s)	6.56 ± 0.23[a]	6.88 ± 0.40	0.01	0.9	98% very likely
15 m (s)	9.49 ± 0.35[a]	9.93 ± 0.60	0.02	0.8	97% very likely
Peak Velocity ($m \cdot s^{-1}$)	1.78 ± 0.08[a]	1.71 ± 0.10	0.03	0.8	95% very likely
Endurance Paddle					
400 m (s)	320.63 ± 13.21[a]	332.94 ± 18.89	0.04	0.7	93% likely, probable
Endurance Velocity ($m \cdot s^{-1}$)	1.25 ± .05[a]	1.21 ± .07	0.05	0.7	92% likely, probable

[a]Significant difference to non-selected athletes ($p \leq 0.05$)

Table 4.3. Mean (± SD) relative vertical jump peak force (rVJPF), vertical jump peak velocity (VJPV), vertical jump height (VJH), isometric mid-thigh pull (IMTP), and relative isometric mid-thigh pull peak force (rIMTP).

Measure	Selected	Non-selected	P value	Effect size *(d)*	Magnitude Inference
rVJPF ($N \cdot kg^{-1}$)	21.90 ± 1.59[a]	20.45 ± 1.40	0.01	0.9	98% very likely
VJPV ($m \cdot s^{-1}$)	2.67 ± 0.22	2.49 ± 0.30	0.06	0.7	91% likely, probable
VJH (m)	0.49 ± 0.05[a]	0.42 ± 0.07	0.01	0.9	98% very likely
IMTP (N)	2063.5 ± 267.5	1902.19 ± 381.13	0.18	0.5	79% likely, probable
rIMTP ($N \cdot kg^{-1}$)	33.18 ± 3.13[a]	30.91 ± 3.17	0.05	0.7	92% likely, probable

[a]Significantly different to non-selected athletes ($p \leq 0.05$)

4.4 Discussion

The aim of this study was to determine whether physical performance characteristics of elite junior competitive surfers selected to represent the Australian Team at the ISA World Championship clearly demonstrated compelling evidence from non-selected athletes. The results demonstrated that there are significant differences between the groups for lower body relative strength, dynamic strength, sprint paddling ability, and endurance paddling. Furthermore, this study provides reference values of anthropometric and physical characteristics of elite competitive junior male surfers. This information provides insight to the surf community about the importance of incorporating strength and conditioning programs entailing lower body dynamic strength development, muscular strength, sprint paddle, and endurance paddle in conjunction to surf training. Additionally, this information can be used for talent identification for coaches working with surfing athletes, particularly with reference to the physical performance attributes of elite junior male surfers.

Although various physical characteristics such as age, mass, stature, and sum7 were not statistically different between the selected and non-selected athletes, the selected athletes demonstrated greater performance outcome in these tasks. For example, the selected athletes had a lower average sum of 7-skinfold measures compared to the non-selected athletes (Table 4.1). Given that this study involved elite athletes and by its very nature participant numbers are low, even borderline significant outcomes should be considered in a view not to overlook where marginal gains can be made. Therefore, with some latitude applied with regard to statistical significance and the relatively low power in this study, based on the effects size magnitude observed, it is clear that the selected athletes were leaner with significantly higher lean mass ratio. This finding is consistent with our previous study (Sheppard et al., 2013) reporting no significant differences for stature ($P=0.102$, $d=0.5$) or body mass ($P=0.827$, $d=0.1$) between elite junior and competitive junior surfers; however the elite group had lower skinfolds ($P=0.005$, $d=0.9$) with higher lean mass ratio ($p=0.001$, $d=1.1$). Lower skinfolds and higher lean mass ratio have been previously reported by

other groups to be positively correlated to surfing ability (Barlow et al., 2012). In addition, having lower skinfold sum and higher lean mass ratio will be advantageous for performance of upper body strength exercises such as pull-ups, which is an important closed chain exercise for surfers as it is similar to the paddle phase (Sheppard et al., 2013).

Sheppard et al. (2012) investigated 10 male competitive surfers and demonstrated a strong correlation between relative pull-up strength and time to 5, 10, and 15 m sprint paddle and sprint paddle velocity (r=0.94, 0.93, 0.88, 0.66 respectively). Recently, Sheppard et al. (2013) demonstrated elite male competitive junior surfers were significantly faster to 5, 10, 15 m and sprint paddle velocity compared to non-elite male competitive junior surfers. The present study further establishes the sprint paddle test as a performance discriminator, as the athletes in this group were a closely matched group of elite surfers, thereby making any observed difference in a physical quality all the more compelling. That the sprint paddle is a major performance factor stands to reason; a surfer that has a faster sprint paddle time compared to his or her opposition will be at an advantage in any form of paddle situation, both in two and four-person competitive heats (Sheppard et al., 2013). The surfer with more powerful paddle strokes will have the choice of sitting deeper on the peak, as due to their paddling ability, can catch waves in the steeper section of the wave. Tactically, this allows them to be on the inside, and have first choice at which wave he or she chooses to ride, hence controlling the line up (Sheppard et al., 2013). In addition, by sitting deeper the surfer is able to take off either on the peak or behind the peak allowing for their first turn to be in the most critical part of the wave, which is judged upon according to established criteria in the sport (ISA, 2012). Furthermore, faster sprint paddling allows for a greater entry speed as the surfer first rises to their feet, allowing them to generate more speed sooner in the ride, making it easier for them to execute maneuvers in the most critical section of the wave, thus maximizing judging criteria (ISA, 2012).

Additionally, the selected athletes demonstrated significantly faster 400 m endurance time and endurance average velocity paddling (Table 4.2), which is in line with previously published research showing that elite juniors are significantly faster than a less competitive junior group

(Sheppard et al., 2013). Although these findings highlight the importance of aerobic capacity for surfing, Farley et al. (2012b) reported there was no correlation (r= -0.02, p=0.97) between peak oxygen uptake and seasonal rank during an aerobic paddle test using a modified ergometer on dry land. In spite of the fact that time-motion analyses during an hour of surfing reported 44-54% devoted to paddling (Farley et al., 2012; Meir et al., 1991; Mendez-Villanueva, Bishop, andHamer, 2006), surfing is judged on wave riding. It may be that having greater aerobic capabilities will benefit surfers, as this would improve one's ability to withstand the demands of the paddling and delay the onset of fatigue. However, it may be that 'in-water' time trials, rather than dry-land ergometer methods, are required to elucidate truly relevant performance differences in paddling for surfers. However, it is important to note that surfing is likely best described as requiring intermittent paddling bouts (Farley et al., 2012; Meir et al., 1991; Mendez-Villanueva, Bishop, and Hamer, 2006), and that although an endurance-based time trial as we have performed in the present study is clearly relevant to this population, a repeated effort style test that incorporates multiple, intensive paddling bouts may be considered even more applicable.

The present study highlights the importance of lower body dynamic strength for surfing, since the selected athletes demonstrated significantly greater jump height during CMJ in comparison to the non-selected athletes (Table 4.3). Although a vertical jump may not immediately appear specific to surfing, surfers do perform an absorption, braking, and propulsion phase when executing maneuvers. For example in the bottom turn, the surfer compresses their body and holds the bottom position, then throws the arms forward and up as they maneuver the surfboard back to the lip of the wave. They then repeat this series for most maneuver types such as bottom turn to carve combinations on the face of the wave. In other words, high-level surfing is a series of compression and extension movements where the surfer produces and arrests force through the riding of a wave. Although jumping may not appear entirely similar, the fundamental neuromuscular action is likely relevant. Furthermore, with the increase in the execution of aerial surfing (Lundgren et al., 2014), it stands to reason that the ability to have greater lower body

explosive power will enable surfers to launch themselves off the lip of the wave to gain greater height during an aerial.

An interesting finding was that there was no significant difference between the groups for lower body absolute strength (P=0.10, *d*=0.61), particularly considering that maximal strength underpins power (Sheppard et al., 2009; Nimphius, McGuigan, and Newton, 2010), and such compelling differences were observed between the S and NS groups in the lower body dynamic strength test. However, the selected athletes did demonstrate significantly greater relative strength, and this difference was practically meaningful when the magnitude was considered in light of our TEM data from a similar population (Sheppard et al., 2013), and considering that the difference was of a moderate effect. Given that previous findings have demonstrated compelling differences between sub-elite and elite groups on maximal lower body strength (Garhammer, 1993), the authors suggest considering lower body strength measures relative to body mass as being most insightful within a population of surfers. It is important to note, the nature of surfing requires the athlete to transfer their body mass across the wave while performing high-risk maneuvers, thus requiring a certain amount of relative lower body strength in combination with skill and dynamic postural stability.

The present study was limited to tests of anthropometry, paddling ability, power, and strength. Although our findings support the relevance of these tests of physical capability, surfing is a dynamic sport requiring high levels of sensorimotor ability. Future research efforts should investigate the importance of dynamic postural control and sensorimotor ability among surfers, as this measure might also discriminate amongst skill levels of surfers, thereby allowing for talent identification and to detect favorable training induced changes.

4.5 Practical Implications

This study provides reference values of anthropometry, lower body power and strength, and sprint and endurance paddling ability for selected and non-selected elite junior surfers. These results, using a pool of elite junior surfers, distinguished differences in physical performance

between the higher and lower level even among this very homogenous group of surfers. As such, these measures can be used as performance tests within the sport. Furthermore, it is recommended that competitive surfers incorporate strength-power and conditioning training in conjunction to surf training, as these qualities clearly have an association with superior surfing performance.

4.6 Conclusions

The purpose of this study was to measure and compare anthropometry characteristics and physical performance between selected and non-selected elite junior male competitive surfers. While only borderline significant, the selected athletes were leaner with significantly higher lean mass ratio compared to the non-selected athletes. Furthermore, the selected athletes demonstrated significantly greater relative vertical jump peak force, vertical jump height, relative lower body maximum isometric strength, time to 5, 10, and 15 m sprint paddle, peak velocity sprint paddle, time to 400 m and endurance average velocity paddling.

Chapter 5

Study 3: The development and evaluation of a drop and stick method to assess landing skills in various levels of competitive surfers

(*Int J Sports Physiol Perform*, 10:396-400, 2015)

5.1 Introduction

The ability to attenuate landing force and regain postural control as quickly as possible upon landing, before transitioning to the next manoeuvre, is of great importance for the sport of surfing. This is due to the increasing complexity of manoeuvres performed in competitive surfing (Lundgren et al., 2014). As a result of these complex manoeuvres, an important element of surfing is dynamic postural control upon landing and rapid compression, which occurs during manoeuvres such as bottom turns, re-entries, aerials, and floaters. However, no known research to date has investigated these qualities in surfing athletes. Previously suggested variables to assess dynamic postural control are time to stabilisation (TTS) and relative peak landing force (rPLF), which may be important for surfing athletes, in relevant landing tasks (Wikstrom et al., 2005). Dynamic postural control involves a combination of the sensory, motor, and central integration to process information and produce appropriate neural responses to control posture and joint stability (Lephart, Riemann, and Fu, 2000; Cardinale, Newton, and Nosaka, 2011). Recently, Paillard et al. (2011) reported that more skilled surfing athletes possess greater postural control compared to less-skilled surfing athletes, however, Chapman et al. (2008) found no difference between skilled and less-skilled surfing athletes. Both studies had their participants perform the required tasks either eyes

open or closed. The difference was Paillard had their participants perform the tasks on an unstable seesaw device, whereas, Chapman had their participants stand as still as possible on a balance platform while performing the tasks. Furthermore, the tasks used in both studies may not be ideal in recreating athletic activities, as standing still may not challenge the neuromuscular system (Colby et al., 1999). It is worth noting that different methods of assessing dynamic postural control have an effect on the current findings in the literature, therefore, indicating that dynamic postural control needs further investigation as the literature confounds the ability to draw clear conclusions.

Wikstrom et al. (2005) investigated the reliability and precision of TTS using a force plate to assess dynamic postural control, reporting fair reliability for TTS in the vertical direction. In another study, Flanagan et al. (2008) reported poor reliability for TTS landing following depth jumps from 0.3 m. Although these studies did not show promising results for the TTS variable, it is important to note that these studies used a complex protocol to quantify postural control. A more simple design would be to use a drop and stick (DS) test, where the athlete start by standing on top of a standardised box height, then take a forward step off the box and land softly with both legs. Furthermore, using a DS test is more relevant for surfers to assess postural control ability in such a manner where control must be regained after the drop. Collectively, these studies provided significant contribution to the postural control literature; however, different protocols will vary the results of the postural control assessment, and need to be modified depending on the age or level of the athletes for which it is developed. An alternative method to quantify postural control ability and landing force may be to implement a reference scale. Adopting a reference scale as part of a surfing development curriculum may ensure that surfers are on path to effective development throughout their junior to senior elite level of competitions. In addition, a reference scale may assist surf coaches determine whether the surfer is physical ready and earn the rights for higher demand training, considering surfing criteria requires surfers to perform more radical manoeuvres to maximize scoring criteria. Performing aerials are high-risk manoeuvres that maximises scoring

when the manoeuvre is completed successfully. However, surfers with a low physical level may expose themselves to higher risk of injury when landing this high-risk manoeuvre.

According to Seegmiller and McCaw (2003), exposure to repetitive high eccentric load landings, is one of the contributing factors to injury in the lower extremity. Therefore, the ability of the surfing athlete to repeatedly land in a stable and controlled posture with low impact force is critical to spare the joints and potentially reduce the likelihood of an injury to the lower extremity. While previous studies have used ground reaction force measurements to assess force production during the concentric phase of the vertical jump, TTS using the ground reaction force during the landing phase has been recently used to quantify dynamic postural control among various populations (Wikstrom et al., 2005; Ebben et al., 2010; Flanagan, Ebben, and Jensen, 2008; Goldie, Bach, and Evans, 1989; Webster and Gribble, 2010). The TTS method using the drop and stick test measures the ability of an athlete to transition from a dynamic movement in a controlled environment to land and remain motionless as quickly as possible. Furthermore, rPLF may quantify how effectively various levels of surfing athletes use different landing techniques to attenuate eccentric load rather than allowing the force to transmit directly through the joints. For instance, it may be suggested that a surfer with the ability to efficiently attenuate the impact force in a landing, and rapidly regain a stable position will be able to quickly transition to the next manoeuvre following a landing from an aerial manoeuvre, or floater during wave riding. Time to stabilisation and rPLF in a DS landing are likely important variables for a surfing athlete. Currently, there is no published research on a standardised postural control assessment such as a DS off a standardised box or reference scale to assess TTS or rPLF in various levels of competitive surfing athletes. Therefore, the purpose of this study was to provide information on the measures of a DS assessment regarding TTS and rPLF. In addition, the results of this investigation might allow us to differentiate between various competitive levels of postural control.

5.2 Methods

5.2.1 Participants

Nine competitive senior elite (SE) male (n=7) and female (n=2), 22 junior elite (JE) male (n=15) and female (n=7), and 17 junior development (JD) male (n=11) and female (n=6) competitive surfers with an overall mean age, mass and stature (mean ± SD for SE: 24.5 ± 3.8 y, 75.1 ± 9.2 kg, 175.0 ± 9.0 cm; JE: 16.1 ± 1.0 y, 61.9 ± 6.7 kg, 171.0 ± 5.5 cm; and JD: 14.7 ± 1.4 y, 56.3 ± 10.6 kg, 167.0 ± 9.5 cm) participated in this study. Body mass (BM) was measured on a scale with resolution to the nearest 0.1 kg with the participant barefoot. Stature was measured on a stadiometer to the nearest 0.5 cm with the participant barefoot, feet together, and head level. All athletes and parents of the minor athletes were informed in detail regarding all test procedures and risks for the study. Prior to participation, athletes voluntarily gave informed consent and informed consent was obtained from the athletes and assent of parents for those under the age of 18 years. All testing and data management was conducted according to the Declaration of Helsinki and approved by the University Human Ethics committee. Following anthropometric measurements, athletes performed a standardised general and dynamic warm-up consisted of skipping, knee hug, squat, duck walk, lateral shuffle, thoracic rotation, hop-hop stick, and knee tuck.

5.2.2 Study Design

5.2.3 Drop and Stick

Drop and stick test was performed on a portable force plate (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia) connected to a computer running data collection and analysis software (InnerBalance, Innervations, Perth, Australia) recording vertical ground reaction force at a sample rate of 600 Hz. Force was not filtered, however, the force threshold was set at 50 N. Athletes attended a single session and were familiarised with the DS test by performing three practice trials prior to data collection. However, if additional trials were necessary to be competent in the landing task, the athletes were provided additional trials. The athletes then

performed five drop and stick trials barefoot from a pre-determined box height of 0.5 m (Figure 1a). They were instructed to step forward off the box with their preferred leg, "land soft" on both feet, and as quickly as possible squat to the final position (upper thighs parallel to the ground, Figure 1b). Time to stabilisation was calculated from the time of initial landing contact till they stabilised within 5% of body mass (Figure 2). For example, if an athlete's initial contact occurred at 1.5 s and stabilisation to within 5% of their body mass occurred at 2.1 s, TTS of 0.6 s was recorded. The rPLF was calculated from peak landing force divided by BM to account for individual differences. In the event the upper thighs were not parallel to the ground, the trial was discarded and the athlete was given another trial. A minimum of fifteen seconds of rest was provided between each drop landing (Read & Cisar, 2001).

(a) (b)

Figure 5.1. Drop and stick from a box height of 0.5 m
(a) start (b) end position

5.2.4 Statistical Analyses

The lowest and highest TTS trials were discarded and the remaining three trials were used to determine single measures repeatability. The average of three trials was then used for further analysis and comparison between groups. One-way analyses of variance were used to identify any

significant differences in TTS and rPLF between groups. Post-hoc analyses of the effects of measure were conducted using LSD adjusted 2-tailed t-tests. All statistical analyses were completed using SPSS, version 22 software (SPSS Inc., Chicago, IL, USA) with criterion level of significance set at $p \leq 0.05$. Reliability for TTS and rPLF were analysed using intraclass correlation coefficient (ICC) with a 95% confidence intervals (CI), and typical error expressed as coefficient of variation (CV). In addition, all reliability coefficients were classified as: poor: < 0.69; fair: 0.70 to 0.79; good: 0.80 to 0.89; and excellent: 0.90 to 1.00 (Portney and Watkins, 1993).

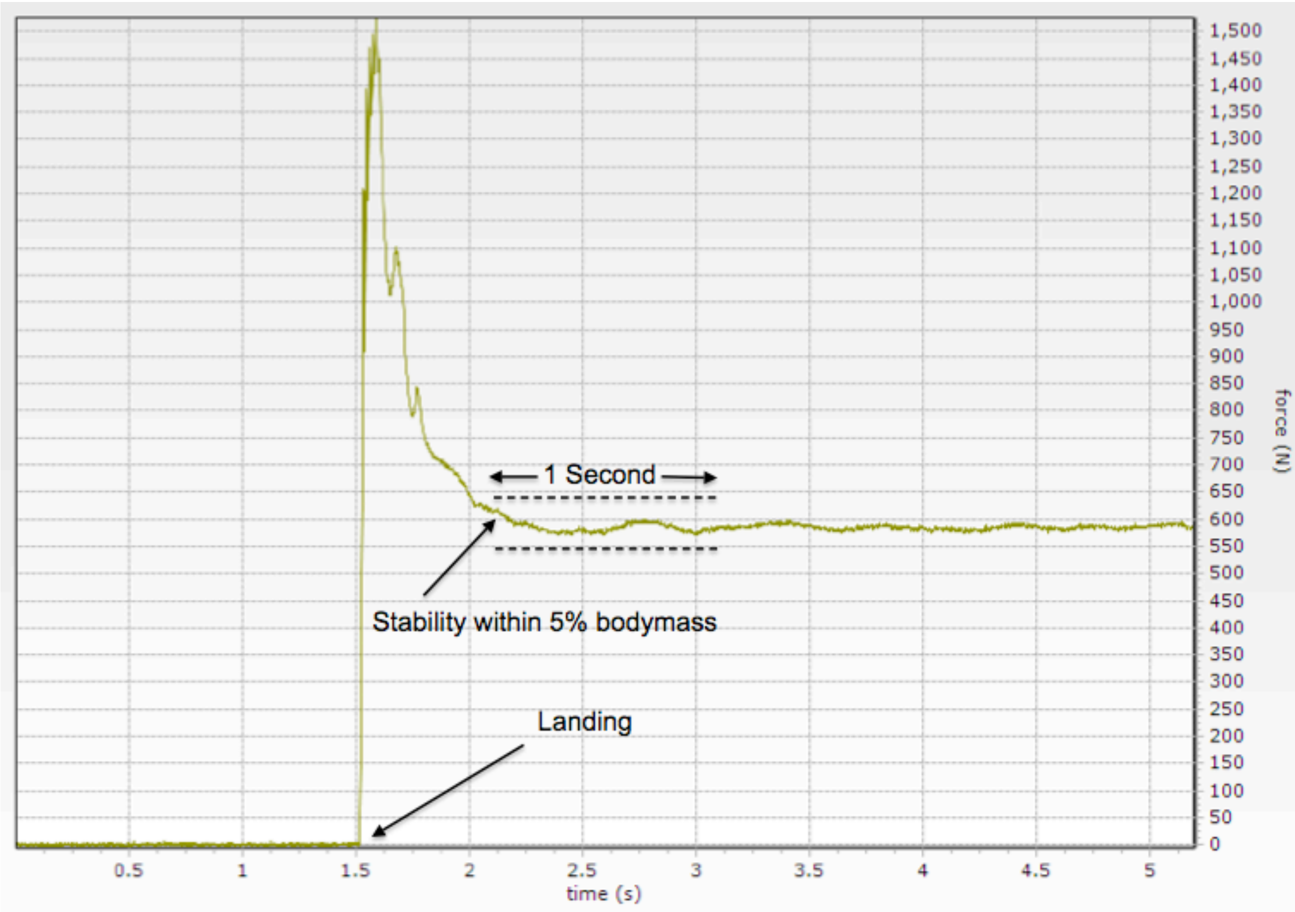


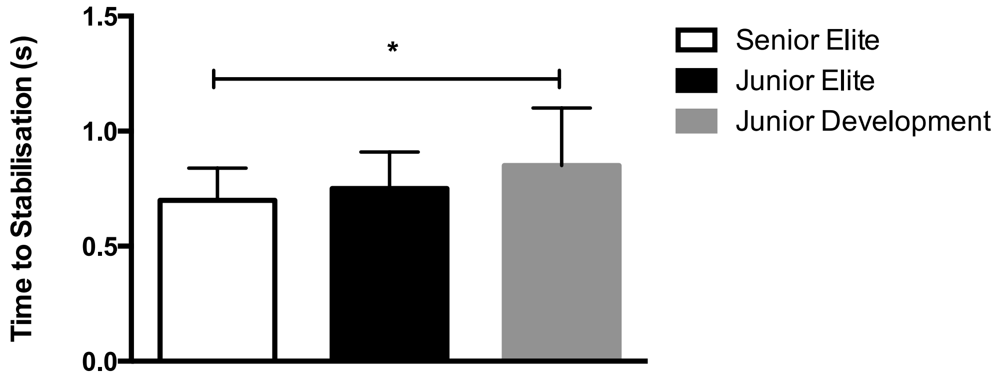
Figure 5.2. Time to stabilisation calculated from initial contact of the landing to the time the athletes stabilised within 5% of body mass.

5.3 Results

Intra-class correlation coefficient and CV for TTS and rPLF are presented in Table 5.1. The SE group demonstrated excellent single measures reliability in the TTS, whereas the JE and JD

groups demonstrated good single measures reliability. In regards to rPLF, the SE group demonstrated poor single measures reliability compared to the JE and JD groups (Table 5.2). There was no significant ($p=0.41$) difference between the SE (0.69 ± 0.13 s) and JE group (0.75 ± 0.16 s) for TTS (Figure 5.3a); however, SE surfers' TTS (0.69 ± 0.13 s) was significantly ($p=0.04$) faster than the JD group (0.85 ± 0.25 s). There was no significant ($p=0.09$) difference between the JE compared to the JD group for TTS. In regards to rPLF (Figure 5.3b), the SE group (2.7 ± 0.4 BM) landed with significantly less relative force compared to the JE (3.8 ± 1.3 BM; $p=0.02$) and JD groups (4.0 ± 1.1 BM; $p=0.01$). There was no significant ($p=0.63$) difference in rPLF between the JE and JD groups. Drop and stick test was able to discriminate between SE and JD groups for TTS and rPLF (Figure 5.3). Furthermore, the test was also able to differentiate SE and JE groups and SE and JD for rPLF.

a



b

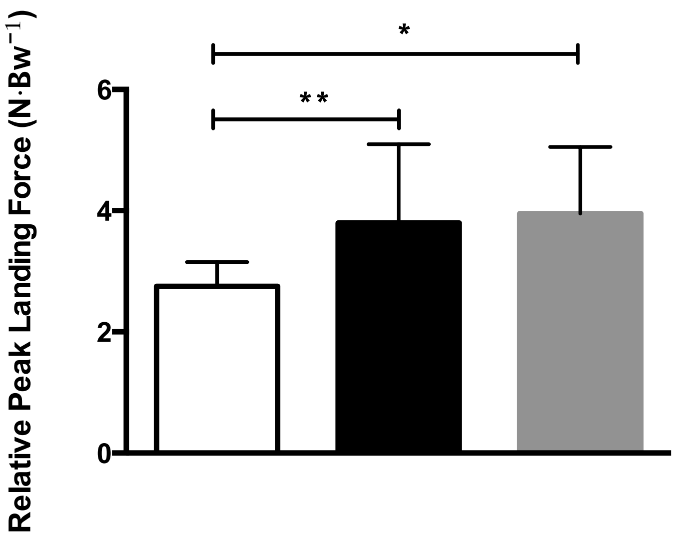


Figure 5.3. *Indicates senior elite competitive surfers were significantly different than junior development surfers. **Senior elite competitive surfers were significantly different than junior elite surfers.

Table 5.1. Reliability measures of time to stabilisation (TTS) and relative peak landing force (rPLF) showing intraclass correlation coefficients (ICC) and coefficient of variation (CV%), from senior elite, junior elite, and junior development competitive surfers

				Intraclass Correlation			CV
				ICC	95% Confidence Interval		
Group	n	Variable			Lower	Upper	%
Senior Elite	9	TTS	(s)	0.90	0.74	0.98	5.3
		rPLF	(BM)	0.62	0.22	0.88	10.4
Junior Elite	22	TTS	(s)	0.82	0.67	0.91	8.0
		rPLF	(BM)	0.76	0.58	0.88	16.2
Junior Development	17	TTS	(s)	0.88	0.75	0.95	10.0
		rPLF	(BM)	0.70	0.45	0.86	7.7

Table 5.2. Dynamic postural control reference scale for time to stabilisation (TTS) and relative peak landing force (rPLF).

TTS	**Elite Senior**	**Elite Junior**	**Junior Development**
Excellent	< 0.60 s	< 0.65 s	< 0.70 s
Good	0.60-0.75 s	0.65-0.80 s	0.70-0.85 s
Poor	> 0.75 s	> 0.80 s	> 0.85 s
rPLF			
Excellent	< 3.0 BM	< 3.5 BM	< 4.0 BM
Good	3.0-4.0 BM	3.5-4.5 BM	4.0-5.0 BM
Poor	> 4.0 BM	> 4.5 BM	> 5.0 BM

5.4 Discussion

The purpose of this study was to determine whether TTS and rPLF from a simple drop and stick test assessments of dynamic postural control differentiate between SE, JE, and JD competitive surfers. The results of this study demonstrated excellent single measures reliability (ICC= 0.90; CV= 5.3%) for TTS in the SE group with poor single measures reliability for rPLF (ICC= 0.62; CV= 10.4%). Junior elite and JD groups demonstrated good reliability for TTS (ICC= 0.82; CV= 8.0% and ICC= 0.86; CV= 10.0%, respectively), with fair reliability for rPLF (ICC= 0.76; CV= 16.2%), and (ICC= 0.70; CV= 7.7%), respectively. This provides new justification to believe that TTS is a measurable variable to assess dynamic postural control. Furthermore, TTS and rPLF demonstrated a significant difference amongst SE and JD, thus supporting the DS test could differentiate between elite and junior development level of ability.

Wikstrom et al. (2005) reported fair reliability (ICC: 0.78 (CI95: 0.59-0.90)) for TTS, however, they used a complex approach to assess TTS by having the participants perform a multi-stage single limb task prior to the actual landing. Whereas Flanagan et al. (2008) used a different approach by having the participants perform a depth jump, then land and stabilise with both feet as quickly as possible. Flanagan et al. (2008) reported low reliability (ICC= 0.68) for TTS using NCAA Division I track and field athletes. They also used a complex task prior to landing compared to the current study, which may be an explanation for differences in the results. It is suggested practitioners standardised and make the TTS assessment simple and suitable for all levels, as this will increase the reliability of a sensitive test. Furthermore, it is recommended the athletes be familiarised with the task to increase competency in an effort to repeatedly perform the test properly.

To overcome concerns for the reliability observed in these studies, one possible approach would be to use TTS as a qualitative measure of dynamic postural stability using reference values to categorise an athlete's baseline value (e.g., excellent: < 0.6 s; good: 0.60-0.75 s; poor: > 0.75 s;

Table 3), based on age groups or training age to quantify TTS upon landing. For instance, using this reference scale as a qualitative measure to discriminate amongst groups, as the results would be expected to vary due to the different levels of ability. The method used in this study to assess dynamic postural control is a general landing task, and therefore possible to standardise for repeated trials, however, there are also some similarities to landing tasks that occur in surfing after aerial or floater manoeuvres. In addition, using a standardised 0.5 m drop height will place loads that make high demand of the neuromuscular system, without eliciting any substantial injury risk (Seegmiller and McCaw, 2003; McNair and Prapavessis, 1999). Therefore, it is imperative that the athletes flex their ankles, knees, and hips upon landing to ensure that the eccentric loads are absorbed by the muscles and sparing the joint structures, which is an important component to reducing injury risks upon landing (Scase et al., 2006).

Because landing skill is highly trainable variable (Aerts et al., 2010), it is expected that adults, or higher-level athletes would be able to exhibit less landing force than adolescents, or lower level surfing athletes. This contention is supported by the results of this study, as the SE group were able to efficiently attenuate the peak landing force compared to the junior groups. The rPLF for all three groups demonstrated ICC ranging from 0.62-0.76) with a CV% ranging between 5.3-16.2%, with only rPLF in the JE group demonstrating unreliable at a CV cutoff of 10% (Cormack et al., 2008). However, before dismissing the utility of this measure, it may be an important variable to measure following a periodised resistance-training phase to assess whether the athlete can efficiently utilise their muscles to attenuate a high landing force. For instance, if a surf athlete lands from an aerial manoeuvre and their muscles cannot withstand the high landing force, the athlete will likely be at increased risk of injury (Dufek and Bates, 1990).

Another interesting finding was that the SE rPLF demonstrated poor single measures reliability compared to the JE and JD groups; however, the SE group was able to land with significantly ($p < 0.05$) lower impact force compared to both groups. The greater variability in landing force might be due to the fact that the athletes were only instructed to land as softly as

possible. It might be possible that some athletes will land with flat feet while others will land on their toes first, then transferring their weight to the heels. It was expected that the SE group would be able to attenuate the landing force better compared to the junior groups, and this was supported with the SE group demonstrating 28.9% and 32.5% less landing force compared to the JE and JD, respectively, over an average of three trials. Junior elite group was able to land with 5.0% less impact force compared to JD, however, there was no significant ($p>0.05$) difference observed. A possible explanation of the observed difference might be a lack of inter-muscular coordination, which limits the ability of the younger, or lower level athletes to repeatedly attenuate the landing force. It has been reported that landing from a 0.5 m drop height produced landing forces ranging between 1.67 BM to 6.18 BM (Mizrahi and Susak, 1982). In another study, involving a cohort of recreational and competitive males and females between the ages of 13-19 years, it was reported that the landing force from a 0.3 m height, range from 2.0-10.4 BM with a mean of 4.5 BM (McNair and Prapavessis, 1999). The present study demonstrated the SE group rPLF was 2.7 ± 0.4 BM, with the JE and JD demonstrated 3.8 ± 1.3 BM and 4.0 ± 1.1 BM, respectively. In contrast, Seegmiller and McCaw (2003) reported that female Division I gymnasts exhibited higher landing force from 0.6 m and 0.9 m compared to recreational females participating in sports that also involve repetitive landings. The higher landing forces in highly trained gymnasts compared to the highly trained surfers in the present study might be due to landing instructions given to the athletes. Seegmiller and McCaw instructed their gymnasts to "land using her natural landing style", whereas, the surfers in the present study were instructed to "land soft on both feet, and as quickly as possible to a squat position." The results from the Seemiller and McCaw study raise the awareness that high-level athletes may also benefit from landing technique training. A simple altitude landing task such as dropping from a box with ankle, knee, and hip flexion and quiet landing should be monitor in a training program. Once the athlete demonstrates safe and effective landings with no valgus knees or minimal ankle, knee, and hip flexion, the athlete can progress to single leg horizontal hop and stick. Landing is trainable and if instructed properly, an athlete will exhibit less landing force (McNair

and Prapavessis, 1999; Scase et al., 2006; Mcnair, Prapavessis, and Callender, 2000; Prapavessis and McNaire, 1999) and reduce the likelihood of an injury from exposure to repetitive high landing forces (Dufek and Bates, 1990).

5.5 Practical Implications

The results of this study provided descriptive data for the drop and stick test among competitive surfing athletes. ICC revealed good to excellent single measures reliability for the DS test via TTS to assess dynamic postural control. This suggests that the DS test using TTS is useful to assess dynamic postural control upon landing across different levels of competitive surfing athletes. Although rPLF demonstrated greater variability, DS is an important measure to assess landing force and force attenuation skills for surfing athletes. The distinctive differences for TTS and rPLF between the SE and JD athletes indicated that the DS is a useful test to assess dynamic postural control. It is suggested that practitioners use both measures as an assessment of landing skills. A possible benchmark approach for practitioners would be to use DS as a qualitative measure of dynamic postural control using a reference scale (e.g., excellent: < 0.6 s; good: 0.60-0.75 s; poor: > 0.75 s) to quantify TTS for elite surfing athletes, and rPLF, (excellent: < 3.0 BM; good: 3.0-4.0 BM; and poor: > 4.0 BM), which will be adjusted depending on the age and level of the athlete. Adopting a reference scale might be useful for coaches and practitioners to determine whether the individual needs to work on stability, reduction of landing forces to spare the joints, or earn the rights to perform high-risk manoeuvres. Furthermore, it may be worthwhile to incorporate an intervention program in landing technique for lower level athletes or those with low training age. This is due to the results from the current study revealing that lower level surf athletes were significantly slower to stabilise and also produced greater landing force.

Chapter 6

Study 4: Effects of unstable and stable resistance training on strength, power, and sensorimotor abilities in adolescent surfers

(*Int J Sports Sci Coach*, Accepted)

6.1 Introduction

In a high-skilled sport such as surfing, elevating strength, power, and dynamic postural control have a significant impact on improved performance (Secomb et al., In Press). Previous research has reported that athletes with greater maximal strength demonstrate a greater transfer to performance, such as sprinting (Seitz, De Villarreal, and Haff, 2014; Young, McLean, and Ardagna, 1995), vertical jump (Wisløff et al., 2004), change of direction (Nimphius, McGuigan, and Newton, 2010), sprint paddle (Sheppard et al., 2012), the pop-up phase of surfing (Eurich et al., 2010), and turning maneuvers during wave riding (Secomb et al., In Press). Although the sport of competitive surfing has been pursued for decades, there is a paucity of evidence-based research in regards to which training interventions are most effective.

Surfing is an intermittent sport that encompasses bouts of explosive activities (e.g., sprint paddle, pop-ups, wave riding, turns, aerials, floaters) and low-moderate intensity activities (e.g., endurance paddling, duck diving, retrieving the board) (Farley, Harris, and Kilding, 2012a; Meir, Lowdon, and Davie, 1991; Mendez-Villanueva, Bishop, and Hamer, 2006). Furthermore, surfing is performed in a dynamic environment that places a high demand on sensorimotor abilities. There are strong beliefs in the surfing community that performance is improved through balance training, but primarily by using unstable surfaces in a stationary position. This approach is commonly incorporated into a surfer's basic training, including resistance training on unstable devices such as a BOSU, balance board, stability cushion, or stability ball to improve sensorimotor abilities with the

intention to transfer to the skills of surfing. Although these training devices are likely suitable for lower-limb rehabilitation purposes, due to the proprioceptive overload they provide (Chapman et al., 2008; Cressey et al., 2007; Paillard et al., 2011), they might not provide an adequate stimulus for strength and power adaptations in un-injured athletes, and are thought to be ineffective in developing these qualities (Anderson and Behm, 2004; Cressey et al., 2007; McBride, Cormie, and Deane, 2006). Furthermore, although the unstable stationary training provides a proprioceptive challenge, it likely doesn't adequately develop vestibular or visual aspects that contribute to sensorimotor control.

In recent years, the popularity of unstable devices has emerged as a training method for athletes to strengthen their "core", improve balance, proprioception, and enhance athletic performance, however, there are few scientific evidence-based studies to support these claims (Anderson and Behm, 2004). Cressey et al. (2007) reported that unstable surface training in collegiate soccer players demonstrated no significant improvement in the bounce drop jump, countermovement jump, or 40-yard sprint over 10 weeks. In addition, McBride, Cormie, and Deane (2006) reported that peak force significantly decreased in an unstable environment. This is in agreement with Behm, Anderson, and Curnew. (2002), who reported a 70.5% decrease in force production in an unstable environment. Furthermore, Gruber et al. (2007) reported no changes in maximum strength gains over four weeks of unstable training. Collectively, these studies demonstrate that unstable training attenuates most athletic performance characteristics (Cressey et al., 2007; McBride, Cormie, and Deane, 2006; Bruhn, Kullmann, and Gollhofer, 2004; Oberacker et al., 2012). Interestingly, training on an unstable surface has been shown to increase explosive strength (Gruber et al., 2007; Gruber and Gollhofer, 2004), which is an important characteristic for surfing performance. In contrast, Taube et al. (2007) demonstrated that six weeks of proprioceptive training (e.g., unstable device) did not improve explosive strength in elite youth athletes. It is important to note that in untrained participants; almost any training stimulus may positively affect explosive strength (Gruber and Gollhofer, 2004).

Investigating the possibility of strength, power, and sensorimotor changes due to specific tasks or training interventions and whether they transfer to performance measures are of great importance for the sport of surfing. Furthermore, the effectiveness of training on an unstable compared to a stable surface can provide further insight into which training intervention is more beneficial for inducing performance gains. To our knowledge, there are no training studies investigating whether training on unstable surfaces provides greater adaptation compared to training on stable surfaces in competitive surfers. Therefore, the purposes of this study were to examine (a) whether training on an unstable surface is more advantageous than traditional resistance training and (b) the effects of unstable and stable training on strength, power, and sensorimotor ability.

6.2 Methods

6.2.1 *Experimental Approach to the Problem*

This study used a within-subject, crossover design where athletes were assigned equally to either an unstable (n=5) or stable (n=5) condition based on age and baseline strength levels. Athletes were given a four-week washout period following the first seven-week training intervention, and then crossed over to complete the second seven-week intervention (unstable became stable and vice-versa). Pre- and post-testing was performed for lower body maximal isometric strength, power, and sensorimotor abilities prior to each seven-week program. Pre-testing data from the first and second seven-week training conditions were then combined for analysis (e.g., first seven-week pre-unstable and second seven-week pre-unstable). Similar to pre-testing, post-testing data was also combined for analysis.

6.2.2 *Participants*

Ten competitive adolescent surfers (14.0 ± 1.1 yr, 53.7 ± 11.6 kg, 1.63 ± 0.08 m), from a high school state surf program volunteered and completed this study. All testing and data management was conducted according to the Declaration of Helsinki and approved by the

institutional review committee. Parents and athletes were informed of the risks and benefits of this study and gave consent or assent respectively, prior to participation.

6.2.3 Study Design

Performance measures consisted of lower body maximal isometric strength (isometric mid-thigh pull; IMTP), power (countermovement vertical jump) and sensorimotor ability (time to stabilization; TTS, via drop and stick; DS). Athletes attended two training sessions per week on non-consecutive days for seven consecutive weeks. A familiarisation session commenced with body mass and stature measurements followed by a standardised 10-minute dynamic warm-up consisting of body weight squats, knee hugs, thoracic rotation, walk out, duck walk, and lateral shuffle. The session concluded with athletes being familiarised with the performance testing protocols. They returned 48 hours later and completed all tests for data analysis. Following this, they were instructed and familiarised with their respective training interventions until they were competent with the exercises. Athletes were given 48 hours of recovery then began their assigned training intervention. A certified strength and conditioning specialist supervised every training session with a 5:1 athlete to coach ratio. Athletes were instructed to continue their daily surf training, and to avoid any resistance training other than their assigned training program. Post-testing was performed at least 48 hours after completion of the 7-week training interventions. Athletes were provided a 4-week wash out period between interventions but continued their normal daily surf training during this time. However, they were instructed to avoid any strength-power exercises. Following the wash out period, they were pre-tested prior to the second 7-week training intervention (unstable became stable and vice-versa), and then post-tested upon completion of the second 7-week training intervention. Both conditions followed a periodised strength-power program; the only difference was the way it was delivered (unstable or stable).

6.2.4 *Training Program*

The unstable condition involved performing all exercises on a BOSU device. Session one consisted of one lower body (LB) explosive exercise (double leg forward jump off the BOSU) and one upper body (UB) explosive exercise (medicine ball slam), two LB strength exercises (overhead squat, dumbbell squat), two UB strength exercises (1-arm row, push-up), and one trunk rotation exercise (medicine ball rotation). Session two was performed with a similar format consisting of vertical jump off the BOSU, medicine ball chest throw, dumbbell squat then shoulder press, 1-arm dumbbell row, assisted (straps) single leg squat, push-up and medicine ball woodchop. The stability condition was identical to the unstable condition, except assisted (bands) pull-up was performed instead of 1-arm dumbbell row in session one. Both conditions were performed in a periodised fashion with equated total volume throughout the seven weeks. The only differences were the weekly variations of repetitions and intensity (Table 1). One minute of rest was provided between all exercise sets (Faigenbaum et al., 2009).

Table 6.1. Seven-week resistance training program for the unstable and stable conditions.

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Power	3x10 @ VL	3x8 @ L	3x6 @ ML	3x5 @ L	3x8 @ ML	3x6 @ M	3x5 @ ML
Strength	3x12 @ VL	3x10 @ L	3x8 @ ML	3x6 @ L	3x10 @ ML	3x8 @ M	3x5 @ ML

Very light (VL), light (L), moderately light (ML), moderate (M)

6.2.5 *Countermovement Vertical Jump*

Athletes were instructed to start in an upright position then complete three separate trials of a countermovement vertical jump, dipping to a self-selected depth while maintaining a light wooden dowel in contact with the back of their shoulders (Amonette et al., 2012). During each jump, if the wooden dowel lost contact with the shoulders, the jump was discarded and repeated. Sixty seconds of rest was provided between each jump. They were encouraged to jump as high as

possible and the jump with the best height was used for analysis. All jumps were performed on the previously described portable force plate. These methods have been previously used in this population (Tran et al., 2015a). Prior to data collection, calibration of the force plate was performed per manufacturer's instructions. The force data was collected at a sampling frequency of 600 Hz and peak force measured as the highest force prior to takeoff. Inverse dynamics were used to calculate peak force as well as peak velocity and jump height based on the impulse momentum relationship. Butterworth filter with cutoff frequencies of 16 and 10 Hz, for velocity and acceleration data respectively, was applied. Displacement and force were not filtered.

6.2.6 Isometric Mid-thigh Pull (IMTP)

Maximum isometric strength was measured on a customized mid-thigh pull apparatus with adjustable straps to accommodate individual height differences. Athletes completed three IMTPs with two minutes rest between trials while standing on a portable force plate (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia) collecting at 600 Hz, which has a built in amplifier and four load cells that measure vertical components for ground reaction force. Prior to data collection, calibration of the force plate was performed per manufacturer's instructions. Prior to the initial trial, athletes were placed in a position similar to the second pull of the clean and stood still on the force plate with their shoulders in line with the bar and hands slightly wider than shoulder width apart. Their knee and hip angles were 130-140° and 140-150°, respectively (Haff et al., 1997; Häkkinen, Alen, and Komi, 1985; Sheppard and Chapman, 2011). This ensures that the position of the bar was at a height corresponding to the mid-thigh for each individual. Athletes were instructed and verbally encouraged to push against the force plate with maximal effort for five seconds while maintaining the bar across their mid-thigh (Tran et al., 2015a).

6.2.7 Sensorimotor

Dynamic postural control was measured by having athletes perform five drop and stick trials while barefoot from a pre-determined box height of 0.5 m (Tran et al., 2015a). They were instructed to step forward off the box with their preferred leg, "land soft" on both feet and as quickly as possible reach the final position (upper thighs parallel to the ground). In the event the upper thighs were not parallel to the ground, the trial was discarded and repeated. They were provided with a minimum of sixty seconds of rest between each drop landing. They were given practice trials until they were competent in the landing task. Commercial software (InnerBalance, Innervations, Perth, Australia) was used to record peak landing force from the force plate describe above and peak landing force was recorded. To determine time to stabilisation (TTS), the lowest and highest trials were discarded and the average of the remaining three trials was used for further statistical analysis (Tran et al., 2015a). Time to stabilisation was calculated from the time of initial landing contact until force stabilised within 5% of body mass (Colby et al., 1999). For example, if an athlete's initial contact occurred at 1,500 ms and stabilisation to within 5% of their body mass occurred at 2,100 ms, a TTS of 600 ms was recorded. Relative peak landing force (rPLF) was calculated as peak landing force divided by body mass.

6.2.8 Statistical Analyses

A two way (condition X time) repeated measures analysis of variance (ANOVA) was used to determine differences between pre-post (time) and unstable and stable (condition). Significant main effects were followed up by paired t-tests with a Bonferroni correction. All statistical analyses were completed using SPSS for Windows, version 22 software (SPSS Inc., Chicago, IL, USA) and presented as mean ± SD with criterion level of significance set at $p \leq 0.05$ for all comparisons. Cohen's effect sizes (ES) were calculated as ES=mean change divided by the standard deviation of the sample scores to reflect the magnitude of difference. The magnitude of the ES's were evaluated as trivial < 0.20; small 0.20-0.49; moderate 0.50-0.79; or large > 0.80 (Cohen, 1988).

6.3 Results

For relative IMTP, there was no significant interaction of condition by time (p=0.12, *d*=0.24) or main effect for condition (p=0.85, *d*=0.004). However, there was a significant main effect for time (p=0.001, *d*=0.72), with post-training demonstrating an overall increase (9.1%, Figure 6.1).

For VJH, there was a significant interaction of condition and time (p=0.01, *d*=0.51). Paired t-test revealed a significant decrease (p=0.002) from pre to post in the unstable condition with a moderate effect size (*d*=-0.75), while the stable condition approached a significant (p=0.09) increase with a small effect size (*d*=0.40, Figure 6.2).

For sensorimotor abilities, TTS and rPLF demonstrated no interaction of condition and time (TTS: p=0.36, *d*=0.09; rPLF: p=0.67, *d*=0.02) and no main effects for time (TTS: p=0.08, *d*=0.30; rPLF: p=0.87, *d*=0.003) or condition (TTS: p=0.31, *d*=0.11; rPLF: p=0.73, *d*=0.01 Figure 6.3).

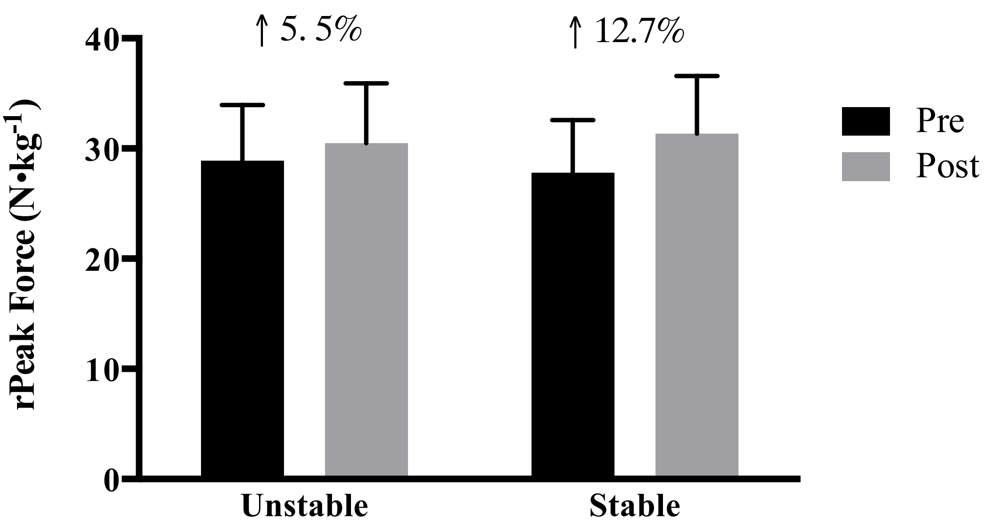


Figure 6.1. Relative maximal strength changes pre-to post resistance training in unstable and stable conditions are presented as relative peak force.

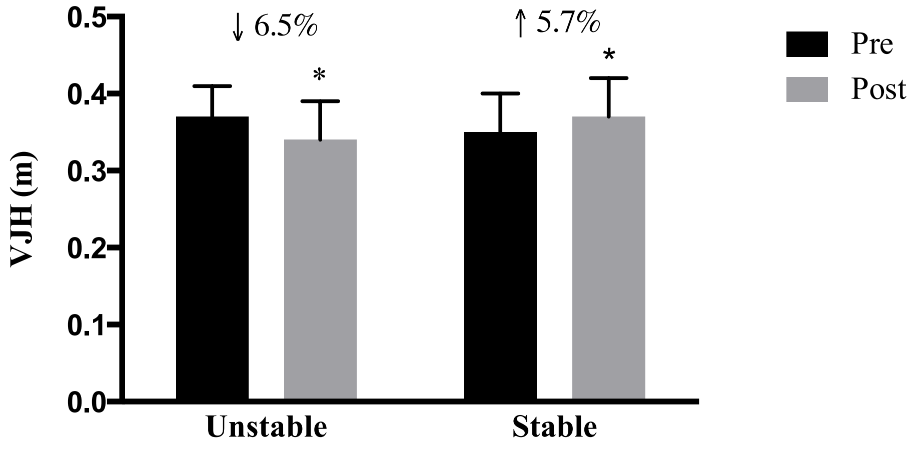


Figure 6.2. Power changes pre- to post resistance training in unstable and stable conditions are presented as vertical jump height (VJH). *Indicates significant changes within condition from pre- to post resistance training.

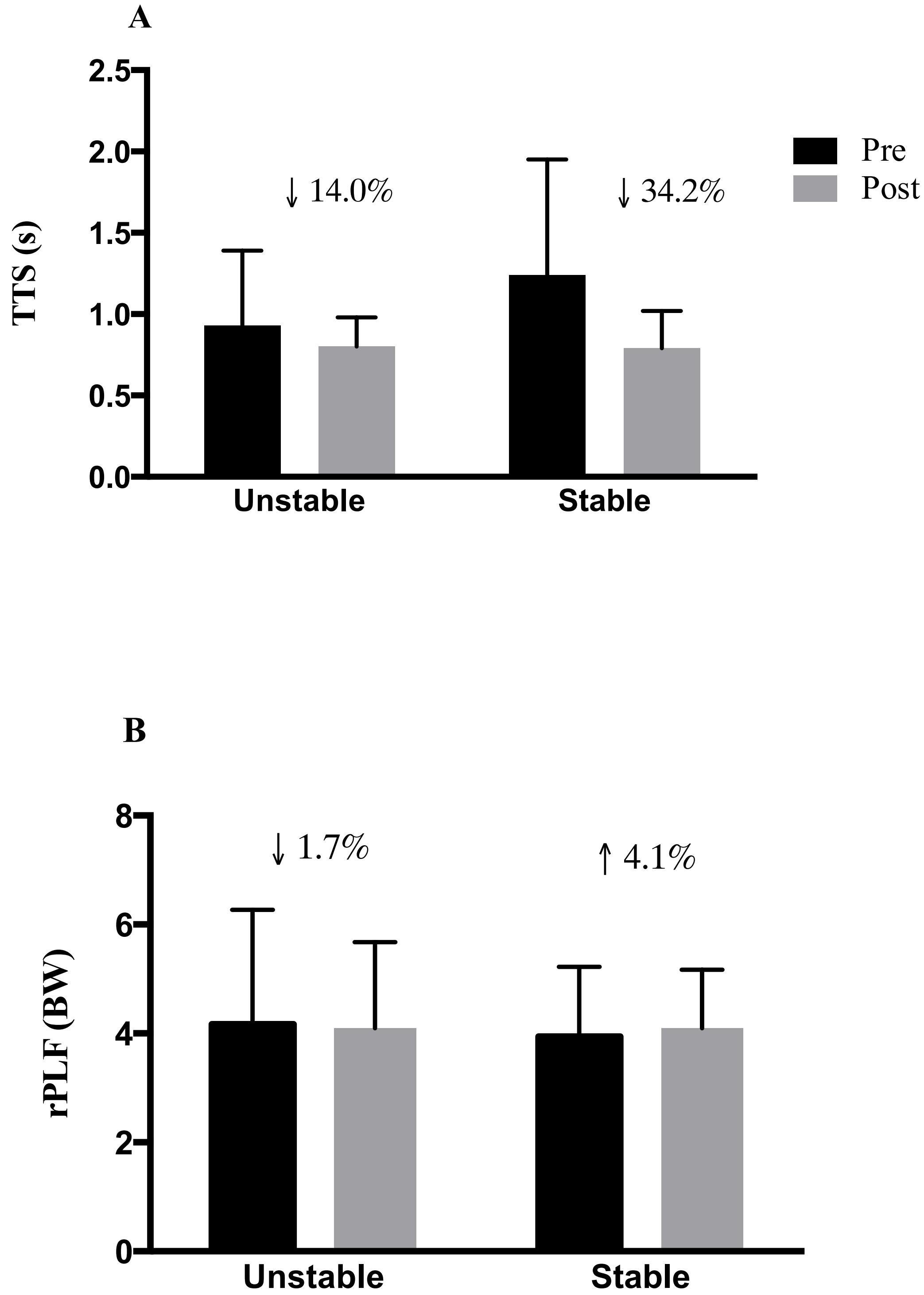


Figure 6.3. Sensorimotor ability changes over time (pre- to post training) for unstable and stable conditions. (A) Time to stabilization (TTS) and (B) relative peak landing force (rPLF).

6.4 Discussion

The purpose of this study was to determine whether training on an unstable surface offers greater benefits compared to traditional stable resistance training in competitive adolescent surfers. In addition, this research provides insight into the effects of unstable and stable training on strength, power, and sensorimotor measures. Previous studies have reported that training on an unstable surface attenuates athletic performance (Cressey et al., 2007), while others have reported an improvement in explosive strength (Gruber et al., 2007; Gruber and Gollhofer, 2004) or no advantages compared to training on a stable surface (Oberacker et al., 2012; Kibele and Behm, 2009).

The main finding of this study was that there were no significant differences between training on an unstable device (BOSU) (5.5% and 14.0%) vs. traditional resistance training (12.7% and 34.2% improvement) for strength and sensorimotor measures. There was a significant (p=0.001) training effect over time, collapsed across conditions, with a 9.1% improvement in relative isometric strength. The lack of significant differences in strength change is consistent with Kibele and Behm (2009), who reported that seven weeks of unstable surface training was not more beneficial for strength gains compared to a stable condition in inexperienced participants. The participants in their study demonstrated strength gains of 9.5% from pre- to post-training. This similarity in strength gains with the present study might be due to the low training age; with almost any training stimulus providing positive adaptations, largely due to improved neuromuscular coordination (Sale, 2003). Due to the low training age of our subjects, we used the resistance training progression recommendations from the National Strength and Conditioning Association Youth Resistance Training Position statement (Faigenbaum et al., 2009).

It is well documented that resistance training loads greater than 80-85% of 1RM elicit maximal strength gains (Oberacker et al., 2012; Häkkinen, Alen, and Komi, 1985; Peterson, Rhea, and Alvar, 2004), while training with intensities of 50-70% result in minimal gains (Peterson, Rhea, and Alvar, 2004). However, Rhea et al. (2003) and Peterson, Rhea, and Alvar (2004) reported that

untrained individuals (< 1 year of consistent resistance training) could show strength gains even when training at 60% 1RM. Although both conditions in the present study demonstrated strength gains, one may argue that seven weeks of resistance training might not be sufficient duration to realize significant differences between unstable and stable conditions.

Interestingly, the unstable condition strength gains (5.5%) in the present study are surprising compared to Behm, Anderson, and Curnew (2002), who reported a 70.5% reduction in unilateral leg extensor force output in an unstable compared to a stable condition. Similarly, Anderson and Behm (2004) reported that performing an isometric chest press in an unstable condition showed 59.6% less force compared to a stable condition. McBride, Cormie, and Deane (2006) demonstrated that isometric force output on an unstable surface was significantly lower compared to a stable surface. Collectively, these studies demonstrate that resistance training on an unstable surface results in significantly lower maximal force output and provides no additional benefits compared to a stable surface. The results of the present study, where a modest strength gain was realized with both stable and unstable resistance training, could be rationalized as specific to this population (adolescents with a low-training age). Despite anecdotal beliefs from surfing coaches and surfing athletes that training on an unstable surface is specific to the sport of surfing and can improve balance, we found no conclusive evidence to support these beliefs. In agreement with our findings, Metcalfe and Kelly (2012) suggest traditional resistance training such as Olympic lifts and ballistic exercises should be the stable of land-based training for surfing athletes.

Different sports require different approaches to training athletes for the specific demands of their sport, and surfing is no different. For example, to maximize scoring criteria, surfers may benefit by having maximal leg strength to apply force on the tail of the surfboard, thus creating a large amount of spray during turns (Secomb et al., In Press). Not only is maximal strength important to produce force, it is also critical for force absorption following landings from aerials or floaters. Recently, Lundgren et al. (2014) reported high-risk maneuvers such as aerials or tube-rides are rewarded with higher scores compared to waves ridden without performing those maneuvers.

With an increased expectation from judges to perform high-risk maneuvers, the risk taking might expose surfers to higher incidence of lower extremity injuries (Furness et al., 2014).

In regards to power, unstable surface training resulted in a -6.5% decrease in lower body power compared to a borderline significant 5.7% improvement in the stable condition. These results are in agreement with Oberacker et al. (2012), who reported a decrease in countermovement jump height for unstable training, while the stable condition training increased vertical jump height. In a similar study, Cressey et al. (2007) reported that a stable condition training intervention improved countermovement jump height by 2.4%, with no changes from training in the unstable condition. Collectively, these studies provide rationale that training on an unstable surface inhibits power gains. It is likely that power has profound effects on performance in surfing (Sheppard and Chapman, 2011; Tran et al., 2015b), with athletes rewarded with higher scores for maneuvers with speed, power, and flow (WSL Rule Book 2014, Article 134: Judging Criteria). In contrast to the decline in power development reported in previous unstable and stable training studies, Gruber and Gollhofer (2004) and Gruber et al. (2007) used a cohort of untrained participants and demonstrated that four weeks of unstable training significantly increased explosive strength. In another study, Granacher, Gollhofer, and Kriemler (2010) used high school students and reported squat jump and countermovement jump height improved following four weeks of balance training. These results contradict the present and previous studies, which have shown training on unstable devices attenuates vertical jump height. The discrepancy may be due to training status; with any training stimulus may elicit explosive strength in untrained participants in the early phase of strength training and adaptations is favourable due to improved neuromuscular coordination (Sale, 2003).

Our study did not show that training on an unstable surface was more beneficial than a stable surface to improve dynamic postural control. In fact, both training interventions demonstrated an improvement in postural control as seen in a decreased time to stabilization, however it was not significant. Bruhn, Kullmann, and Gollhofer (2004) demonstrated that four weeks of traditional resistance training significantly improved postural control. Based on the

present study and that of Bruhn, Kullmann, and Gollhofer (2004), it could be suggested that dynamic and static postural control can be improved, but that unstable, proprioceptive training is not necessarily a superior method to accomplish this.

Indeed, surfing is performed in a dynamic environment and it might seem logical to some practitioners to perform resistance training on an unstable surface to improve balance. However, it is worth noting, that as the surfer generates and increases speed across the wave face, the level of instability decreases. This follows a basic physics relationship, which dictates that as velocity increases so does stability between the water and the surfboard (Metcalfe and Kelly, 2012). Having good balance is essential for the sport of surfing, however, the time spent training on unstable surfaces to achieve better balance at the expense of strength and power gains is questionable. It is important to consider that maintaining basic postural control (e.g., standing on unstable devices) whilst under a high proprioceptive demand is likely to only develop proprioceptive abilities in that specific context, and it is unknown whether this transfers to increased performance in able-bodied (e.g., uninjured) surfers or to such a specific and variable task as surfing. Although some static postural control tasks have been observed to discriminate between surfers and non-surfers (Chapman et al., 2008), this was only observed when a surf-specific pattern recognition task was included as part of the test. This perhaps highlights the importance of dual-task abilities rather than an actual physical superiority. Furthermore, a static postural control task discriminating between surfing abilities does not indicate that further development of static postural control through proprioceptive overload will influence dynamic sensorimotor ability (Chapman et al., 2008; Paillard et al., 2011). In addition, it is unclear whether increased balance through proprioceptive training alone is trainable in elite surfers as they may already possess these skills at a high level due to their inherit and already well developed sensorimotor qualities.

Interestingly, Behm et al. (2005) reported there was no significant correlation ($r = -0.28$) between skating performance and balance measures for competitive hockey athletes over the age of 19 years, whereas, those under the age of 19 demonstrated a significant correlation ($r = -0.65$). This

implies that training on an unstable surface in conjunction with a stable surface may benefit younger and lower level athletes. The premise behind training on an unstable device is to improve athleticism, however, from a practical point of view, training on these devices might not be ideal for recreating athletic activities, as it may not challenge the neuromuscular system sufficiently or in a context-specific manner (Colby et al., 1999). However, instead of discarding this method of training, it may be an appropriate strategy for athletes returning from an injury in order to regain proprioception and improve sensory signals (Granacher et al., 2011) and to apply in modest amounts as part of the overall physical preparation programs.

6.5 CONCLUSION

Despite common beliefs that resistance training on unstable devices improves athletic performance in surfers, this study demonstrated that unstable training presented no major advantages over traditional stable resistance training in enhancing strength, power, or sensorimotor ability. To maximize strength and power gains, strength coaches and practitioners should emphasize traditional stable resistance training methods. Using unstable devices to improve sensorimotor ability in conjunction with traditional stable resistance training might be suitable for those with a low training age or as a means of rehabilitation. More advance athletes may require sensorimotor training that also involves visual and vestibular challenges, not just proprioceptive challenges offered by unstable surfaces. With previous research demonstrating as much as a 60-70% decrease in force output on unstable devices, caution should be used when training athletes on these devices when maximizing strength and power is the objective.

Chapter 7

Study 5: Effect of four weeks detraining on strength, power, and sensorimotor ability of adolescent surfers

(*J Strength Cond Res*, In Review)

7.1 Introduction

Surfing is a high skill demand sport that requires a considerable amount of time in a variety of ocean conditions to help develop the fundamental techniques. It has been reported that recreational and competitive surfers spend as much as 6.6 ± 4.4 and 12.3 ± 2.8 hours of surfing per week, respectively (Loveless and Minahan, 2010). In comparison, resistance training has been reported as total durations of 1.5 ± 2.7 and 0.5 ± 0.6 hours per week for recreational and competitive surfers, respectively (Loveless and Minahan, 2010). With this in mind, resistance training does not appear to be a priority within the surfing community, as more time is spent in the water to improve surfing ability. Anecdotally, surf coaches and adolescent surfers believe spending more time surfing, in the absence of resistance training, is a sufficient stimulus to maintain physical capabilities. Due to the inconsistency of the environment, the priority of the athlete is to surf when the conditions are favourable and resistance train when the conditions are poor (Everline, 2007). This surf mantra might make it challenging for surfing athletes to be consistent with a periodised resistance-training program because they are busy chasing favourable surfing conditions. Currently there are no research published on the effects of a periodised resistance-training program or the effects of detraining on strength, power, and sensorimotor abilities in competitive surfing athletes. Therefore, it is imperative to investigate adaptations from resistance training, and then cease

training to determine whether surfing in the absence of resistance training is a sufficient stimulus to maintain physical characteristics.

Detraining (cessation of resistance training) has potential negative implications for athletic performance. It is well documented that an adequate resistance-training stimulus elicits positive neuromuscular adaptations (Faigenbaum et al., 1993; Faigenbaum et al., 2001); conversely, cessation of resistance training negatively affects strength and power parameters within a relatively short period (Andersen et al., 2005; Faigenbaum et al., 1996; Izquierdo et al., 2007). Previous studies have highlighted decrements in strength and power as a result of detraining following completion of a resistance training program in various populations: children (Faigenbaum et al., 1996), sedentary (Andersen et al., 2005), college-age women (Staron et al., 1991), and power athletes (Hortobagyi et al., 1993). However, little is known with regards to the effect of detraining on performance parameters in adolescent surfers.

Faigenbaum et al. (1996) demonstrated that children (7-12 y) significantly decreased upper (-19.3%) and lower body (-28.1%) strength over an eight-week detraining period. Izquierdo et al. (2007) demonstrated that four weeks of detraining subsequent to 16 weeks of resistance training had a significant negative effect on strength (-9%) and power (-17%) in physically active men. In another study, Staron et al. (1991) demonstrated that college-age women significantly decreased leg press (32%) and leg extension (29%) strength following 30-32 weeks of detraining. Furthermore, Andersen et al. (2005) reported strength, power, and muscle CSA decreased to pre-training levels after three months of detraining in sedentary men. Conversely, Hortobagyi et al. (1993) demonstrated power athletes' strength level did not significantly alter following 14 days of detraining, however, Type II muscle fibre area decreased 6.4%. Interestingly, Santos and Janeira (2009) were able to demonstrate explosive power was maintained during 16 weeks of detraining in adolescent male basketball players. Collectively, with the exception of Hortobagyi et al. (1993) and Santos and Janeira (2009), these studies have demonstrated a decrease in strength (Andersen et al., 2005; Faigenbaum et al., 1996; Staron et al., 1991), power (Andersen et al., 2005; Izquierdo et al.,

2007), and muscle CSA (Andersen et al., 2005; Hortobagyi et al., 1993), however, it is important to note that different individuals respond and adapt to training stimuli differently. Specifically, the studies by Hortobagyi et al. (1993) and Santos and Janeira (2009) represent the potential for a population with longer training history to be able to decrease or not experience the decrements in physical capacity seen in populations with lower training history.

Postural control and dynamic balance are critical for the sport of surfing; however, there is a lack of scientific evidence regarding the effect of detraining on sensorimotor ability for adolescent competitive surfers. Drop landing from a pre-determined height followed by a motionless posture is relevant to the sport of surfing as the athletes are required to transition from a dynamic to a static position with the TTS currently the accepted test for this ability (Wikstrom et al., 2005). This method quantifies the time an athlete takes to stabilize their posture within 5% of body mass upon landing. In addition, this test also quantifies landing force from a vertical direction as this might demonstrate whether detraining affects the ability to effectively attenuate landing forces. Wikstrom et al. (2005) reported vertical TTS method established fair reliability with an ICC measure of 0.78 with a 95% confidence interval of 0.59-0.90. Additionally, drop landing might suggest whether this method is sensitive and valuable to detect small changes of sensorimotor ability for adolescent surfers. For example, during a floater manoeuvre, surfers launch themselves on top of the face of the wave, then drop land to the bottom in front of the broken wave. If the surfer is able to stabilize and control their posture quickly and efficiently, they are more likely to land successfully and transition to the next manoeuvre.

While there is a considerable amount of literature on the positive adaptations from acute and long-term resistance training in young athletes (Faigenbaum et al., 1993; Faigenbaum et al., 1996; Faigenbaum, 2000; Faigenbaum et al., 2002; Faigenbaum et al., 2009), it is uncertain whether adolescent surfers are able to maintain physical performance with surfing alone. Therefore, the purpose of this study was to determine the magnitude of changes in physical performance over a four-week detraining period during which the athletes completed no resistance training.

7.2 Methods

7.2.1 Experimental Approach to the Problem

This study investigated the impact of detraining on strength, power, and sensorimotor ability in adolescent surfers following seven weeks of periodized resistance training. Performance parameters of power (vertical jump height; VJH), maximal isometric strength (isometric mid-thigh pull; IMTP), and sensorimotor ability (time to stabilization during a drop and stick (DS); TTS) pre-test results were determined from the conclusion (post-test) of a seven-week training block while post-test results were measured at the start (pre-test) of a second seven-week training block. In other words, the four-week washout period between two seven-week training blocks was used to assess the effect of a detraining period. Four weeks cessation of resistance training was based on the participants' school break schedule. Athletes performed three countermovement jumps to self-selected depth, three IMTP, and five DS trials. The best trial for each variable was used for further analysis.

7.2.2 Participants

Nineteen competitive adolescent surfers with an overall mean age, mass and stature (mean ± SD) of 14.1 ± 1.6 y, 54.0 ± 10.75 kg and 165.0 ± 9.0 cm, respectively, volunteered to participate in this four-week study. Competitive adolescent surfers are defined as surfers who have competed in regional, state, or national competitions. All testing and data management was conducted according to the Declaration of Helsinki and approved by the institutional review committee. Parents and athletes were informed of the risks and benefits of this study and gave consent or assent prior to participation.

7.2.3 Study Design

The performance test session commenced with body mass and stature measurements, followed by a standardized dynamic warm-up. Prior to the performance test session, athletes were

provided details and familiarised with the testing protocols. The athletes then practiced the countermovement vertical jump (CMJ), isometric mid-thigh pull (IMTP), and the drop and stick (DS) testing protocols to reduce possible learning effects. Performance parameters consisted of lower body power (CMJ), maximal isometric strength (IMTP), and sensorimotor ability (time to stabilization during a DS; TTS). Athletes continued their surf training sessions but did not complete any resistance training throughout the four-week period cessation of resistance training. Prior to this study, the surfing athletes completed a seven-week training program consisted of one lower body (LB) explosive exercise (double leg forward jump) and one upper body (UB) explosive exercise (medicine ball slam), two LB strength exercises (overhead squat, dumbbell squat), two UB strength exercises (1-arm row, push-up), and one trunk rotation exercise (medicine ball rotation). Session two was performed with a similar format consisting of vertical jump, medicine ball chest throw, dumbbell squat then shoulder press, assisted pull up, 1-arm dumbbell row, assisted (straps) single leg squat, push-up and medicine ball woodchop.

7.2.4 Vertical Jump Performance

The CMJ was used to assess vertical jump height. Athletes were instructed to start in an upright position while standing still on a portable force plate (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia), which has a built in amplifier and four load cells that measure vertical components of ground reaction force. Prior to data collection, calibration of the force plate was performed as per manufacturer's instructions. The force data was collected at a sampling frequency of 600 Hz and inverse dynamics calculations were used to calculate peak force as well as peak velocity and jump height based on the impulse momentum relationship as per manufacturer software (Ballistic Measurement System, Innervations, Perth, Australia). These methods have been previously used in this population (Sheppard et al., 2013). A low-pass 4th order Butterworth filter with cutoff frequencies set at 16 and 10, Hz for velocity, and acceleration data respectively was applied. Displacement and force were not filtered. Athletes were instructed to

complete three trials dipping to a self-selected depth while holding a light wooden dowel in contact with the back of their shoulders and then jumping vertically for maximum height (Amonette et al., 2012). During each jump, if the wooden dowel lost contact with the shoulders, the jump was discarded and repeated. Sixty seconds of rest was provided between jumps. Athletes were encouraged to jump as high as possible and the best jump height was used for further analysis of the following variables: peak velocity, jump height, and absolute and relative peak force.

7.2.5 Mid-thigh Pull Performance

Maximum isometric strength was measured on a customized mid-thigh pull system with adjustable straps to accommodate individual height differences. Athletes completed three IMTPs with two minutes rest between pulls. Prior to the initial pull, the athletes stood still on the force plate with the shoulders in line with the bar and hands slightly wider than shoulder width apart. They were then placed in a position similar to the second pull of the clean with knee and hip angles corresponding to 130-140° and 140-150°, respectively (Haff et al., 1997; Kawamori et al., 2006; Sheppard et al., 2011). In other words, the position of the bar was at a height corresponding to the mid-thigh for each athlete. Athletes were instructed and verbally encouraged to push against the force plate as hard as possible while holding the bar across their mid-thigh with maximal effort for five seconds. Recently, Sheppard et al. (2013) have reported excellent reliability (ICC: 0.99 (0.97-0.99)) with a percent typical error of measurement of 2.25% in this population. Although Haff et al. (1997) used instruction to "pull as fast and hard as possible", the current authors observed during pilot trials that "push" was the appropriate instruction for this population. The same force plate, personal computer and software used to measure vertical jump performance was used to record and analyse vertical landing force and to derive peak force.

7.2.6 Sensorimotor

Sensorimotor ability was measured via a drop and stick manoeuvre on a portable force plate (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia) connected to

computer software (InnerBalance, Innervations, Perth, Australia) recording landing peak force with a sample rate of 600 Hz. Athletes were given practice trials, however, if additional trials were needed to become competent in the landing task, they were given more. Athletes performed five drop and stick trials barefoot from a pre-determined box height of 0.5 m. They were instructed to step forward off the box with their preferred leg, “land soft” on both feet, and as quickly as possible reach a position with the upper thighs parallel to the ground, similar to the bottom position of a squat. In the event the upper thighs were not parallel to the ground, the trial was discarded and repeated (upper thighs parallel to the ground and holding for three seconds was deem acceptable). To determine the average of three drop and stick trials, trials with the lowest and highest TTS were discarded. Time to stabilization was calculated from initial contact on landing to the time the athletes stabilized within 5% of body mass (Figure 7.1). For example, if an athlete’s initial contact occurred at 1.5 s and stabilisation to within 5% of their body mass occurred at 2.1 s, TTS of 0.6 s was recorded. The rPLF was calculated from peak landing force divided by BM to account for individual differences. In the event the upper thighs were not parallel to the ground, the trial was discarded and the athlete was given another trial. A minimum of sixty seconds of rest was provided between each drop landing.

Relative peak landing force was calculated by dividing maximum landing force by body mass. Time to stabilization demonstrated fair test-retest reliability with greater variability shown in relative peak landing force (Table 7.1).

7.2.7 Statistical Analyses

In order to determine if there were any significant differences from pre- to post-test, pair t-tests were used to compare anthropometry and performance results. All statistical analyses were completed using SPSS for Windows, version 22 software (SPSS Inc., Chicago, IL, USA) with criterion level of significance set at $p \leq 0.05$. Cohen’s effect sizes (ES) were calculated as ES=mean change divided by the standard deviation of the sample scores (Batterham and Hopkins, 2006). The

magnitudes of the ES's were evaluated as trivial < 0.2; small 0.2-0.5; moderate 0.5-0.8; or large > 0.8 (Cohen, 1988).

7.3 Results

Average power, strength, and sensorimotor ability performance are presented in Table 7.1 and percent changes for pre to post measures are shown in Figures 7.1-7.3. Power performance measures significantly decreased for vertical jump peak velocity (-3.7%, $p<0.001$, ES =-0.51), vertical jump height (-5.3%, $p=0.037$, ES=-0.40), isometric absolute peak force (-5.5%, $p= 0.012$, ES= -0.21), and relative peak force (-7.3%, $p= 0.003$, ES=-0.47). Sensorimotor ability, via time to stabilization, significantly increased (61.4%, $p=0.004$, ES=0.99). In addition, there was no significant change in relative peak landing force during the DS (-2.3%, $p>0.05$, ES=-0.06). There was no significant change observed for relative vertical jump peak force (1.8%, $p>0.05$, *ES*=-0.06).

Table 7.1. Performance measures between pre- and post-detraining (surfing participation maintained but resistance training ceased) mean (± SD). [a]Significantly different from pre-test values.

Measure	Pre	Post	CV (95% Confidence Interval)	Effect size (*d*)	Effect descriptor
VJH (m)	0.38 ± 0.05	0.36 ± 0.05[a]	0.78 (0.60-0.90)	-0.40	Small
VJPV ($N\bullet kg^{-1}$)	2.41 ± 0.18	2.32 ± 0.17[a]	0.88 (0.76-0.95)	-0.51	Moderate
rVJPF ($N\bullet kg^{-1}$)	20.25 ± 1.95	20.62 ± 1.07	0.67 (0.43-0.84)	0.24	Small
IPF (N)	1691.83 ± 430.05	1598.79 ± 437.42[a]	0.93 (0.86-0.97)	-0.21	Small
rIPF ($N\bullet kg^{-1}$)	31.51 ± 5.10	29.22 ± 4.68[a]	0.80 (0.62-0.91)	-0.47	Small
TTS (s)	0.88 ± 0.30	1.42 ± 0.71[a]	0.72 (0.50-0.87)	0.99	Large
rPLF ($N\bullet kg^{-1}$)	42.8 ± 15.5	41.8 ± 16.0	0.47 (0.19-0.72)	-0.06	Trivial

Vertical jump height (VJH), vertical jump peak velocity (VJPV), relative vertical jump peak force (rVJPF), isometric peak force (IPF), relative isometric peak force (rIPF), time to stabilization (TTS), and relative time to stabilization peak landing force (rPLF).

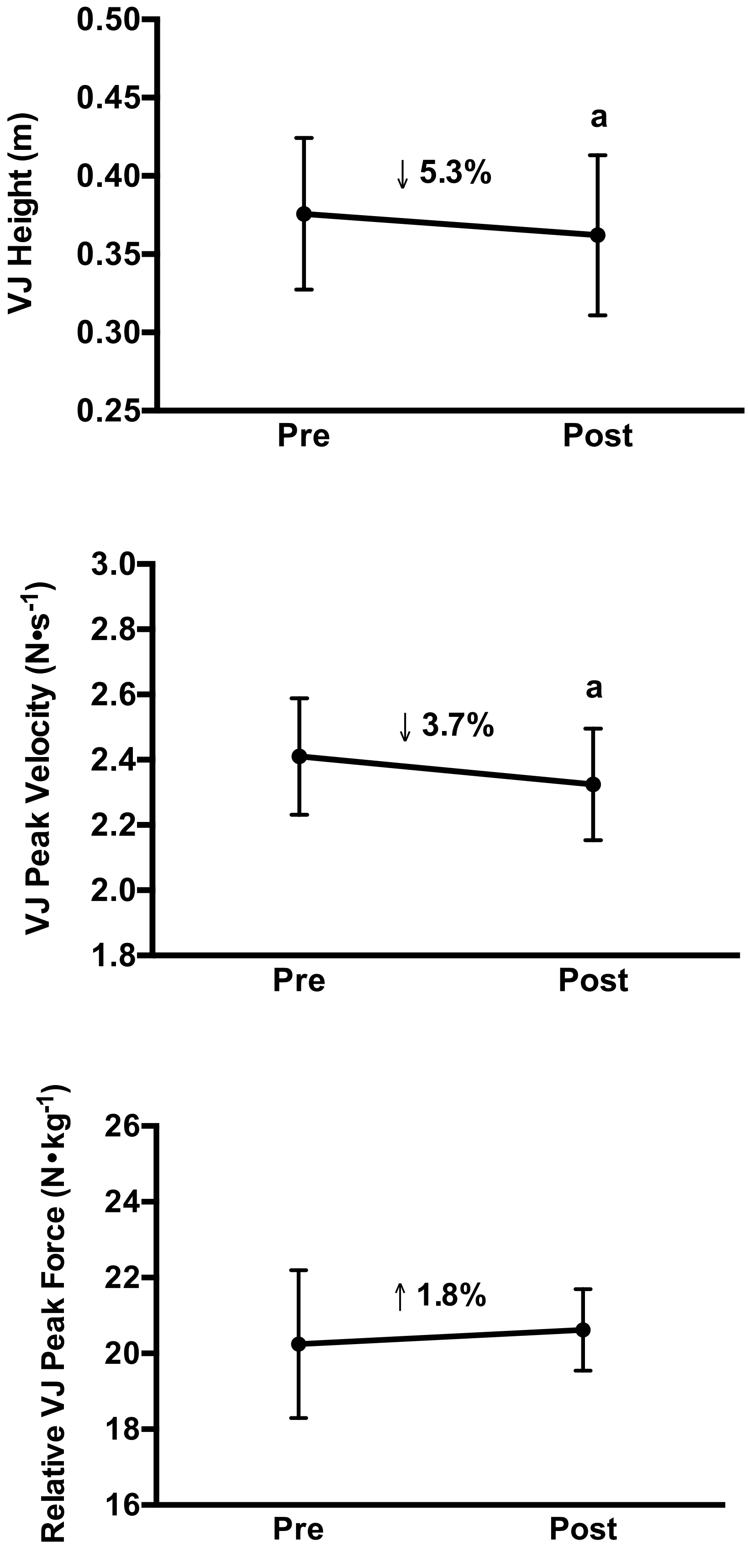


Figure 7.1. Percent changes for lower body power via countermovement vertical jump (VJ). [a]Significantly different from pre-test values.

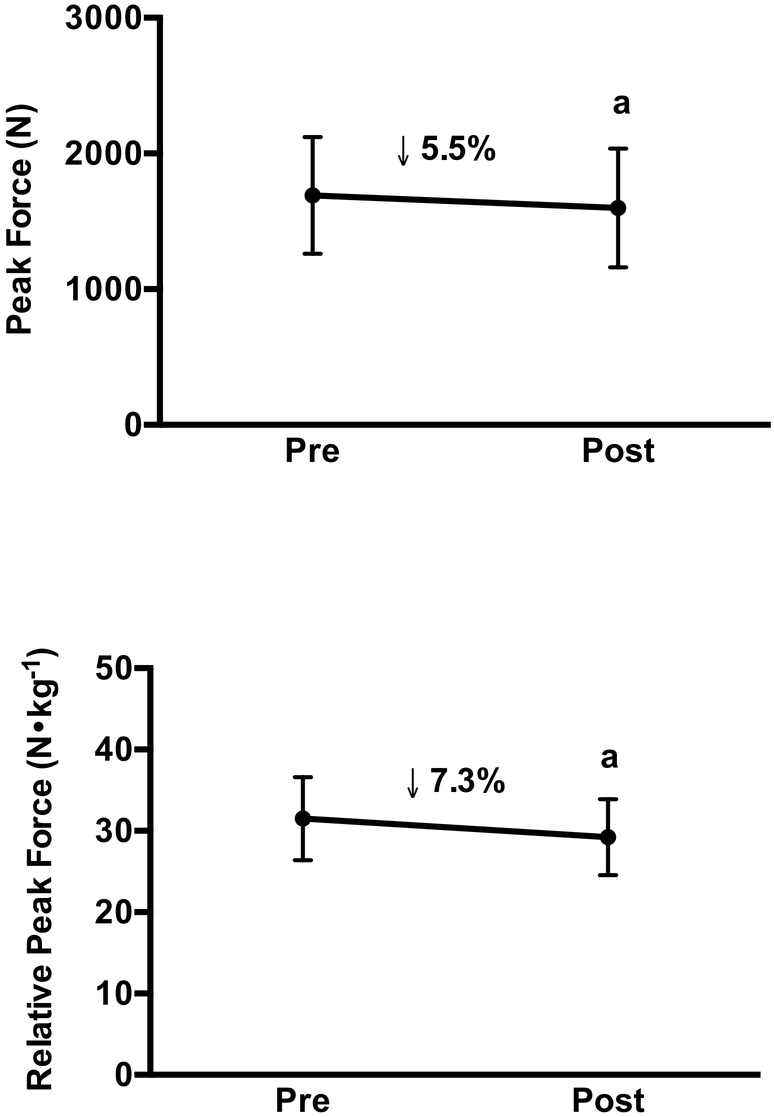
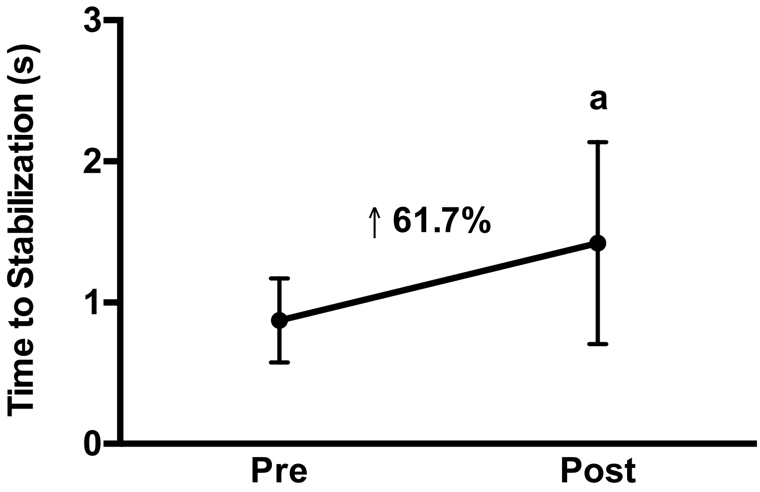


Figure 7.2. Percent changes fro absolute and relative lower body strength via Isometric mid-thigh pull. [a]Significantly different from pre-test values.



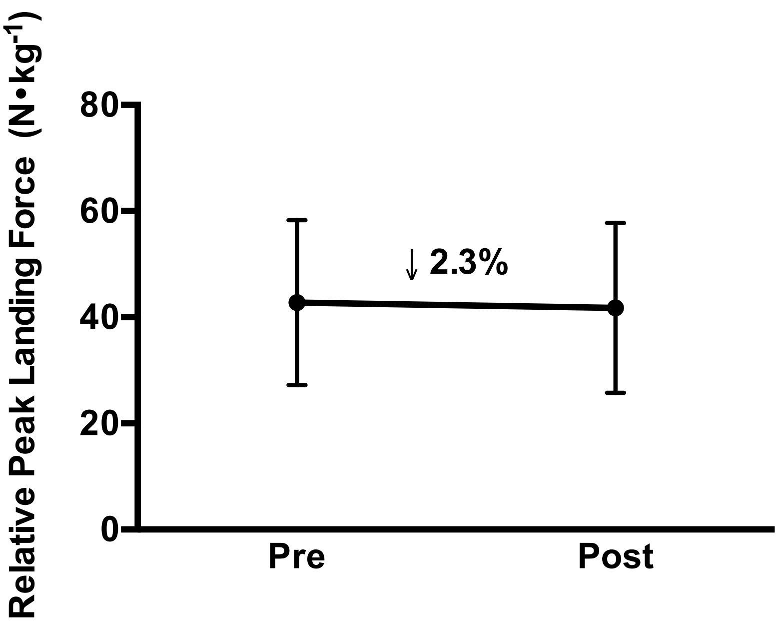


Figure 7.3. Percent changes for sensorimotor ability via drop and stick.
[a]Significantly different from pre-test values.

7.4 Discussion

The purpose of this study was to investigate the effects of a period of cessation of resistance training or detraining on power, strength, and sensorimotor ability subsequent to short-term resistance training. The main finding of this study was that cessation of resistance training for four-weeks negatively affected performance parameters for competitive adolescent surfers. This study provides evidence that surfing, in the absence of resistance training, is not a potent enough stimulus to maintain or increase physical capabilities. Recently, Loveless and Minahan (2010) reported that recreational and competitive surfers spend between 2-11 and 9.5-15 hours surfing per week, respectively, while participation in resistance training was reported as 0-2 hours per week. This finding is in line with Mendez-Villanueva et al. (2005), indicating that the majority of surfers' training is performed in the water. The adolescent surfers in our study surfed an average of 12-19 hours per week. It is possible that the higher number of surf hours in the current study might suggest adolescent surfers have more time and access and engage for the fun rather than purposeful training in the water.

In response to four weeks of detraining, power measures for the vertical jump of peak velocity and jump height significantly decreased by 3.7%, with a moderate magnitude (*ES*=-0.51) and 5.3%, with a small magnitude (*ES*=-0.40), respectively. Declines in vertical jump height in the present study are consistent with Faigenbaum et al. (1996), who reported a 4.0% decrease subsequent to eight weeks of detraining in adolescents. However, these findings conflict with Santos and Janeira (2009), who reported male adolescent basketball athletes were able to maintain explosive power following 16 weeks of detraining. An explanation for this conflict might be due to a higher volume of plyometrics involved in basketball practice throughout the 16-week detraining period. For example, basketball is a sport that involves continuous use of the stretch shortening cycle during activities such as lay-ups, dunks, rebounding, changes of direction, or blocking shots throughout practice. Although surfers perform similar absorption, braking, and propulsion phase

activities during wave riding, the volume is less due to the nature of the sport as wave riding represents only 3.8-8.0% of total activity (Farley, Harris, and Kilding, 2012a; Meir, Lowdon, and Davie, 1991; Mendez-Villanueva, Bishop, and Hamer, 2006). Therefore, it might be concluded that higher plyometric volume during basketball practice provides adequate stimulus to maintain power in adolescent basketball athletes compared to adolescent surfers. In another study, Hortobagyi et al. (1993) reported that 14 days of detraining did not significantly decrease vertical jump height in power athletes. A possible explanation for this might be that athletes with a longer training age are able to maintain explosive power for an extended time or that acute training cessation was not adequate to induce an effect on explosive power in power athletes.

Lower body isometric strength measures for absolute and relative peak force demonstrated significant decreases of 5.5% ($p=0.012$) with a small magnitude (*ES*=-0.21) and 7.3% ($p=0.003$), also of a small magnitude (*ES*=-0.47), respectively. These findings are consistent with Faigenbaum et al. (1996), who reported that detraining subsequent to eight weeks of resistance training significantly decreased lower body strength (-28.1%) in children ranging from 7-12 years. The magnitude of strength loss in the Faigenbaum study is much greater compared to the present study. Although the duration of their detraining period was double that of the current study, the differences in strength loss are quite large. It has been previously shown that lower physical level athletes have a larger window for adaptation (Cardinale, Newton, and Nosaka, 2011); hence, a possibility for the large decline might be similar for strength losses and gains in younger athletes compared to those with higher physical capacities.

Interestingly, Hortobagyi et al. (1993) reported significant decreases in Type II fibre area (6.4%) in power athletes over four weeks of detraining, however, there was no significant decrease identified in lower body strength (-0.9%). Although it has been documented that muscle CSA is associated with strength gains Maughan, Watson, and Weir, (1984), their findings further support the contention that highly trained athletes are able to maintain their strength following an acute detraining period compared to those with lower strength levels. An interesting finding from the

current study is that detraining had a greater effect on muscular strength compared to power output. Similarly, Faigenbaum et al. (1996) demonstrated a greater loss in strength than power during eight weeks of detraining. Conversely, Izquierdo et al. (2007) reported that Basque ball athletes demonstrated a greater loss in power (-17.0%) compared to muscular strength (-9.0%) after four weeks of detraining. Basque ball involves a diverse of sports played with one's bare hand, a racket, a wooden bat or basket, against a wall (Izquierdo et al., 2007). Collectively, these studies strongly suggest the effect of detraining on power and strength appears to be dependent on training age as well as the duration of detraining. Furthermore, consideration of the type, intensity and volume of physical activity undertake during the detraining period must also be taken into account regarding the magnitude of changes resulting from detraining (Faigenbaum et al.,1996). In other words, physical activities such as basketball, soccer, or volleyball place a greater demand on the neuromuscular system compared to activities that limit stretch shortening cycle loading from jumping and landing.

Although surfing is performed in a dynamic environment, the surfer is relatively stable as the speed of the board increases. In response to sensorimotor ability (TTS during drop and stick) following four weeks of detraining, the athletes took significantly ($p=0.004$) longer to stabilize from a drop landing. However, relative peak landing force was not significantly ($p>0.05$) altered. Interestingly, strength performance significantly decreased with an associated increase in TTS, however, athletes were able to maintain relative peak landing force.

In light of these findings, adolescent surfers experienced a reversal effect when resistance training was discontinued for four weeks. These results demonstrate that surfing, in the absence of resistance training, is not a potent enough stimulus to maintain performance parameters. The results of this study will increase awareness within the surfing community of the deleterious impact of detraining on strength, power, and sensorimotor ability.

7.5 Practical Applications

Competitive adolescent surfers with a relatively low training age should strive to maintain consistent resistance training in conjunction with surf training to avoid the negative decrements in power, strength, and sensorimotor ability, as these are likely to reduce physical capabilities. Therefore, by continuing resistant training in adolescent surfers, training age increases and continued gains in power, strength and sensorimotor abilities can be continued and therefore more likely to be able to contribute to increased performance during surfing or decreased injury risk and ability to tolerate surfing training loads.

Chapter 8

Conclusion

The overall purposes of this thesis were to develop and evaluate novel testing protocols and investigate sensorimotor ability training effects in competitive adolescent surfing athletes. This thesis is comprised of five studies. The first study established reliable and valid testing protocols for the 15 m sprint paddle to assess physical qualities that are relevant for the sport of surfing. The second study compared physical qualities between non-selected and selected junior competitive surfers and whether physical qualities reflect international competition selections. The third study developed and evaluated a drop and stick test to determine whether this novel test can detect differences in various levels of dynamic postural control. The fourth study investigated whether unstable surface training is more advantageous than stable surface training and the effects of both training interventions on physical qualities. The last study addressed the effect of short term detraining and the magnitude of changes in the physical qualities of surfing athletes.

The main finding of study 1 demonstrated that the comprehensive testing protocols used to measure physical qualities were reliable and valid. Furthermore, they were able to differentiate physical qualities among a pool of competitive surfing athletes. Elite junior surfers demonstrated greater lean mass, strength, and faster sprint and endurance paddling ability compared to competitive junior surfers. These findings have important practical implications and support the incorporation of these performance-testing protocols into a national high performance curriculum. Future research may adopt performance reference scales, then create a timeline of developmental stages to ensure young surfing athletes are on path throughout their junior and senior careers.

Study 2 revealed similar findings as study 1, with the selected junior surfers demonstrating significantly greater vertical jump height, relative isometric strength, and faster sprint and

endurance paddle ability compared to non-selected junior surfers. These results further validate the comprehensive test protocol from study 1 as being suitable to detect physical quality differences in a cohort of competitive junior surfing athletes. Long-term studies should investigate changes in physical qualities each year for those selected to represent the junior international team to determine whether physical qualities continue to reflect selection. Furthermore, the data from performance measures may be used to tailor individual programs in an effort to enhance physical qualities and prepare the surfing athletes for competition.

Study 3 demonstrated that a novel drop and stick test expressed good to excellent single measures reliability for time to stabilisation in assessing dynamic postural control. Although relative landing force revealed greater variability, this measure provides important practical implications to assess landing force and force attenuation in various surfing levels. Therefore, it is suggested that practitioners create reference scales for both measures to track competitive surfing athletes throughout their development pathways. It was expected that lower level athletes would exhibit greater landing force, and these results, along with previous studies, confirmed that lower level athletes exhibit greater landing force than adults or higher-level athletes. Landing is a trainable skill; therefore landing intervention programs should be implemented into a performance curriculum. Further research is necessary to investigate the effects of short and long-term landing intervention programs on sensorimotor ability.

Study 4 provided greater insight into short-term unstable and traditional stable surface training adaptations. It is not surprising that the unstable condition provided no advantages over traditional resistance training in strength and power gains. Furthermore, unstable training was not more beneficial in sensorimotor abilities when compared to stable training. Substantial evidence has been reported that unstable surface training does not provide an adequate training stimulus for higher-level athletes. Furthermore, the results of this study confirm previous studies reporting that unstable surface training has negative implications on athletic performance. The goal of any resistance-training program is to promote positive adaptations that transfer to the demands of the

sport. Therefore, it would be of great interest for long-term studies to determine whether traditional resistance training results in increased strength, power, and sensorimotor ability and correlates with more explosive surfing manoeuvres (e.g., bottom turns, cutbacks, snaps, or top turns).

Study 5 demonstrated that surfing alone, in the absence of resistance training, does not provide a sufficient stimulus to increase or maintain strength and power measures over the duration of four weeks of detraining. In addition, time to stabilisation significantly worsened, with surfing athletes taking longer to stabilise following a drop landing. This is important information for surfing communities involved with the development pathway of young surfing athletes. There is conflicting evidence from earlier studies regarding the rate of decline in physical qualities. It appears the rate of decline differs markedly by detraining duration, training age, prior training, or sport participation and significantly influences physical qualities. The present data suggest that competitive surfing athletes must include resistance training in conjunction with surfing practice. From a practical standpoint, investigating the effect of tapering on strength, power, and sensorimotor ability would be more applicable for surfing athletes rather than the effects of long-term detraining.

Overall, this thesis established reliable and valid testing protocols to assess physical qualities of competitive surfing athletes. With the rate of young surfing athletes participating in competitive surfing increasing every year, these findings support implementing these protocols in a performance curriculum to evaluate and track physical qualities throughout the surfer's development pathway. Furthermore, these findings also suggest that surfing athletes incorporate and maintain periodised resistance training in land-based programs throughout their competitive season in order to maintain physical qualities. Long-term resistance training follow up studies are warranted to provide further understanding regarding resistance training and performance changes throughout the surfer's junior and senior pathways.

References

Aerts, I., Cumps E., Verhagen E., Meeusen R. Efficacy of a 3 month training program on the jump-landing technique in jump-landing sports. Design of a cluster randomized controlled trial. *BMC Musculoskeletal Disorders.* 2010;11:281.

Amonette, W. E., Brown, L. E., De Witt, J. K., Dupler, T. L., Tran, T. T., Tufano, J. J., Spiering, B, A. Peak vertical jump power estimations in youths and young adults. *J Strength Cond Res*. 2012;26(7):1749-1755.

Anderson, K. G., Behm, D. G. Maintenance of EMG activity and loss of force output with instability. *J. Strength Cond. Res.* 18(3):637-640, 2004.

Anderson, K., Behm, D. G. Trunk muscle activity increases with unstable squat movements. *Canadian J Appl Physiol*. 30(1):33-45, 2005.

Andersen, L. L., Andersen, J. L., Magnusson, S. P., Suetta, C., Madsen, J. L., Christensen, L. R., Aagaard, P. Changes in the human muscle force-velocity relationship in response to resistance training and subsequent detraining. *J Appl Physiol* 99: 87-94, 2005.

Association of Surfing Professionals, Rule Book, 2014.

Baechle, T. R., Earle, R. W. *Essentials of Strength Training and Conditioning* (3rd ed). Champaign, IL: Human Kineics, 2008.

Baker, D. Improving vertical jump performance through general, special, and specific strength training: A brief review. 10(2):131-136, 1996.

Baker, D., Nance, S., Moore, M. The load that maximizes the average mechanical power output during explosive bench press throws in highly trained athletes. *J. Strength Cond. Res*. 15(1):20-24, 2001.

Barlow, M. J., Findlay, M., Gresty, K., Cooke, C. Anthropometric variables and their relationship to performance and ability in male surfers. *Eur J Sport Sci*. 7(39):1-7, 2012.

Batterham, A., Hopkins, W. Making meaningful inferences about magnitudes. *Int J Sports Physiol Perform* 1:50-57, 2006.

Behm, D.G.,. Anderson, K. A., Curnew, R. S. Muscle force and activation under stable and unstable conditions. *J. Strength Cond. Res.* 16(3):416-422, 2002.

Behm, D.G., Wahl, M. J., Button, D. C., Power, K. E., Anderson, K. G. Relationship between hockey skating speed and selected performance measures. *J. Strength Cond. Res.* 19(2):326-331, 2005.

Behringer M., Vom Heede, A., Matthews, M., Mester, J. Effects of strength training on motor performance skills in children and adolescents: A meta-analysis. *Pediatr Exerc Sci*. 23:188-206, 2011.

Bruhn, S., Kullmann, N., Gollhofer, A. The effects of a sensorimotor training and a strength training on postural stabilisation, maximum isometric contraction and jump performance. *Int. J. Sports Med.* 25(1):56-60, 2004.

Cardinale, M., Newton, R. U., Nosaka, K. *Strength and Conditioning: Biological principles and practical applications*. 2011.

Chaouachi, A., Hammami, R., Kaabi, S., Camari, K., Drinkwater, E. J., Behm, D. G. Olympic weightlifting and plyometric training with children provides similar or greater performance improvements than traditional resistance training. *J. Strength Cond. Res*. 28(6):1483-1495, 2014.

Chapman, D. W., Needham, K. J., Allison, G. T., Lay, B., Edwards, D. J. Effects of experience in a dynamic environment on postural control. *Br J Sports Med.* 42(1):16-21, 2008.

Christou, M., Smilios, I., Sotiropoulos, K., Volaklis, K., Pilianidis, T., Tokmakidis, S. P. Effects of resistance training on the physical capacities of adolescent soccer players. *J Strength Cond Res*. 20(4):783-791, 2006.

Cohen J. Statistical power analysis for the behavioural sciences. *Lawrence Erbaum Associates* (2nd ed), 1988.

Colby, S. M., Hintermeister, R. A., Torry, M. R., Steadman, J. R. Lower limb stability with ACL impairment. *J Orthop Sports Phys Ther*. 29(8):444-451, 1999.

Cormack, S. J., Newton, R. U., McGuigan, M. R., Doyle, T. L. Reliability of measures obtained during single and repeated countermovement jumps. *Int J Sports Physiol Perform*. 3:131-44, 2008.

Cressey, E. M., West, C. A., Tiberio, D. P., Kraemer, W. J., Maresh, C. M. The effects of ten weeks of lower-body unstable surface training on markers of athletic performance. *J Strength Cond Res*. 21(2):561-567, 2007.

DeRenne, C., Ho, K. W., Murphy, J. C. Effects of general, special, and specific resistance training on throwing velocity in baseball. A brief review. *J Strength Cond Res*. 15(1):148-156, 2001.

Dufek, J. S., Bates, B. T. The evaluation and prediction of impact forces during landings. *Med Sci Sports Exerc*. 22(2):370-377, 1990.

Ebben, W. P., Vanderzanden. T., Wurm, B. J., Petushek, E. J. Evaluating plyometric exercises using time to stabilization*. J Strength Cond Res.* 24(2):300-306, 2010.

Eisen, T. C., Danoff, J. V., Leone, J. E., Miller, T. A. The effects of multiaxial and uniaxial unstable surface balance training in college atheltes. *J Strength Cond Res*. 24(7):1740-1745, 2010

Eurich, A. D, Brown, L. E., Coburn, J. W., Noffal, G. J., Nguyen, D., Khamoui, A.V., Uribe, B. P. Performance differences between sexes in the pop-up phase of surfing. *J Strength Cond Res*. 24(10):2821-2825, 2010.

Everline, C. Shortboard performance surfing: A qualitative assessment of maneuvers and a sample periodized strength and conditioning program in and out of the water. *Strength Cond J*. 29(3):32-40, 2007.

Faigenbaum, A. D., Zaichkowsky, W., Westcott, W.L., Micheli, L. J., Fehlandt, A. The effects of a twice per week strength training program on children. *Pediatr Exerc Sci.* 5:339-346, 1993.

Faigenbaum, A. D., Westcott, W. L., Micheli, L. J., Outerbridge, A. R., Long, C. J., LaRosa-Loud, R., Zaichkowsky, L. D. The effects of strength training and detraining on children. *J Strength Cond Res.* 10(2):109-114, 1996.

Faigenbaum, A. D. Strength training for children and adolescents. *Clin Sports Med.* 19(4):593-619, 2000.

Faigenbaum, A. D., Loud, R. L., O'Connell, J., Glover, S., Westcott, W. L. Effects of different resistance training protocols on upper-body strength and endurance development in children. *J Strength Cond Res.* 15(4):459-465, 2001.

Faigenbaum, A. D., Milliken, L .A., Loud, R. L., Burak, B. T., Doherty, C. L., Westcott, W. L. Comparison of 1 and 2 days per week of strength training in children. *Res Q Exerc Sport.* 73(4):416-424, 2002.

Faigenbaum, A. D., Kraemer, W. J., Blimkie, C. J., Jeffreys, I., Micheli, L. J.,Nitka, J. M., Rowland, T. W. Youth resistance training: updated position statement paper from the national strength and conditioning association. *J. Strength Cond. Res*. 23(5Suppl):S60-79, 2009.

Farley, O. R., Harris, N. K., Kilding, A. E. Physiological demands of competitive surfing. *J. Strength Cond. Res*. 26(7):1887-1896, 2012a.

Farley, O. R., Harris, N. K., Kilding, A. E. Anaerobic and aerobic fitness profiling of competitive surfers. *J Strength Cond Res*. 26(8):2243-2248, 2012b.

Flanagan, E. P., Ebben, W. P., Jensen, R. L. Reliability of the reactive strength index and time to stabilization during depth jumps. *J Strength Cond Res.* 22(5):1677-82, 2008.

Furness, J., Hing, W., Abbot, A., Walsh, J., Sheppard, J. M., Climstein, M. Retrospective analysis of chronic injuries in recreational and competitive surfers: Injury location, type, and mechanism. *Int J Aqua Res Educ*. 8(3):277-287, 2014.

Gabbett, T. J. Physiological characteristics of junior and senior rugby league players. *Br J Sports Med*. 36:334-339, 2002.

Gabbett, T. J. Physiological and anthropometric characteristics of starters and non-starters in junior rugby league players, aged 13-17 years. *J Sports Med Phys Fitness*. 49(3):233-239, 2009.

Gabbett, T. J., Kelly, J., Ralph, S., Driscoll, D. Physiological and anthropometric characterises of junior elite and sub-elite rugby league players, with special reference to starters and non-starters. *J Sci Med Sports*. 12:215-222, 2009.

Garhammer, J. A review of power output studies of olympic and powerlifting: Methodology, performance prediction, and evaluation tests. *J Strength Cond Res*. 7:76-89,1993.

Gharahdaghi, N., Alvar, Y. M., Ashrostaghi, M., Barancheshmeh, M. The effects of a short-term detraining on anthropometric, hormonal and functional factors in male wrestlers. *J Res Appl Sci.* 1(3):54-59, 2014.

Goldie, P. A., Bach, T. M., Evans, O. M. Force platform measures for evaluating postural control: reliability and validity. *Arch Phys Med Rehabil.* 70:510-517, 1989.

Gore, C. J. *Physiological tests for elite athletes*. Canberra: Australian Sports Commission, 2000.

Granacher, U., Gollhofer, A., Kriemler, S. Effects of balance training on postural sway, leg extensor strength, and jumping height in adolescents. *Res Q Exerc Sport*. 81(3):245-251, 2010.

Granacher, U., Muehlbauer, T., Taube, W., Gollhofer, A., Gruber, M. Sensorimotor Training. Cardinale, M., Newton, R. U., Nosaka, K. (Eds). *Strength and Conditioning - Biological Principles and Practical Applications.* Wiley-Blackwell, Oxford, UK. 399-409, 2011.

Gruber, M., Gollhofer, A. Impact of sensorimotor training on the rate of force development and neural activation. *Eur J Appl Physiol*. 92:98-105, 2004.

Gruber, M., Gruber, S. B., Taube, W., Schubert, M., Beck, S. C., Gollhofer A. Differential effects of ballistic versus sensorimotor training on rate of force development and neural activation in humans. *J. Strength Cond. Res*. 21(1):274-282, 2007.

Haff, G. G., Stone, M., O'Bryant, H., Harman, E., Dinan, C., Johnson, R., Han, K. Force-Time dependent characteristics of dynamic and isometric muscle action. *J Strength Cond Res*. 11:269-272, 1997.

Häkkinen, K., Alen, M., Komi, P. V. Changes in isometric force-and relaxation-time, electromyographic and muscle fibre characteristics of human skeletal muscle during strength training and detraining. *Acta Physiol. Scand*. 125:573-585, 1985.

Harries, S. K., Lubans, D. R., Callister, R. Resistance training to improve power and sports performance in adolescent athletes athletes: A systematic review and meta-analysis. *J Sci Med Sport*. 15:532-540, 2012.

Harris, N. K., Cronin, J. B., Hopkins, W. G., Hansen, K. T. Squat jump training at maximal power loads vs. heavy loads: effect on sprint ability. *J Strength Cond Res*. 22(6):1742-1749, 2000.

Hopkins, W. G. How to analyze a straighforward controlled trial (Excel spreadsheet). *Sportscience*. 2003.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 41:3-13, 2009.

Hortobagyi, T., Houmard, J. A., Stevenson, J. R., Fraser, D. D., Johns, R. A., Israel, R. G. The effects of detraining on power athletes. *Med Sci Sports Exerc.* 25:929-935, 1993.

Humberstone-Gough, C. E., Saunders, P. U., Bonetti, D. L., Stephens, S., Bullock, N., Anson, J. M., Gore, C. J. Comparison of live high: Train low altitude and intermittent hypoxic exposure. *J Sports Sci Med*. 12:394-401, 2013.

ISA International Judging and Officiating. 2012.

Izquierdo, M., Ibanez, J., Gonzalez-Badillo, J. J., Ratamess, N. A., Kraemer, W. J., Hakkinen, K., Bonnabau, H., Granados, C., French, D. N., Gorostiaga, E. M. Detraining and tapering effects on hormonal responses and strength performance. *J Strength Cond Res* 21:768-775, 2007.

Kawamori, N., Rossi, S. J., Justice, B. D., Haff, E. E., Pistilli, E. E., O'Bryant, H. S., Stone, M. H., Haff, G. G. Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. *J. Strength Cond. Res*. 20(3):483-491, 2006.

Kibele, A., Behm, D. G. Seven weeks of instability and traditional resistance training effects on strength, balance and functional performance. *J. Strength Cond. Res.* 23(9):2443-2450, 2009.

Kraemer, W. J., Koziris, L. P., Ratamess, N. A., Häkkinen, K., Triplett-McBride, N. T., Fry, A. C., Gordon, S. E., Volek, J. S., French, D. N., Rubin, M. R., Gomez, A. L., Sharman, M. J., Lynch, J. M., Izquierdo, M., Newton, R. U., Fleck, S. Detraining produces minimal changes in physical performance and hormonal variables in recreationally strength-trained men. *J Strength Cond Res.* 16(3):373-382, 2002.

Kraska, J. M., Ramsey, M. W., Haff, G. G., Fethke, N., Sands, W. A., Stone, M. E., Stone, M. H. Relationship between strength characteristics and unweighted and weighted vertical jump height. *Int J Sports Physiol Perform*. 4:461-473, 2009.

Lephart, S. M., Riemann, B. L., Fu, F. H. Proprioception and neuromuscular control in joint stability. *(eds SM Lephart and FH Fu)* Human kinetics, Champaign, IL. 17-24, 2000.

Loveless, D. J., Minahan, C. Peak aerobic power and paddling efficiency in recreational and competitive junior male surfers. *Eur J Sport Sci*. 10:407-415, 2010a.

Loveless, D. J., Minahan, C. Two reliable protocols for assessing maximal paddling performance in surfboard riders. *J Sport Sci*. 28:797-803, 2010b.

Lowdon, B. J., Pateman, N. A., Pitman, A. J. Surfboard-riding injuries. *Med J Aust*. 2:613-616, 1983.

Lowdon, B. J., Pitman, A. J., Pateman, N. A., Ross, K. Injuries to international competitive surfboard riders. *J Sports Med Phys Fitness*. 27:57-63, 1987.

Lundgren, L., Tran, T. T., Dunn, M., Nimphius, S., Sheppard, J. M. Analysis of manoeuvres and scoring in competitive surfing. *Int J Sport Sci Coach*. 9:663-669, 2014.

Maughan, R. J., Watson, J. S., Weir, J. Muscle strength and cross-sectional area in man: A comparison of strength-trained and untrained subjects. *Br J Sports Med* 18:149-157, 1984.

McNair, P. J., Prapavessis, H. Normative data of vertical ground reaction forces during landing from a jump. *J Sci Med Sport.* 2:86-88, 1999.

McNair, P. J., Prapavessis, H., Callender, K. Decreasing landing forces: effect of instruction. *Br J Sports Med.* 34:293-296*,* 2000.

Meir, R. A., Lowdon, B. J., Davie, A. J. Heart rates and estimated energy expenditure during recreational surfing. *Aust J Sci Med Sport*. 23:70-74, 1991.

Mendez-Villanueva, A., Bishop, D. Physiological aspects of surfboard riding performance*. Sports Med*. 35:55-70, 2005.

Mendez-Villanueva, A., Perez-Landaluce, J., Bishop, D., Fernandez-Garcia, B., Ortolano, R., Leibar, X., Terracios, N. Upper body aerobic fitness comparison between two groups of competitive surferboard riders*. J Sci Med Sport*. 8:43-51, 2005.

Mendez-Villanueva, A., Bishop, D., Hamer, P. Activity profile of world-class professional surfers during competition: a case study*. J Strength Cond Res*. 20:477-482, 2006.

Metcalfe, J., Kelly, J. Land-based conditioning for UK-based surfers. *UK Strength and Conditioning Association*. 25:23-28, 2012.

Meylan, C., Malatesta, D. Effects of in-season plyometric training within soccer practice on explosive actions of young players. *J Strength Cond Res*. 23(9):2605-2613, 2009.

McBride, J. M., Triplett-McBride, T., Davie, A., R. U. Newton. The effect of heavy- vs. light-load jump squats on the development of strength, power, and speed. *J Strength Cond Res.* 16(1):75-82, 2002.

McBride, J. M., Cormie, P., Deane, R. Isometric squat output and muscle activity in stable and unstable conditions. *J. Strength Cond. Res.* 20(4):915-918, 2006.

Mizrahi, J., Susak Z. In-vivo elastic and damping responses of the human leg to impact forces. *J Biomech Eng.* 104:63-66, 1982.

Mohammadi, A., Alizadel, M., Galeni, A. The effects of six weeks strength exercises on static and dynamic balance of young male athletes. Procedia Social Behavioral Sci. 32: 247-250, 2012.

Myer, G. D., Ford, K. R. Brent, J. L. Hewett, T. E. The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing force in female athletes. *J Strength Cond Res.* 20(2):345-353, 2006.

Newton, R. U., Kraemer, W. J. Häkkinen, K. Effects of ballistic training on preseason preparation of elite volleyball players. *Med Sci Sports Exerc*. 31:323-330, 1999.

Newton, R. U., Hakkinen, K., Hakkinen, A., McCormick, M., Volek, J., Kraemer, W. J. Mixed-methods resistance training increases power and strength of young and older men. *Med Sci Sports Exerc*. 34:1367-1375, 2002.

Nimphius, S., McGuigan, M. R., Newton, R. U. Relationship between strength, power, speed, and change of direction performance of female softball players. *J Strength Cond Res*. 24:885-95, 2010.

Nuzzo, J. L., McBride, J. M., Cormie, P., McCaulley, G. O. Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. *J Strength Cond Res*. 22(3):699-707, 2008.

Oberacker, L. M., Davis, S. E., Haff, G. G., Witmer, C. A., Moir, G. L. The yo-yo IR2 test: Physiological response, reliability, and application to elite soccer. *J. Strength Cond. Res.* 26(10):2734-2740, 2012.

Paillard, T., Margnes, E., Portet, M., Breucq, A. Postural ability reflects the athletic skill level of surfers. *Eur J Appl Physiol*. 111:1619-1623, 2011.

Pereira, A., Izquierdo, M., Siva, A. J., Costa, A. M., González-Badillo, J. J., Marques, M. C. Muscle performance and functional capacity retention in older women after high-speed power training cessation. *Exp Gerontol*. 1-5, 2012.

Peterson, M. D., Rhea, M. R., Alvar, B. A.. Maximizing strength development in athletes: A meta-analysis to determine the dose-response relationship. *J. Strength Cond. Res.* 18(2):377-382, 2004.

Portney, L. G., Watkins, M. P. *Foundations of Clinical Research: Applications to Practice*. Norwalk, CT: Appleton and Lange. 509-615, 1993.

Read, M. M., Cisar, C. The influence of varied rest interval lengths on depth jump performance. *J Strength and Cond Res*. 15(3):279-283, 2001.

Rhea, M. R., Alvar, B. A., Burkett, L. N., Ball, S. D. A meta-analysis to determine the dose response for strength development. *Med Sci Sports Exerc*. 35(3):456-464, 2003.

Ross, S., Guskiewicz, K. Examination of static and dynamic postural stability in individuals with functionally stable and unstable ankles. Clin J Sport Med. 14:332-338, 2004.

Ross, S., Guskiewicz, K. Single-leg jump-landing stabilization times in subjects with functionally unstable ankles. *J Athl Train*. 40: 298-304, 2005.

Sale, D.G. Neural adaptation to strength training. *In: Strength and Power in Sport*, Komi, P. V. (2nd ed.) Malden, MA: Blackwell Science. 281-314, 2003.

Salehzadeh, K., Karimiasi, A., Borna, S., Shirmohammadzadeh, M. The effects of 8-week strength, plyometric and combinational trainings on dynamic balance of teenager handball players. *J Basic Appl Sci Res*. 1(12):3316-3321, 2011.

Santos, E. J. A. M., Janeira, M. A. A. S. Effects of reduced training and detraining on upper and lower body explosive strength in adolescent male basketball players. *J Strength Cond Res* 23(6): 1737-1744, 2009.

Santos, E. J. A. M., Janeira, M. A. A. S. The effects of resistance training on explosive strength indicators in adolescent basketball players. *J Strength Cond Res. 26(10): 2641-2647, 2012.*

Scase, E., Cook, J., Makdissi, M., Gabbe, B., Shuck, L. Teaching landing skills in elite junior Australian football: evaluation of an injury prevention strategy. *Br J Sports Med*. 40(10):834-838, 2006.

Secomb, J. L., Farley, O. R. L., Lundgren, L., Tran, T. T., King, A., Nimphius, S., Sheppard, J. M. Associations between the performance of scoring manoeuvres and lower-body strength and power in elite surfers. *Int J Sports Sci Coach*. In Press.

Seegmiller, J. G., McCaw, S. T. Ground reaction forces among gymnasts and recreational athletes in drop landings. *J Athl Train*. 38(4):311-314, 2003.

Seitz, L. B., De Villarreal, E. S. Haff, G. G. The temporal profile of postactivation potentiation is related to strength level. *J. Strength Cond. Res.* 28(3):706-715, 2014.

Sheppard, J. M., Cormack, S., Taylor, K. L., McGuigan, M. R., Newton, R. U. Assessing the force-velocity characteristics of well trained athletes: the incremental load power profile. *J Strength Cond Res*. 22(4):1320-1326, 2008.

Sheppard, J.M., Chapman, D. W., Gough, C., McGuigan, M. R. Newton, R. U. Twelve-month training-induced changes in elite international volleyball players. *J Strength Cond Res*. 23(7):2096-2101, 2009.

Sheppard, J. M., Chapman, D.W. An evaluation of a strength qualities assessment test for the lower body. *J. Aust. Strength Cond*. 19:14-20, 2011.

Sheppard, J. M., McNamara, P., Osborne, M., Andrews, M., Oliveira Borges, T., Walshe, P., Chapman, D. W. Association between anthropometry and upper-body strength qualities with sprint paddling performance in competitive wave surfers. *J. Strength Cond. Res.* 26(12):3345-3348, 2012a.

Sheppard, J. M., Osborne, M., Chapman, D., Andrews, M. Anthropometric characteristics, upper-body strength, and sprint paddling performance in competitive surfers. *J Aus Strength Cond*. 20:5-10, 2012b.

Sheppard, J. M., Nolan, E., Newton, R. U. Changes in strength and power qualities over two years in volleyball players transitioning from junior to senior national team. *J Strength Cond Res*. 26(1):152-157, 2012c.

Sheppard, J. M., Osborne, M., Chapman, D., Andrews, M., McNamara, P. Technique adjustments influence the performance of sprint paddling in competitive male surfers. *Int J Sports Sci Coach*. 8:42-51, 2013a.

Sheppard, J. M., Nimphius, S., Haff, G. G., Tran, T. T., Spiteri, T., Brooks, H., Slater, G., Newton, R. U. Development of a comprehensive performance testing protocol for competitive surfers. *Int J Sports Physiol Perform*. 8:490-495, 2013b.

Slater, G. J., Duthie, G. M., Pyne, D. B., Hopkins, W. G. Validation of a skinfold based index for tracking proportional changes in lean mass. *Br J Sports Med*. 40:208-213, 2006.

Staron, R. S., Leonardi, M. J., Karapondo, D. L., Malicky, E. S., Falkel, J. E., Hagermanm, F. C., Hikida, R. S. Strength and skeletal muscle adaptations in heavy-resistance-trained women after detraining and retraining. *J Appl Physiol* 70:631-640, 1991.

Surfing Australia National Curriculum Book, 2012.

Szymanski, D., Szymanskoi, J., Bradford, J., Schade, R., Pascoe, D. Effect of twelve weeks of medicine ball training on high school baseball players. *J Strength Cond Res*. 21(1):894-9001, 2007.

Taaffe, D. R., Marcus, R. Dynamic muscle strength alterations to detraining and retraining in elderly men. Clinical Physiology. 17(3):311-324, 1997.

Taube, W., Kullmann, N., Leukel, C., Kurz, O., Amtage, F., Gollhofer, A. Differential reflex adaptations following sensorimotor and strength training in young elite athletes. *Int. J. Sports Med*. 28(12): 999-1005, 2007.

Till, K., Cobley, S., O'Hara, J., Brightmore, A., Cooke, C., Chapman, C. Using anthropometric and performance characteristics to predict selection in junior UK Rugby League players. *J Sci Med Sport.* 14(3):264-269, 2011.

Tran, T. T., Lundgren, L., Secomb, J., Farley, O. R. L., Haff, G. G., Seitz, L. B., Nimphius, S., Newton, R. U., Sheppard, J. M. Comparison of physical capacities between non-selected and selected elite male competitive surfers for the national junior team. *Int J Sports Physiol Perform*. 10:178-182, 2015a.

Tran, T. T., Lundgren, L., Secomb, J., Farley, O. R. L., Haff, G. G., Nimphius, S., Newton, R. U., Sheppard, J. M. The development and evaluation of drop and stick method to assess landing skills in various levels of competitive surfers. *Int J Sports Physiol Perform*. 10:396-400, 2015b.

Webster, K. A., Gribble, P. A. Time to stabilization of anterior cruciate liagment-reconstructed versus healthy knees in National Athlete Association Division I female athletes. *J Athl Train*. 45(6):580-585, 2010.

Wikstrom, E. A., Powers, M. E., Tillman, M. D. Dynamic stabilization time after isokinetic and functional fatigue. *J Athl Train*. 39(3): 247-253, 2004.

Wikstrom, E. A., Tillman, M. D., Borsa, P. A. Detection of dynamic stability deficits in subjects with functional ankle instability. *Med Sci Sports Exerc.* 37:169-179, 2005a.

Wikstrom, E. A., Tillman, M. D., Smith, A. N., Borsa, P. A. A new force-plate technology measure of dynamic postural stability: The dynamic postural stability index. *J Athl Train*. 40(4):305-309, 2005b.

Wikstrom, E. A., Tillman, M. D., Chmielewski, T. L., Borsa, P. A. Measurement and evaluation of dynamic joint stability of the knee and ankle after injury. *Sports Med*. 36: 393-410, 2006.

Wilson, G. J., Murphy, A. J., Walshe, A. The specificity of strength training: the effect of posture. *Eur J Appl Physiol*. 73:346-352, 1996.

Wisløff, U., Castagna, C., Helgerud, J., Jones, R., Hoff, J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med*. 38(3):285-288, 2004.

Yaggie, J. A., Campbell, B. M. Effects of balance training on selected skills. *J Strength Cond Res.* 20(2):422-428*,* 2006.

Young, W., McLean, B., Ardagna, J. Relationship between strength qualities and sprinting performance. *J Sports Med Phys Fitness*. 35(1):13-19, 1995.

Appendices

Appendix 1: Ethics Approval Letter

From: Research Ethics
Sent: Monday, 3 December 2012 11:27 AM
To: Tai TRAN
Cc: Sophia NIMPHIUS; Rob NEWTON; Jeremy SHEPPARD; Research Assessments; FCHS Student Information Office
Subject: 8947 TRAN Ethics approval

Dear Tai

Project Number: 8947 TRAN
Project Name: THE EVALUATION AND TRAINING OF SENSORIMOTOR ABILITIES IN COMPETITIVE SURFERS

Student Number: 10261944

The ECU Human Research Ethics Committee (HREC) has reviewed your application and has granted ethics approval for your research project. In granting approval, the HREC has determined that the research project meets the requirements of the National Statement on Ethical Conduct in Human Research.

The approval period is from 3 December 2012 to 31 December 2014.

The Research Assessments Team has been informed and they will issue formal notification of approval. Please note that the submission and approval of your research proposal is a separate process to obtaining ethics approval and that no recruitment of participants and/or data collection can commence until formal notification of both ethics approval and approval of your research proposal has been received.

All research projects are approved subject to general conditions of approval. Please see the attached document for details of these conditions, which include monitoring requirements, changes to the project and extension of ethics approval.

Please feel free to contact me if you require any further information.

Regards
Sue

Sue McDonald
Research Ethics Support Officer
Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 5122
Fax: (08) 6304 5044
Email: research.ethics@ecu.edu.au<mailto:research.ethics@ecu.edu.au>

Appendix 2: Information Letter and Inform Consent Study 1

INFORMATION LETTER TO PARTICIPANTS

The development and evaluation of a comprehensive sport-science testing protocol for competitive surfers.

Chief Investigator:

Dr. Jeremy Sheppard

Email: Jeremy.sheppard@ecu.edu.au

Thank you for expressing interest in this research project. The reason for providing you with the following information is to fully inform you of the purpose and the nature of the study. This research project has been approved by the ECU Human Research Ethics Committee.

You are invited to participate in a research project that will investigate the physical abilities of surfers. Appropriate and valid testing protocols evaluating the physical performances of surfing athletes is not well refined. This project will develop and evaluate a comprehensive sport-science testing protocol for use with surfers, including measures of anthropometry (height, weight, leanness), strength and power, endurance, and sensorimotor (balance) abilities. The outcomes from this study will result in the creation of a national sport-science testing protocol for surfing. This outcome is integral to future research projects involving the physical capabilities of competitive surfers, as standard, defensible testing protocols have not been clearly established.

The data for this study will be collected in appropriate facilities, including office space (for the anthropometry), a training facility (strength and power and sensorimotor), and an outdoor pool (endurance testing). The entire testing procedure will take ~90 minutes.

All information collected in this study will be confidential. Only the primary investigator will have access to any information collected and all written documents and data will be coded so that individual identification of your data will not be possible for anyone else.

The primary benefit of your participation in this study is obtaining information about your physical capabilities. This information will be shared with you by the primary investigator, and any additional findings that can improve your performance will also be provided. You should be assured that results presented at conferences or in scientific publications will not include any information that may identify individual participants.

Participation is voluntary and no explanation or justification is needed if you choose not to participate. You are also free to withdraw your consent to further involvement in the research project at any time. If you are interested in participating in the study you will need to complete an informed consent and return it to the principal investigator.

If you have any questions or require any further information about the research project, please contact: Dr. Jeremy Sheppard at 043 3334 849 email jeremy@surfingautralia.com or jeremy.sheppard@ecu.edu.au. If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer
Human Research Ethics Officer
Edith Cowan University
100 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Email: research.ethics@ecu.edu.au

INFORMED CONSENT

The development and evaluation of a comprehensive sport-science protocol for competitive surfers.

I have been informed that the purpose of this study is to investigate the physical abilities of surfers. I understand that I will participation in a series of testing protocols for evaluation of my physical characteristics and physical fitness. Through participation in these tests a testing protocol may be developed to assist in my future training as well as to help set standards of physical capabilities for competitive surfers.

I have been informed that my participation in this study will involve having my anthropometry measured (height, weight and leanness) as well as participation in physical fitness tests (strength, power, endurance an balance). I have been informed that the anticipated risks, including minor muscle strains and muscle soreness, are very minimal and uncommon. I have been informed that risk of serious or life-threatening complications, for healthy individuals like myself, when exercising in this manner, is near zero.

I have been informed of the procedures involved in this study. I have been fully informed of the nature of the tests and potential risks involved, of which I assume voluntarily. I have been informed that I may withdraw my participation at any time and for any reason without penalty. The primary benefit of participation in this study will be obtaining information about my individual physical fitness capabilities.

Any information that is obtained in connection with this study and that can be identified will remain confidential (only shared with the primary investigators and team coaches) and any further disclosure will only occur with my permission. I have been informed that the results of this study may be published in scientific literature or presented at professional meetings using grouped or de-identified data only.

If you have any questions or require any further information about the research project, please contact: Dr. Jeremy Sheppard at 0433334849, email jeremy.sheppard@ecu.edu.au. If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer
Human Research Ethics Officer
Edith Cowan University
100 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170 Email: research.ethics@ecu.edu.au

Declaration

I ____ have read all of the information contained on this sheet and have had all questions relating to the study answered to my satisfaction.

I agree to participate in this study realising that I am free to withdraw at any time, for any reason without prejudice.

I agree that the research data obtained from this study may be published, provided I am not identifiable in any way.

Participant: ____________________________ Date: __________________

Participants under the age of 18:

Parent/Legal Guardian: __________________________________ Date: __________________

Investigator: ___________________________ Date: __________________

Appendix 2: Information Letter and Inform Consent Study 2

INFORMATION LETTER TO PARTICIPANTS

Thank you for expressing your interest in this research. The purpose of this document is to explain the nature of the study that you may choose to participate as a participant. This research project has been approved by ECU Human Research Ethics Committee. Please read this document carefully, and do not hesitate to ask any questions.

Project Title
Comparison of physical capacities between non-selected and selected elite male competitive surfers for the national junior team

Purpose of the study
The purpose of this study is to investigate whether tests of physical performance reflect selection for international competition from a pool of elite competitive junior surfers.

Methods
This investigation is a single testing session, which will last approximately an hour to one and a half hour consisting of anthropometric (stature, body mass, and sum of 7 skinfolds), muscular power (vertical jump; VJ), lower body strength (isometric mid-thigh pull; IMTP), 15 m sprint paddle, and 400 m endurance paddle measurements. The testing procedures will begin with anthropometry, followed by a standardised 10-minute dynamic warm-up. You will then be familiarised with the VJ, IMTP, 15 m sprint paddle, and 400 m endurance paddle protocol.

Measurements
During testing you will be required to perform the following tests:

- Anthropometric measures (stature and mass) will be determined using standard procedures. Stature will measure with a wall-mounted stadiometer to the nearest millimetre and body mass will be measured on an electronic scale to the nearest 100 grams.

- Vertical jump will require you to stand completely still on the force plate. Following a 3,2,1 countdown, you will jump as high as possible while maintaining a wooden dowel on the back of the shoulders. You will perform three jumps with one-minute rest between each trial.

- Isometric mid thigh pull will require you to stand completely still on the force plate. You will be instructed to stand in a position similar to the second pull of the power clean and snatch. Following a 3,2,1 countdown, you will push on the force platform as hard as possible. You will perform three trials with 2 minutes rest between each trial.

- 15 m sprint paddle will require you to perform two 15 m maximum sprint paddle trials with one minute of rest between each trial. You will start in a stationary prone position on the surfboard with a horizontal position transducer attached to the rear waistline of your board short to measure sprint paddle split time and velocity.

- 400 m endurance paddle will require you to start in a stationary prone position on your surfboard. On a "ready, set, go" command, you will then paddle around two weighted buoys positioned 20 m apart and completing a total of 10 laps as quickly as possible.

Eligibility

You will be eligible for this study if:

- You are under the age of 18 years
- You are a male competitive surfer who have competed in the Australian Nationals or World Junior Championship
- You have no orthopaedic or musculoskeletal injuries within six months

Risks

There are no other inherent risks involved with this investigation. However, there is the possibility of muscle pulls or strains associated with the testing, common to any type of physical activity. Furthermore, with any exercise intervention there is some risk of delayed onset muscle soreness and/or injury to participants but having all testing sessions supervised by qualified personnel will minimize this. In addition, qualified personnel with certification to minimize these risks will monitor proper warm-up and cool down procedures.

Benefits

Participation in this study will provide you with a detailed indication of your dynamic time to stabilisation abilities, lower body strength and explosive power. All study activities are provided at no cost to the participants.

Confidentiality of Information

All data collected during this research will be kept on a password locked computers. Data will be kept in the possession of the principal researcher and during external data collection computers will still be under password protection. All forms of paper data collection and video data collection collected off site will be accounted for prior to departing the external location and secured by the principal researcher and then returned to a secure locked location upon return to the Surfing Australia (SA) facility. Data will remain as part of SA official records and per Australian Sports Commission data storage normal process. In addition, data will be kept following student completion by the lead ECU investigator using storage security precautions listed above. Original data from this research will be kept under password protection of the chief investigators computer for a period of at least 5 years after publication. Data will be kept for the previously stated minimum of 5 years post publication and access will only be allowed by the chief and named investigators, coaches and players upon request to the chief investigator. After the 5 year period, if data is no longer of use, it will be permanently deleted from the chief investigators computer using a 7 pass data deletion process; Hard copy data will be destroyed by the University confidential document destruction process.

Results of the Research Study

The results of this study are intended for completion of a PhD by research thesis and may be presented at conferences/seminars and published in peer-reviewed journals, as magazine articles, as an online article or part of a book section or report. Published results will not contain information that can be used to identify participants unless

specific consent for this has been obtained. A copy of published results can be obtained from the investigator upon request.

Voluntary Participation
Your participation in this study is voluntary. No monetary reward will be provided. No explanation or justification is needed if you choose to not participate. Your decision if you do not want to participate will not disadvantage you or involve any penalty.

Withdrawing Consent to Participate
If you decide to participate in the study, but later change your mind, you may withdraw at any time. There are no penalties or consequences of any kind if you decide that you want to withdraw. You also have the right to withdraw any personal information that has been collected during the research.

Contacting the Investigators
We are happy to answer any questions you may have at this time. If you have any queries later, please do not hesitate to contact Tai T. Tran at 04 2073 3419, email tai@surfingaustralia.com, Dr Jeremy Sheppard at 02 6671 0000, email Jeremy@surfingaustralia.com, Professor Robert Newton at 08 6304 5037, email r.newton@ecu.edu.au or Dr. Sophia Nimphius at 08 6304 5848, email s.nimphius@ecu.edu.au. If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer
Human Research Ethics Officer
Edith Cowan University
100 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Email: research.ethics@ecu.edu.au

INFORMED CONSENT FORM

Project Title
Comparison of physical capacities between non-selected and selected elite male competitive surfers for the national junior team

I have read the information sheet and the consent form. I agree to participate in the study entitled 'Comparison of physical capacities between non-selected and selected elite male competitive surfers for the national junior team' and give my consent freely. I understand that the study will be carried out as described in the information sheet, a copy of which I have retained. I have had all questions answered to my satisfaction.

I do not have to participate in this study. If I decide to participate in the study, but later change my mind, I may withdraw at any time. There are no penalties or consequences of any kind if I decide that I want to withdraw. My participation in this study may be terminated at any time by the investigators if they believe that it is in my best interest to do so or if I fail to follow the study procedures.

This study does not require subjects' name to be mentioned, therefore, each subject will be given a code for statistical analyses. Subjects' privacy will be protected and all data and results will be strictly confidential to the extent allowed by law. All data will be kept in a locked cabinet and office. Electronic data will be stored on password protected computer and locked laboratory. Data may be used for future educational conferences or published in scientific journals, however, subjects' name will not be provided. After the 5 year period, if data is no longer of use, it will be permanently deleted from the chief investigators computer using a 7 pass data deletion process; Hard copy data will be destroyed by the University confidential document destruction process.

Participant: ________________________________ Date: __________________

Participants under the age of 18:

Parent/Legal Guardian: _________________________ Date: __________________

Witness: __________________________________ Date: __________________

Appendix 2: Information Letter and Inform Consent Study 3

INFORMATION LETTER TO PARTICIPANTS

Thank you for expressing your interest in this research. The purpose of this document is to explain the nature of the study that you may choose to participate as a subject. This research project has been approved by ECU Human Research Ethics Committee. Please read this document carefully, and do not hesitate to ask any questions.

Project Title
The development and evaluation of a drop and stick method to assess landing skills in various levels of competitive surfers

Purpose of the study
The purpose of this study is to investigate the development and evaluation of a drop and stick method to assess dynamic postural control in senior elite, junior elite, and junior development surfers.

Methods
This investigation is a single testing session, which will last approximately an hour consisting of anthropometric (stature, body mass) and drop and stick measurements. Upon anthropometric measurements, you will perform a standardised 10-minute dynamic warm-up, and then be familiarise with the drop and stick protocol.

Measurements
During testing you will be required to perform the following measurements:

- Anthropometric measures (height, mass) will be determined using standard procedures. Height will measure with a wall-mounted stadiometer to the nearest millimetre and body mass will be measured on an electronic scale to the nearest 100 grams.

- Drop and Stick - start from a standing position on top of a 0.5 m box. You will be given a 3,2,1 countdown, then step forward off the box, land both feet simultaneous on the force plate with both arms flexing 90° at the shoulder. You will perform 3 drop landing with one-minute rest between each trial.

Eligibility
You will be eligible for this study if:
- You are a male and female competitive surfer
- You have no orthopaedic or musculoskeletal injuries within six months

Risks
There are no other inherent risks involved with this investigation. However, there is the possibility of muscle pulls or strains associated with the testing, common to any type of physical activity. Furthermore, with any exercise intervention there is some risk of

delayed onset muscle soreness and/or injury to participants but this will be minimized by having all testing sessions supervised by qualified personnel. In addition, proper warm-up and cool down procedures will be monitored by qualified personnel with certification to minimize these risks.

Benefits

Participation in this study will provide you with a detailed indication of your ability to restabilise following a drop from 0.5 m box height and your ability to absorb landing force. All study activities are provided at no cost to the participants.

Confidentiality of Information

All data collected during this research will be kept on a password locked computers. Data will be kept in the possession of the principal researcher and during external data collection computers will still be under password protection. All forms of paper data collection and video data collection collected off site will be accounted for prior to departing the external location and secured by the principal researcher and then returned to a secure locked location upon return to the Surfing Australia (SA) facility. Data will remain as part of SA official records and per Australian Sports Commission data storage normal process. In addition, data will be kept following student completion by the lead ECU investigator using storage security precautions listed above. Original data from this research will be kept under password protection of the chief investigators computer for a period of at least 5 years after publication. Data will be kept for the previously stated minimum of 5 years post publication and access will only be allowed by the chief and named investigators, coaches and players upon request to the chief investigator. After the 5 year period, if data is no longer of use, it will be permanently deleted from the chief investigators computer using a 7 pass data deletion process; Hard copy data will be destroyed by the University confidential document destruction process.

Results of the Research Study

The results of this study are intended for completion of a PhD by research thesis and may be presented at conferences/seminars and published in peer-reviewed journals, as magazine articles, as an online article or part of a book section or report. Published results will not contain information that can be used to identify participants unless specific consent for this has been obtained. A copy of published results can be obtained from the investigator upon request.

Voluntary Participation

Your participation in this study is voluntary. No monetary reward will be provided. No explanation or justification is needed if you choose to not participate. Your decision if you do not want to participate will not disadvantage you or involve any penalty.

Withdrawing Consent to Participate

If you decide to participate in the study, but later change your mind, you may withdraw at any time. There are no penalties or consequences of any kind if you decide that you want to withdraw. You also have the right to withdraw any personal information that has been collected during the research.

Contacting the Investigators

We are happy to answer any questions you may have at this time. If you have any queries later, please do not hesitate to contact Tai T. Tran at 04 2073 3419, email t.tran@ecu.edu.au, Dr. Jeremy Sheppard at 02 6671 0000, email jeremy.sheppard@ecu.edu.au, Professor Robert Newton at 08 6304 5037, email r.newton@ecu.edu.au or Dr. Sophia Nimphius at 08 6304 5848, email s.nimphius@ecu.edu.au. If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer
Human Research Ethics Officer
Edith Cowan University
100 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Email: research.ethics@ecu.edu.au

INFORMED CONSENT FORM

Project Title
The development and evaluation of a drop and stick method to assess landing skills in various levels of competitive surfers

I have read the information sheet and the consent form. I agree to participate in the study entitled 'The development and evaluation of a drop and stick method to assess landing skills in various levels of competitive surfers' and give my consent freely. I understand that the study will be carried out as described in the information sheet, a copy of which I have retained. I have had all questions answered to my satisfaction.
I do not have to participate in this study. If I decide to participate in the study, but later change my mind, I may withdraw at any time. There are no penalties or consequences of any kind if I decide that I want to withdraw. My participation in this study may be terminated at any time by the investigators if they believe that it is in my best interest to do so or if I fail to follow the study procedures.

This study does not require subjects' name to be mentioned, therefore, each subject will be given a code for statistical analyses. Subjects' privacy will be protected and all data and results will be strictly confidential to the extent allowed by law. All data will be kept in a locked cabinet and office. Electronic data will be stored on password protected computer and locked laboratory. Data may be used for future educational conferences or published in scientific journals, however, subjects' name will not be provided. After the 5 year period, if data is no longer of use, it will be permanently deleted from the chief investigators computer using a 7 pass data deletion process; Hard copy data will be destroyed by the University confidential document destruction process.

Participant: ______________________________ Date: _________________

Participants under the age of 18:

Parent/Legal Guardian: ________________________ Date: _________________

Witness: ________________________________ Date: _________________

Appendix 2: Information Letter and Inform Consent Studies 4 and 5

INFORMATION LETTER TO PARTICIPANTS

Thank you for expressing your interest in this research. The purpose of this document is to explain the nature of the study that you may choose to participate as a subject. This research project has been approved by ECU Human Research Ethics Committee. Please read this document carefully, and do not hesitate to ask any questions.

Project Title
Effects of unstable and stable resistance training on strength, power, and sensorimotor abilities in adolescent surfers

Purpose of the study
The purpose of this study was to investigate two different training interventions on strength, power, and sensorimotor abilities in adolescent surfing athletes

Methods
This investigation requires you to attend two training sessions per week on non-consecutive days for seven straight weeks. Performance measures will consist of lower body power (countermovement vertical jump; CMJ) and maximal isometric strength (isometric mid-thigh pull; IMTP) and sensorimotor ability (drop and stick; DS). Familiarization session will commence with stature and body mass measurements follow by a 10-minute standardised dynamic warm-up. You will then be familiarise with performance testing protocols to become competent with the performance tests. You will return 48 hours later and complete performance test measurements. Following performance tests, you will be instructed and familiarized on your respective training intervention and become competent with the exercises. You will be given another 48 hours of recovery then start your assigned training intervention. A certified strength and conditioning specialist will monitor every training session. You are encouraged to continue your daily surf training, however avoid any resistance training other than your assigned training program. You will follow a periodized strength-power program according to your assigned intervention. Post-test will be perform at least 48 hours upon completion of the 7-week training intervention. You will then be provided a 4-week break and again be encouraged to continue your daily surf training, however, avoid any strength-power exercises. Following a 4-week break, you will be pre-tested prior to the second 7-week training intervention (unstable group will become stable group and vice-versa), and then post-test upon completing the second 7-week training intervention.

Measurements
During testing you will be required to perform the following tests:

- Anthropometric measures (stature, body mass) will be determined using standard procedures. Stature will be measured with a wall-mounted stadiometer to the nearest millimetre and body mass will be measured on an electronic scale to the nearest 100 grams.

- Countermovement jump (CMJ) - perform three countermovement jumps to a self-selected depth while maintaining a light wooden dowel in contact with the back of the shoulders. One minute of rest will be provided between jumps.

- Isometric mid-thigh pull (IMTP) – perform three trials with two-minute rest between each trial. You will be instructed and verbally encourage to push against the ground as hard as possible for five seconds.

- Drop and Stick - start from a standing position on top of a 50 cm box. You will be given a 3,2,1 countdown, then step forward off the box, land both feet simultaneous on the force plate with both arms flexing 90° at the shoulder. You will perform 3 drop landing with one-minute rest between each trial.

Eligibility

You will be eligible for this study if:

- You are between the age of 12 and 19 years
- You are a competitive male or female surfer
- You have no orthopaedic or musculoskeletal injuries within six months

Risks

There are no other inherent risks involved with this investigation. However, there is the possibility of muscle pulls or strains associated with the testing, common to any type of physical activity. Furthermore, with any exercise intervention there is some risk of delayed onset muscle soreness and/or injury to participants but this will be minimized by having all testing sessions supervised by qualified personnel. In addition, proper warm-up and cool down procedures will be monitored by qualified personnel with certification to minimize these risks.

Benefits

Participation in this study will provide you with a detailed indication of your strength, power, and dynamic postural control. It is expected that you will experience considerable improvements in strength, power, and dynamic postural control. All study activities are provided at no cost to the participants.

Confidentiality of Information

All data collected during this research will be kept on a password locked computers. Data will be kept in the possession of the principal researcher and during external data collection computers will still be under password protection. All forms of paper data collection and video data collection collected off site will be accounted for prior to departing the external location and secured by the principal researcher and then returned to a secure locked location upon return to the Surfing Australia (SA) facility. Data will remain as part of SA official records and per Australian Sports Commission data storage normal process. In addition, data will be kept following student completion by the lead ECU investigator using storage security precautions listed above. Original data from this research will be kept under password protection of the chief investigators

computer for a period of at least 5 years after publication. Data will be kept for the previously stated minimum of 5 years post publication and access will only be allowed by the chief and named investigators, coaches and players upon request to the chief investigator. After the 5 year period, if data is no longer of use, it will be permanently deleted from the chief investigators computer using a 7 pass data deletion process; Hard copy data will be destroyed by the University confidential document destruction process.

Results of the Research Study
The results of this study are intended for completion of a PhD by research thesis and may be presented at conferences/seminars and published in peer-reviewed journals, as magazine articles, as an online article or part of a book section or report. Published results will not contain information that can be used to identify participants unless specific consent for this has been obtained. A copy of published results can be obtained from the investigator upon request.

Voluntary Participation
Your participation in this study is voluntary. No monetary reward will be provided. No explanation or justification is needed if you choose to not participate. Your decision if you do not want to participate will not disadvantage you or involve any penalty.

Withdrawing Consent to Participate
If you decide to participate in the study, but later change your mind, you may withdraw at any time. There are no penalties or consequences of any kind if you decide that you want to withdraw. You also have the right to withdraw any personal information that has been collected during the research.

Contacting the Investigators
We are happy to answer any questions you may have at this time. If you have any queries later, please do not hesitate to contact Tai T. Tran at 04 6839 7904, email t.tran@ecu.edu.au, Dr Jeremy Sheppard at 02 6671 0000, email jeremy.sheppard@ecu.edu.au, Professor Robert Newton at 08 6304 5037, email r.newton@ecu.edu.au or Dr. Sophia Nimphius at 08 6304 5848, email s.nimphius@ecu.edu.au. If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer
Human Research Ethics Officer
Edith Cowan University
100 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Email: research.ethics@ecu.edu.au

INFORMED CONSENT FORM

Project Title
Effects of unstable and stable resistance training on strength, power, and sensorimotor abilities in adolescent surfers

I have read the information sheet and the consent form. I agree to participate in the study entitled 'Effects of unstable and stable resistance training on strength, power, and sensorimotor abilities in adolescent surfers' and give my consent freely. I understand that the study will be carried out as described in the information sheet, a copy of which I have retained. I have had all questions answered to my satisfaction.

I do not have to participate in this study. If I decide to participate in the study, but later change my mind, I may withdraw at any time. There are no penalties or consequences of any kind if I decide that I want to withdraw. My participation in this study may be terminated at any time by the investigators if they believe that it is in my best interest to do so or if I fail to follow the study procedures.

This study does not require subjects' name to be mentioned, therefore, each subject will be given a code for statistical analyses. Subjects' privacy will be protected and all data and results will be strictly confidential to the extent allowed by law. All data will be kept in a locked cabinet and office. Electronic data will be stored on password protected computer and locked laboratory. Data may be used for future educational conferences or published in scientific journals, however, subjects' name will not be provided. After the 5 year period, if data is no longer of use, it will be permanently deleted from the chief investigators computer using a 7 pass data deletion process; Hard copy data will be destroyed by the University confidential document destruction process.

Participant: ________________________________ Date: __________________

Participants under the age of 18:

Parent/Legal Guardian: _________________________ Date: __________________

Witness: __________________________________ Date: __________________

Appendix 3: Study 1 Publication

International Journal of Sports Physiology and Performance, 2013, 8, 490-495

INTERNATIONAL JOURNAL OF
SPORTS PHYSIOLOGY AND PERFORMANCE
www.IJSPP-Journal.com
ORIGINAL INVESTIGATION

Development of a Comprehensive Performance-Testing Protocol for Competitive Surfers

Jeremy M. Sheppard, Sophia Nimphius, Greg G. Haff, Tai T. Tran, Tania Spiteri, Hedda Brooks, Gary Slater, and Robert U. Newton

Purpose: Appropriate and valid testing protocols for evaluating the physical performances of surfing athletes are not well refined. The purpose of this project was to develop, refine, and evaluate a testing protocol for use with elite surfers, including measures of anthropometry, strength and power, and endurance. ***Methods:*** After pilot testing and consultation with athletes, coaches, and sport scientists, a specific suite of tests was developed. Forty-four competitive junior surfers (16.2 ± 1.3 y, 166.3 ± 7.3 cm, 57.9 ± 8.5 kg) participated in this study involving a within-day repeated-measures analysis, using an elite junior group of 22 international competitors (EJG), to establish reliability of the measures. To reflect validity of the testing measures, a comparison of performance results was then undertaken between the EJG and an age-matched competitive junior group of 22 nationally competitive surfers (CJG). ***Results:*** Percent typical error of measurement (%TEM) for primary variables gained from the assessments ranged from 1.1% to 3.0%, with intraclass correlation coefficients ranging from .96 to .99. One-way analysis of variance revealed that the EJG had lower skinfolds ($P = .005$, $d = 0.9$) than the CJG, despite no difference in stature ($P = .102$) or body mass ($P = .827$). The EJG were faster in 15-m sprint-paddle velocity ($P < .001$, $d = 1.3$) and had higher lower-body isometric peak force ($P = .04$, $d = 0.7$) and superior endurance-paddling velocity ($P = .008$, $d = 0.9$). ***Conclusions:*** The relatively low %TEM of these tests in this population allows for high sensitivity to detect change. The results of this study suggest that competitively superior junior surfers are leaner and possess superior strength, paddling power, and paddling endurance.

Keywords: paddle, strength, power, assessment, surfing

Surfing (wave riding) is a mass-participation sport worldwide, enjoyed by both sexes and a broad age demographic. Waves are being surfed on every continent, with 69 countries having a national federation membership in the International Surfing Association (ISA) and 30 to 35 of these federations contesting ISA World Junior Championships and World Surfing Games each year, as well as hundreds of elite athletes contesting the professional contests of the World Tour of the Association of Surfing Professionals.

Competitive surfing involves grouping 2 to 4 surfers in each 20- to 40-minute competitive heat, dependent on the format of the competition and surf conditions. Competitive success is determined by judging criteria applied to the act of wave riding only (the point the athlete moves from prone to standing on the breaking wave to the completion of the wave being ridden). The criteria examine the athlete's ability to ride the best waves and perform controlled complex maneuvers. Generally, the athlete's highest-scoring 2 waves in each heat are used to determine the heat outcome. In other words, success is judged by the ability to obtain and ride the best waves during a competition and ride them better than their competition. Like any tournament-style competition, the successful surfers from each round of competitive heats progress through the competition until quarterfinal, semifinal, and final rounds are completed and placing is determined.

Surfing competition takes places under a variety of conditions that have a large effect on activity patterns, such as duration of wave riding and time spent paddling.[1,2] The type of wave break and changing conditions such as wind, swell, and tide conditions greatly influence the nature of the surfing activity. In a competition, wave-riding duration was found to be 3.8% of total time, with paddling accounting for 51.4% of time and no activity (ie, stationary sitting on board) representing 42.5% of total time (miscellaneous activities 2.2%).[2] Although the mean paddling bout in a surfing competition was found to be ~30 seconds, the majority (~60%) of these paddling bouts were only 1 to 20 seconds (~25% <10 s, ~35% 10–20 s), highlighting the importance of shorter

Sheppard, Nimphius, Haff, Tran, Spiteri, and Newton are with the Centre for Sport and Exercise Research, Edith Cowan University, Joondalup, WA, Australia. Brooks is with the Sport Science Dept, Queensland Academy of Sport, Nathan, QLD, Australia. Slater is with the Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Maroochydore, QLD, Australia.

bouts of intense paddling.[2,3] As such, analysis of both competitive and recreational surfing suggests that surfing can be characterized as a sport requiring multiple short-duration intermittent paddle efforts.[1,2]

Sprint paddling appears to be a key feature of competition to catch waves and gain a position advantage over one's competitors during a heat, as well as to ensure fast entry speed into waves to optimize position on the wave face for the execution of maneuvers that will maximize the judges' score.[3–5] Indeed, adult competitive surfers are superior in sprint paddling to junior competitive surfers, highlighting this physical quality as an important development consideration.[6] When you also consider the repeated bouts and extensive nature of surfing activity,[1,2] endurance-paddling ability is also likely to be a highly relevant physical quality.[5] As such, assessments of both sprint- and endurance-paddle ability in surfers are likely an important component of a comprehensive testing protocol for competitive surfers.

Surfboard paddling is considered a closed-kinetic-chain task, as the surfers "pull" their body over the water surface as opposed to pulling the water surface toward them. Previous examinations have used stationary paddle ergometry to determine sprint- and endurance-paddle performance, which was an open-kinetic-chain task, with conflicting results in discriminating between higher- and lower-performing surfers.[1,4,5] It would seem more appropriate, and indeed more practical, to evaluate paddling ability with surfers in the water to provide greater context validity.

Surfing a wave requires a continual and relatively rapid production and arresting of force, particularly in the lower body, to execute the maneuvers required to maximize scores under the judging criteria. Despite this, there have been no studies involving surfers that have examined strength and power measures of the lower body, despite their likely importance to performance.[3] As such, currently there is no established protocol for the assessment of strength and power from which to implement measures into a comprehensive protocol.

To advance the understanding of the physical capabilities of surfers, and to pursue further research into the responses and adaptations of these qualities with training, valid test measures must first be established. Therefore, the purpose of this study was to develop and evaluate a testing protocol with practical reliability and context validity, such that the testing protocols assess physical qualities that relate to performance in the sport, including measures of anthropometry, strength and power, and sprint and endurance qualities.

Methods

Subjects

Forty-four competitive junior surfers (16.2 ± 1.3 y, 166.3 ± 7.3 cm, 57.9 ± 8.5 kg) participated in this study, which involved 2 groups: an elite junior group of 22 international competitors (EJG) and an age-matched group of 22 domestic competitors (CJG). The EJG were both nationally and internationally competitive surfers at junior competitions (eg, World Junior Championships) and were included in national-team programs, while the CJG competed in national competitions (eg, state and national titles) but were not a part of the national program.

All subjects received a clear written and verbal explanation of the study and all risks and benefits, with written informed consent obtained by the subjects and their parent or guardian. The study procedures were approved by the human ethics committee at Edith Cowan University, and procedures conformed to the code of ethics of the World Medical Association (Declaration of Helsinki).

Design

After a development and refinement process, subjects were familiarized with the testing procedure and conducted practice trials. After this, a repeated-measures analysis was conducted within the same day with the subjects from the EJG to establish reliability of the measures. To assess the validity of the testing measures to discriminate athlete ability, a comparison of performance results was then performed between the EJG and the CJG.

Methodology

After a 10-minute warm-up involving whole-body movements (squats, lunges, and dynamic mobility similar the subjects' typical pretraining routine), both the EJG and CJG were assessed on tests in the following order: anthropometry, lower-body power, lower-body strength, sprint paddling, and endurance paddling.

Anthropometry. Subjects were assessed for height, body mass, and the sum of 7 skin folds. The sum of 7 skin folds was determined after measurement of the triceps, subscapulae, biceps, supraspinale, abdominale, thigh, and calf skin folds using a Harpenden skinfold caliper (British Indicator, Hertfordshire, UK). A composite ratio of body mass divided by the sum of 7 skin folds was then determined to reflect the amount of mass that was made up of lean tissue, termed the lean-mass index,[7] modified by original methods.[8] All tests were conducted in accordance with the International Society for the Advancement of Kinanthropometry's guidelines by a practitioner whose percent typical error of measurement (TEM) for skinfold measurements was 1.12% to 1.70%, and 0.10% for all other measures.

Lower-Body Strength and Power. With a lightweight wooden bar across the shoulders, subjects conducted 3 or 4 trials of a jump squat from a self-selected depth.[9] Subjects then performed 2 trials of a maximal isometric midthigh pull, using a 130° knee angle and corresponding hip angle of 155° to 165°, as described in previous research,[10–12] with the hip and knee angles determined using a handheld goniometer. If the trials differed by >250 N, a third trial was performed.[13] The best trials as determined by maximum force (isometric midthigh pull) and maximum jump height were retained for analysis.

All movements were conducted with the subjects standing on a commercially available force plate sampling at 600 Hz (400 Series Performance force plate, Fitness Technology, Adelaide, Australia). The force plate was interfaced with computer software (Ballistic Measurement System, Fitness Technology, Adelaide, Australia) that allowed for direct measurement of force–time characteristics (force plate), and data were then analyzed using the Ballistic Measurement System software (Fitness Technology, Adelaide, Australia). Force–time data recorded from the jumps were processed using the impulse-momentum method to determine velocity and displacement data. Peak force and jump height determined as the peak in displacement were used as the representative performance measures. Before all data-collection procedures, the force plate was calibrated using a spectrum of known loads spanning the likely measurement range (20 and 200 kg) and then assessed against 3 criterion masses (of 40, 100, and 200 kg).

Sprint and Endurance Paddling. Sprint-paddle testing was conducted in an outdoor 25-m swimming pool. This allowed for easy outline of distances for the subjects and control of the potential effect of tides and currents. Subjects used their own surfboard for the testing (the one they use in competition) to provide context validity. All subjects wore surf boardshorts.

Before the paddling test and in addition to the general warm-up, subjects performed a progressive paddling warm-up consisting of 200 m of low-intensity paddling, followed by a specific sprint-paddling warm-up of 4 × 15-m sprint-paddling efforts at 60%, 70%, 80%, and 90% volitional effort at ~2-minute time intervals. After 2 minutes rest, the subjects then performed 2 maximal-effort sprint-paddling time trials (ie, 2 × 15 m) to determine maximum sprint-paddling performance. The sprint-paddle efforts were initiated from a stationary, prone position.

Using a purpose-built horizontal position transducer (I-REX, Southport, Australia) attached to the back of each subject's shorts, kinematic data were obtained and stored for analysis on a personal computer. The position transducer recorded a time stamp for each 0.02 m of displacement, thereby allowing determination of sprint time from the start to 5 m, 10 m, and 15 m and by differentiation to determine peak sprint-paddle velocity, a procedure that has been validated previously with surfboard paddling in a pool.[14]

The timed endurance-paddle test was conducted over a 20-m up-and-back course in the same pool, using 2 pool-lane widths, so that continuous paddling to a total of 400 m could be accomplished. The paddling test was conducted with small buoy markers at both ends of the 20-m segment. As such, the subjects paddled 20 m and completed a turn at each end around the buoy until the 400 m was completed. The subjects paddled up to and around the buoy, completing a 180° turn while remaining prone on their surfboards. The time to complete the endurance-paddle test allowed for determination of subjects' maximum aerobic speed, which was intended to reflect their endurance capabilities in the specific context of surfboard paddling.

Statistical Analyses

Reliability data were calculated by determining the intraclass correlation coefficient, TEM, and percentage TEM (as covariance, percent TEM). Comparisons of the difference between higher (EJG) and lower performers (CJG) was determined by ANOVA, with Cohen's effect size (d) applied to determine the magnitude of any differences observed. For all means-based testing, minimum significance was considered to be achieved when $P < .05$, with a 90% confidence interval.

Results

Table 1 outlines the reliability of experimental measures used in this study. The EJG had lower total skin-fold values ($P = .005$, $d = 0.9$), despite no difference in height ($P = .102$, $d = 0.5$) or mass ($P = .827$, $d = 0.1$) (Figure 1), consequently resulting in a higher lean-mass index ($P = .001$, $d = 1.1$).

The EJG had a higher peak force (1802 ± 351 N) than the CJG (1531 ± 308 N) in the isometric midthigh pull ($P = .041$, $d = 0.7$). In regard to peak jump height, there were no clear differences observed between the EJG (0.40 ± 0.07 m) and the CJG (0.38 ± 0.09 m; $P = .505$, $d = 0.3$), or for the peak velocity ($P = .521$, $d = 0.2$) or peak force ($P = .787$, $d = 0.1$) in the jump squat (Figure 2).

Table 1 Reliability (90% Confidence Intervals) of Measures on the Tests in Elite Junior Competitive Surfers

Measure	Intraclass correlation	Typical error of measurement (TEM)	%TEM
Jump squat			
height (m)	.98 (.094–.99)	0.01 m (0.01–0.02)	2.67% (2.00–4.30)
peak force (N)	.97 (.91–.99)	37.3 N (27.3–58.8)	2.99% (2.20–4.80)
Isometric midthigh-pull peak force (N)	.99 (.97–.99)	42.5 N (32.9–60.1)	2.25% (1.80–3.20)
15-m sprint paddle (s)	.97 (.93–.99)	0.11 s (0.09–0.16)	1.13% (0.90–1.60)

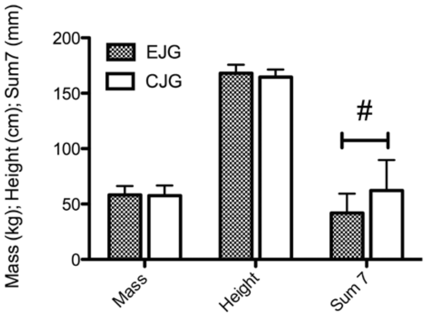


Figure 1 — The mean (± SD) mass, height, and sum of 7 site skinfolds of an elite junior group (EJG, n = 22) and an aged-matched group of competitive junior surfers (CJG, n = 22). #Significant difference (*P* = .005).

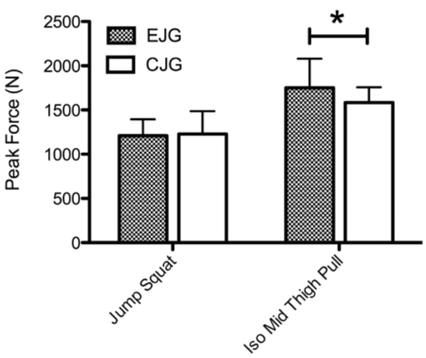


Figure 2 — The mean (± SD) peak force of a body-weight jump squat and isometric midthigh pull of an elite junior group (EJG, n = 22) and an aged-matched group of competitive junior surfers (CJG, n = 22). *Significant difference (*P* = .04).

EJG produced superior sprint-paddle times to 5 (P = .000, d = 1.4), 10 (P = .000, d = 1.3), and 15 m (P = .000, d = 1.2) and a higher sprint-paddle velocity (P = .000, d = 1.3), which was achieved in the 5- to 14-m interval. The EJG also had a lower endurance-paddle time (P = .008, d = 0.9) and consequently a higher endurance-paddling velocity (P = .000, d=0.9; Table 2).

Discussion

To advance sport science's knowledge of the physical capabilities of competitive surfers, and to advance further research into the responses and adaptations of these qualities, valid test measures must first be established for use with this population. The first purpose of this study was to develop and evaluate a testing protocol that demonstrated practical reliability such that practitioners can be confident that small training-induced changes can be detected by the tests and not attributed to biological and measurement noise. The second purpose was to evaluate the protocol for its ability to discriminate between competitive levels, thereby reflecting the validity of the measurements.

The relatively low TEM values for the variables obtained in this study demonstrate considerable practical use for coaches and sport scientists; a high TEM makes interpreting small changes in performance difficult, because unless the change measured is larger than the TEM, the practitioner cannot be confident that the change is due to training or detraining or simply due to measurement and biological noise associated with the testing protocol. Previously, favorable reliability has been found with a 10-second paddling time trial with surfers,[14] and we previously found high reliability using the jump-squat and isometric-midthigh-pull protocols in other sports.[9,10] However, this is the first study to comprehensively evaluate the repeatability of measures usable in an entire suite of tests to evaluate the physical qualities of surfers. The low TEM observed across the entire protocol indicates that comparably small magnitudes of change can be detected in the test scores, likely providing a sensitive protocol for practitioners working with surfing athletes.

Although the EJG and the CJG did not differ in terms of height or mass, the EJG had lower total sum of

Table 2 Mean (± SD) Sprint- and Endurance-Paddle Results Comparing an Elite Junior Group (n = 22) and an Age-Matched Group of Competitive Junior Surfers (n = 22)

Measure	Elite junior group	Competitive junior group	*P*	Effect size
Sprint-paddle time (s)				
5 m	3.96 ± 0.30	4.35 ± 0.25	.000	1.4
10 m	7.08 ± 0.49	7.69 ± 0.44	.000	1.3
15 m	10.23 ± 0.68	11.04 ± 0.63	.000	1.2
Peak velocity (m/s)	1.66 ± 0.11	1.53 ± 0.09	.000	1.3
400-m endurance-paddle time (s)	324 ± 25	360 ± 18	.008	0.9
Endurance velocity (m/s)	1.17 ± 0.08	1.11 ± 0.05	.006	0.9

skin folds and a higher lean-mass index (Figure 1), as well as superior lower-body maximal strength (Figure 2). It is surprising that the importance of low fat mass in surfers has not been previously supported by empirical evidence.[15] Lower fat mass and greater strength would seem a logical advantage in a sport such as surfing, where the act of wave riding involves a sequence of force production and absorption to complete whole-body maneuvers, thereby making physical capabilities relative to body mass highly important. This has been found in numerous other contexts[7,16] and speculated on previously in regard to competitive surfing.[3] Although our previous work identified superior upper-body strength relative to body mass in senior competitive surfers compared with junior surfers, this was easily accounted for by maturation.[6] Our current findings are novel as the subjects in this study were age-matched, so the differences observed offer strong support for the importance of strength in higher-performing surfers. These results suggest that maximum strength is an important aspect of physical preparation for surfers. It could be speculated that traditional strength exercises (pull-ups, squats, presses, and Olympic lifts) have an important role to play in the physical preparation of surfers, but generally and as yet, this is not a common training practice of the majority of elite competitors.

A 10-second sprint-paddle assessment has previously been demonstrated to be a reliable method to evaluate paddling ability in surfers,[14] and sprint-paddling ability has been shown to be a relevant quality to assess in competitive surfers.[6] The results of this study demonstrate the relatively large difference in peak sprint-paddling velocity (d = 1.3) between the higher-performing EJG and the CJG, further highlighting the importance of sprint-paddling ability. Considering that competitive heats comprise many relatively short-duration paddling bouts, interspersed with some inactive periods (sitting on the surfboard),[2] it stands to reason that sprint-paddling ability is critical for performance in obtaining and maintaining positional dominance in the water during a heat over fellow competitors. Furthermore, well developed sprint-paddling ability is an important component of achieving early, efficient entry, and high-speed entry into waves, so that competitors can initiate their first combination of maneuvers (eg, bottom turn and reentry) as soon as possible to maximize the scoring potential of the wave.

The ability of laboratory-based endurance-paddling ergometer assessments to discriminate between higher- and lower-performing surfers has not been well established, with some studies suggesting that superior aerobic qualities can be determined with paddling ergometers,[5] while other studies have not been able to detect maximal aerobic differences between groups.[4] The current research is novel in that the endurance-paddling time trial was performed in the water, in a closed-kinetic-chain environment, and clearly delineated capacity between higher and lower performers (Table 2). Based on the current findings, if practitioners are examining paddling endurance in surfers, a paddling time trial may be most effective to achieve context validity. Furthermore, the time trial can be used for decision making on training needs, as the velocity achieved in the sprint paddle can be directly compared with that of the endurance-paddle time trial (a ratio of sprint-paddle to endurance-paddle velocity), to assert the relative performance of each quality (and thereby set training priorities). Further research and analysis should include a cross-sectional analysis of the sprint- and endurance-paddling velocities of a range of competitors at varying levels, to assist with creating guidelines that may help practitioners determine training-emphasis needs for sprint-paddling and endurance-paddling ability.

There are several limitations to this current data set that require future research focus. Due to the exhausting nature of the 400-m endurance-paddle time trial, we were unable to obtain reliability data from this population for the endurance assessment. Despite the large differences observed between groups (Table 2), this current limitation prevents us from calculating reliability statistics that allow for a determination of the smallest worthwhile change.

In addition, although the low TEM, and indeed the large differences observed between performance groups, suggests that the tests involved in this protocol will be sensitive to detect training-induced changes, this was not assessed specifically in this study. To evaluate this, future research should assess the ability of the testing protocol to detect potential training and detraining effects in the endurance qualities of surfers.

Practical Applications

Appropriate and valid testing protocols evaluating the physical performances of surfing athletes have not been well refined. This project developed and evaluated a comprehensive sport-science testing protocol for use with surfers, including measures of anthropometry, lower-body strength and power, and sprint and endurance ability. The outcomes from this study resulted in the creation of a national sport-science testing protocol for competitive surfers that can be adopted wholly, or in part, or expanded on by other training programs and for use with future research.

Higher-performing competitive junior surfers are leaner and stronger and have superior sprint- and endurance-paddling ability than lower-performing competitive surfers. As such, practitioners can emphasize developing these capabilities and use assessments of anthropometry, strength and power, and sprint- and endurance-paddling ability to evaluate the physical qualities of competitive surfers.

Acknowledgments

This research project was conducted through the Hurley Surf Science Research Project scheme and was funded by an Edith Cowan University Early Career Research Grant.

The authors would like to thank Martin Dunn, national coaching director with Surfing Australia, and Ben Falvey, head surf coach with Palm Beach Currumbin High School, for their involvement in this research project.

References

1. Meir R, Lowdon BJ, Davie AJ. Heart rates and estimated energy expenditure during recreational surfing. *Aust J Sci Med Sport*. 1991;20:70–74.
2. Mendez-Villanueva A, Bishop D, Hamer P. Activity profile of world-class professional surfers during competition: a case study. *J Strength Cond Res*. 2006;20:477–482. PubMed
3. Mendez-Villanueva A, Bishop D. Physiological aspects of surfboard riding performance. *Sports Med*. 2005;35:55–70. PubMed doi:10.2165/00007256-200535010-00005
4. Loveless DJ, Minahan C. Peak aerobic power and paddling efficiency in recreational and competitive junior male surfers. *Eur J Sport Sci*. 2010;10:407–415. doi:10.1080/17461391003770483
5. Mendez-Villanueva A, Perez-Landaluce J, Bishop D, et al. Upper body aerobic fitness comparison between two groups of competitive surfboard riders. *J Sci Med Sport*. 2005;8:43–51. PubMed doi:10.1016/S1440-2440(05)80023-4
6. Sheppard JM, Osborne M, Chapman D, Andrews M. Anthropometric characteristics, upper-body strength, and sprint paddling performance in competitive surfers. *J Aust Strength Cond*. 2012;20:5–10.
7. Sheppard JM, Chapman D, Gough C, McGuigan MR, Newton RU. Twelve month training induced changes in elite international volleyball players. *J Strength Cond Res*. 2009;23:2096–2101. PubMed doi:10.1519/JSC.0b013e3181b86d98
8. Slater GJ, Duthie GM, Pyne DB, Hopkins WG. Validation of a skinfold based index for tracking proportional changes in lean mass. *Br J Sports Med*. 2006;40:208–213. PubMed doi:10.1136/bjsm.2005.019794
9. Sheppard JM, Cormack S, Taylor KL, McGuigan MR, Newton RU. Assessing the force-velocity characteristics of well trained athletes: the incremental load power profile. *J Strength Cond Res*. 2008;22:1320–1326. PubMed doi:10.1519/JSC.0b013e31816d671b
10. Sheppard JM, Chapman DW. An evaluation of a strength qualities assessment test for the lower body. *J Aust Strength Cond*. 2011;19:14–20.
11. Nuzzo JL, McBride JM, Cormie P, McCaulley GO. Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. *J Strength Cond Res*. 2008;22:699–707. PubMed doi:10.1519/JSC.0b013e31816d5eda
12. Haff GG, Stone M, O'Bryant HS, et al. Force–time dependent characteristics of dynamic and isometric muscle actions. *J Strength Cond Res*. 1997;11:269–272.
13. Kraska JM, Ramsey MW, Haff GG, et al. Relationship between strength characteristics and unweighted and weighted vertical jump height. *Int J Sports Physiol Perform*. 2009;4:461–473. PubMed
14. Loveless DJ, Minahan C. Two reliable protocols for assessing maximal paddling performance in surfboard riders. *J Sports Sci*. 2010;28:797–803. PubMed doi:10.1080/02640411003770220
15. Barlow JM, Findlay M, Gresty K, Cooke C. Anthropometric variables and their relationship to performance ability in male surfers. *Eur J Sport Sci*. 2012; in press.
16. Gore CJ. *Physiological Tests for Elite Athletes*. Canberra: Australian Sports Commission; 2000.

International Journal of Sports Physiology and Performance, 2015, 10, 178-182
http://dx.doi.org/10.1123/ijspp.2014-0222

INTERNATIONAL JOURNAL OF SPORTS PHYSIOLOGY AND PERFORMANCE
www.IJSPP-Journal.com
ORIGINAL INVESTIGATION

Comparison of Physical Capacities Between Nonselected and Selected Elite Male Competitive Surfers for the National Junior Team

Tai T. Tran, Lina Lundgren, Josh Secomb, Oliver R.L. Farley, G. Gregory Haff, Laurent B. Seitz, Robert U. Newton, Sophia Nimphius, and Jeremy M. Sheppard

Purpose: To determine whether a previously validated performance-testing protocol for competitive surfers is able to differentiate between Australian elite junior surfers selected (S) to the national team and those not selected (NS). ***Methods:*** Thirty-two elite male competitive junior surfers were divided into 2 groups (S = 16, NS = 16). Their age, height, body mass, sum of 7 skinfolds, and lean-body-mass ratio (mean ± SD) were 16.17 ± 1.26 y, 173.40 ± 5.30 cm, 62.35 ± 7.40 kg, 41.74 ± 10.82 mm, 1.54 ± 0.35 for the S athletes and 16.13 ± 1.02 y, 170.56 ± 6.6 cm, 61.46 ± 10.10 kg, 49.25 ± 13.04 mm, 1.31 ± 0.30 for the NS athletes. Power (countermovement jump [CMJ]), strength (isometric midthigh pull), 15-m sprint paddling, and 400-m endurance paddling were measured. ***Results:*** There were significant ($P \le .05$) differences between the S and NS athletes for relative vertical-jump peak force ($P = .01$, $d = 0.9$); CMJ height ($P = .01$, $d = 0.9$); time to 5-, 10-, and 15-m sprint paddle; sprint paddle peak velocity ($P = .03$, $d = 0.8$; PV); time to 400 m ($P = .04$, $d = 0.7$); and endurance paddling velocity ($P = .05$, $d = 0.7$). ***Conclusions:*** All performance variables, particularly CMJ height; time to 5-, 10-, and 15-m sprint paddle; sprint paddle PV; time to 400 m; and endurance paddling velocity, can effectively discriminate between S and NS competitive surfers, and this may be important for athlete profiling and training-program design.

Keywords: surfing, physical characteristics, strength, power, sprint and endurance paddle

The level of competition in surfing has increased exponentially over the last decade. Surf coaches and surfers are beginning to realize the importance of physical preparation in enhancing performance to undertake high-risk maneuvers, as well as tolerate the physical demands of participation. For instance, surfing is performed in a dynamic environment with challenging conditions and situations,[1] so surfing athletes must adapt to the conditions and situations all while maintaining a high level of performance.[2] In other words, high levels of strength, power, endurance power, dynamic postural control, and the ability to respond to the challenging situations during competition or free surfing are important for the sport of surfing.[1] Having these qualities will help surfing athletes paddle past the breaking point, sprint paddle to catch a wave followed by an explosive pop-up (transition from a prone position to standing) on the surfboard, and then perform radical maneuvers such as bottom turns, top turns, and reentries or land from aerials. Thus, whole-body strength and power characteristics are likely important parameters necessary to produce and attenuate force during high-risk maneuvers and landings.

Previous research has shown that 44% to 54% of surfing activity is devoted to paddling,[3–5] and paddling performance has been shown to highlight performance differences in surfing populations.[6,7] While wave riding only represents 3.8% to 8%[3–5] of time spent in a surfing competition, surfers are awarded points for their ability to perform high-risk maneuvers such as turns, aerials, barrels, and floaters under control in the most critical parts of the wave.[8] Although paddling is a major physical requirement to perform in the sport, surfers are judged only on the wave riding itself. This is not to say that coaches or athletes should dismiss the relevance of monitoring or improving the physical quality of sprint paddling. Having the physicality to out-paddle their opposition will give surfing athletes the advantage to sit deeper on the peak, control the lineup, first choice of wave section, and the ability for faster entry speed,[9] thus increasing the opportunity to maximize judging criteria.

Surfing is an individual sport; however, every year national federations select their best junior surfers to represent their country and compete with the most promising elite junior surfers at the International Surfing Association (ISA) World Junior Surfing Championship. Each year, 16 young elite competitive male surfers are selected to attend an Australian Team Selection Camp (SC) and compete against each other to earn 1 of 8 spots to represent the Australian Team at the ISA World Junior Surfing Championship. Of the 16 elite competitive surfers, 8 compete in the under-18 (U18) age group and the remainder in the under-16 (U16) age group (vying for 4 spots in each age category). The selection criteria are based on surfing performance during the SC and previous competition results for making the Surfing Australia National Junior Surfing Team, as evaluated by a panel of national coaches.

Surfing can be considered a skill-based sport. As such, when applying fundamental tests of physical performance, it is important to justify the inclusion of each test, particularly if it may be considered to partly influence selection, talent identification, and performance improvement. Although recent studies have shown differences between competitive and recreational surfers' physical capacities,[10,11] there are no studies to our knowledge that distinguish physical capacities between closely matched groups of elite surfers. Therefore, the purpose of this study was to determine whether tests of physical performance reflect selection for international competition from a pool of elite competitive junior surfers.

The authors are with the Centre for Exercise and Sport Science Research, Edith Cowan University, Joondalup, WA, Australia. Address author correspondence to Tai Tran at taitran151@yahoo.com.

Methods

Thirty-two Australian elite competitive male junior surfers from the 2012 (U18 n = 8, U16 n = 8) and 2013 (U18 n = 8, U16 n = 8, Table 1) SC participated in this study. A summary of the athletes' characteristics is presented in Table 1. Elite junior surfers are defined as competitive surfers who have competed in the Australian Nationals or World Junior Championships.[12] Data collection was part of the athletes' participation in the SC, and all testing and data management were conducted according to the Declaration of Helsinki and approved by the institutional human ethics committee.

The current study required the participants to complete 1 testing session consisting of measures of anthropometrics (stature, body mass, and sum of 7 skinfolds), muscle power (vertical jump), lower-body strength (isometric midthigh pull), 15-m sprint paddle, and 400-m endurance paddle. Data from the 2012 and 2013 SC were combined for comparison between the athletes who were selected for the ISA Junior World Championships (selected group, S), and the nonselected group (NS).

The testing procedures began with anthropometry, followed by a standardized dynamic warm-up and, after this, the 4 performance tests. Participants were measured for body mass, height, and sum of 7 skinfolds (triceps, biceps, subscapulae, supraspinale, abdominal, quadriceps, and calf) via a Harpenden skinfold caliper (British Indicator, UK). Body mass was measured on a scale with resolution to the nearest 0.1 kg with the participant barefoot and wearing board shorts only. Height was measured on a stadiometer to the nearest 0.5 cm with the participant barefoot, feet together, and head level. A single researcher certified by the International Society for the Advancement of Kinanthropometry (ISAK), in accordance with the ISAK guidelines, performed all skinfold measures. Lean-body-mass ratio was then calculated by dividing body mass by the sum of 7 skinfolds.[12]

The countermovement jump was used to assess lower-body dynamic strength. Athletes were instructed to complete 3 trials, dipping to a self-selected depth while maintaining a light wooden dowel in contact with the back of the shoulders and then jumping vertically for maximum height.[13] During each jump, if the wooden dowel lost contact with the shoulders, the jump was discarded and repeated. Sixty seconds of rest was provided between jumps. Athletes were encouraged to jump as high as possible, and the best jump height was used for further analysis. The athletes were instructed to start in an upright position while standing still on a portable force plate (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia), which used a built-in amplifier and 4 load cells, that measures vertical components for ground-reaction force. Before data collection, calibration of the force plate was performed per the manufacturer's instructions. The force data were collected at sampling frequency of 600 Hz, and inverse-dynamics calculations were used to calculate displacement, velocity, and acceleration data per the manufacturer software previously used in this population[12] (Ballistic Measurement System, Innervations, Perth, Australia). Data were filtered using a fourth-order Butterworth filter with cutoff frequencies set at 16 and 10 Hz for velocity and acceleration data, respectively. Displacement and force were not filtered.

Maximum isometric strength was measured on a customized midthigh-pull system with adjustable straps to accommodate individual height differences. Athletes completed 3 isometric midthigh pulls with 2 minutes rest between pulls. Before the initial pull, the athletes stood still on the force plate with the shoulders in line with the bar and hands slightly wider than shoulder width apart. The athletes were placed in a position similar to the second pull of the power clean and snatch, which has been reported to maximize force and power production.[14] In other words, the position of the bar was relative to the midthigh for each athlete. Athletes were instructed and verbally encouraged to push against the force plate as hard as possible[15] while holding the bar across their midthigh with maximal effort for 5 seconds. The same force plate, personal computer, and software were used to measure vertical-jump performance recorded and analyzed the vertical ground-reaction force and to derive peak-force and force–time characteristics.

The 15-m sprint paddle test previously described by Sheppard et al[12,16] was performed in an outdoor 25-m swimming pool reserved specifically for paddle testing, which has been reported to have 1.13% typical error of measurement.[12] This testing environment enabled the researchers to control and avoid variable environment factors such as wind and wave currents. Athletes performed the paddle test with their competition surfboard due to individual differences in height and body mass. Before testing, they performed a 200-m warm-up paddle at an easy pace followed by a specific sprint paddle of 4 × 15 m (60%, 70%, 80%, and 90% of individual deliberate effort) separated by 2 minutes of rest between sprint paddle trials. A rest period of 3 to 4 minutes was allowed before performing 2 × 15-m maximum sprint paddle trials with 2 minutes of rest between sprints. The athletes started in a stationary prone position on their surfboards with a horizontal position transducer (I-REX, Southport, Australia) attached to the rear waistline of their shorts to measure sprint paddle split time and velocity. The position transducer recorded a time stamp for each 0.02 m of displacement, thereby allowing determination of sprint time from the start to 5, 10, and 15 m and by differentiation to determine peak sprint paddle velocity.[16]

After 10 minutes of recovery, the athletes performed the 400-m endurance paddle test.[12,16] Athletes were in a stationary prone position on their surfboards and started on a "ready, set, go" command. The athletes were instructed to paddle around 2 weighted buoys positioned 20 m apart and complete a total of 10 laps. Endurance average velocity was determined from the time to complete the endurance paddle test.[12]

Table 1 Physical Characteristics Between Selected and Nonselected Elite Competitive Junior Surfers, Mean ± SD

Characteristic	Selected	Nonselected	*P*	Effect size (*d*)	Magnitude inference
Age (y)	16.18 ± 1.26	16.13 ± 1.02	.91	0.0	42% possibly, may (not)
Mass (kg)	62.36 ± 7.40	61.46 ± 10.10	.78	0.1	40% possibly, may (not)
Stature (cm)	173.41 ± 5.35	170.57 ± 6.60	.19	0.5	77% likely, probable
Sum of 7 skinfolds (mm)	41.74 ± 10.83	49.25 ± 13.04	.09	0.6	88% likely, probable
Ratio	1.56 ± 0.34[a]	1.31 ± 0.31	.04	0.7	94% likely, probable

[a]Significantly different from nonselected athletes ($P \leq .05$).

Statistical Analysis

To determine if there were any significant differences between the S and NS groups, all statistical analyses were analyzed using magnitude-based inferences.[17] A magnitude-based-inferences scale was applied as positive, trivial, or negative based on the likelihoods that the true (population) values of the differences represented substantial change. The likelihoods that the true (population) differences were substantial were assessed using 0.2 standardized units (change in mean divided by the between-subjects SD) and expressed as both percentages and qualitatively, using practical inferences with the certainty of difference classified as 50% to 74%, possibly; 75% to 95%, likely; 95% to 99%, very likely; and >99% almost certainly.[18] Furthermore, the effect was considered trivial if the confidence interval overlapped the true (population) values for both positive and negative change. The magnitude-based-inferences scale has been suggested for practical importance to detect small effects in elite athletes.[19] In addition, independent *t*-tests with ±90% confidence limits and alpha $P \leq .05$ were used to compare anthropometry and performance-test results. Cohen (*d*) effect sizes (ES) were calculated as ES = mean change divided by the standard deviation of the sample scores.[20] The magnitudes of the ESs were considered trivial, <0.2; small, 0.2 to 0.5; moderate, 0.5 to 0.8; and large, >0.8.[20]

Results

There were no significant differences between groups for age, height, body mass, or sum of 7 skinfolds, but there was a significant difference in lean-mass ratio between the groups. Paddling-performance variables showed significant, highly probable, and large differences between the groups (P = .01–.03, 95–98%, d = 0.8–0.9) for time to 5-, 10-, and 15-m sprint paddle and peak velocity in sprint paddling. Significant, highly probable, and moderate differences were observed for 400-m time (P = .04, 93%, d = 0.7) and endurance paddling velocity (P = .05, 92%, d = 0.7) (Table 2).

When normalized to body mass, the selected athletes' relative vertical-jump peak force was significantly greater (P = .01, 98%, d = 0.9) than that of the nonselected athletes. Although there was no significant difference between the 2 groups for vertical-jump peak velocity (P = .06), the selected athletes demonstrated significantly greater vertical-jump height than the nonselected athletes, with high probability and a large magnitude of difference (P = .01, 98%, d = 0.9) (Table 3). With respect to strength, there was no significant difference found between the 2 groups for absolute isometric strength; however, when normalized to body mass, relative isometric strength was significantly greater for the selected athletes, with high probability and a moderate magnitude (P = .05, 92%, d = 0.7) (Table 3).

Discussion

The aim of this study was to determine whether physical-performance characteristics of elite junior competitive surfers selected to represent the Australian Team at the ISA World Championship clearly demonstrated differences from those of nonselected athletes. The results demonstrated that there are significant differences between the groups for lower-body relative strength, dynamic strength, sprint paddling ability, and endurance paddling. Furthermore, this study provides reference values of anthropometric and physical characteristics of elite competitive junior male surfers. This information provides insight for the surf community about the importance of incorporating strength and conditioning programs

Table 2 Sprint and Endurance Paddle Performance, Mean ± SD

Measure	Selected	Nonselected	*P*	Effect size (*d*)	Magnitude inference
Sprint paddle					
5 m (s)	3.67 ± 0.15[a]	3.86 ± 0.23	.01	0.9	98% very likely
10 m (s)	6.56 ± 0.23[a]	6.88 ± 0.40	.01	0.9	98% very likely
15 m (s)	9.49 ± 0.35[a]	9.93 ± 0.60	.02	0.8	97% very likely
peak velocity (m/s)	1.78 ± 0.08[a]	1.71 ± 0.10	.03	0.8	95% very likely
Endurance paddle					
400 m (s)	320.63 ± 13.21[a]	332.94 ± 18.89	.04	0.7	93% likely, probable
endurance velocity (m/s)	1.25 ± .05[a]	1.21 ± .07	.05	0.7	92% likely, probable

[a]Significantly different from nonselected athletes ($P \leq .05$).

Table 3 Relative Vertical-Jump Peak Force, Vertical-Jump Peak Velocity, Vertical-Jump Height, Isometric Midthigh Pull, and Relative Isometric Midthigh-Pull Peak Force, Mean ± SD

Measure	Selected	Nonselected	*P*	Effect size (*d*)	Magnitude inference
Relative vertical-jump peak force (N/kg)	21.90 ± 1.59[a]	20.45 ± 1.40	.01	0.9	98% very likely
Vertical-jump peak velocity (m/s)	2.67 ± 0.22	2.49 ± 0.30	.06	0.7	91% likely, probable
Vertical-jump height (m)	0.49 ± 0.05[a]	0.42 ± 0.07	.01	0.9	98% very likely
Isometric midthigh pull (N)	2063.5 ± 267.5	1902.19 ± 381.13	.18	0.5	79% likely, probable
Relative isometric midthigh-pull peak force (N/kg)	33.18 ± 3.13[a]	30.91 ± 3.17	.05	0.7	92% likely, probable

[a]Significantly different from nonselected athletes ($P \leq .05$).

entailing lower-body dynamic strength development, muscle strength, sprint paddling, and endurance paddling in conjunction with surf training. In addition, this information can be used for talent identification for coaches working with surfing athletes, particularly with reference to the physical-performance attributes of elite junior male surfers.

Although various physical characteristics such as age, mass, height, and sum of 7 skinfolds were not statistically different between the S and NS athletes, the S athletes demonstrated greater performance in these tasks. For example, the S athletes had lower average sum-of-7-skinfold measures than the NS athletes (Table 1). Given that this study involved elite athletes, and, by its very nature, participant numbers are low, even borderline significant outcomes should be considered so as to not overlook where marginal gains can be made. Therefore, with some latitude applied with regard to statistical significance and the relatively low power in this study, based on the ES magnitude observed, it is clear that the S athletes were leaner with significantly higher lean-mass ratio. This finding is consistent with our previous study[12] reporting no significant differences for height ($P = .102$, $d = 0.5$) or body mass ($P = .827$, $d = 0.1$) between elite junior and competitive junior surfers; however, the elite group had lower skinfolds ($P = .005$, $d = 0.9$) with higher lean-mass ratio ($P = .001$, $d = 1.1$). Lower skinfolds and higher lean-mass ratio have been previously reported by other groups to be positively correlated to surfing ability.[10] In addition, having lower skinfold sums and higher lean-mass ratio will be advantageous for performance of upper-body-strength exercises such as pull-ups, which is an important closed-chain exercise for surfers as it is similar to the paddle phase.[9]

Sheppard et al[16] investigated 10 male competitive surfers and demonstrated a strong correlation between relative pull-up strength and time to 5-, 10-, and 15-m sprint paddle and sprint paddle velocity ($r = .94$, .93, .88, and .66, respectively). Recently, Sheppard et al[12] demonstrated that elite male competitive junior surfers had significantly higher 5-, 10-, and 15-m and sprint paddle velocity than nonelite male competitive junior surfers. The current study further establishes the sprint paddle test as a performance discriminator, as the athletes in this group were a closely matched group of elite surfers, thereby making any observed difference in physical quality all the more compelling. The fact that the sprint paddle is a major performance factor stands to reason; a surfer who has a faster sprint paddle time than his or her opposition will be at an advantage in any form of paddle situation, in both 2- and 4-person competitive heats.[9] Surfers with more powerful paddle strokes will have the choice of sitting deeper on the peak, because due to their paddling ability, they can catch waves in the steeper section of the wave. Tactically, this allows them to be on the inside and have first choice of which wave they choose to ride, hence controlling the lineup.[9] In addition, by sitting deeper a surfer is able to take off either on the peak or behind the peak, enabling the first turn to be in the most critical part of the wave, which is judged according to established criteria in the sport.[8] Furthermore, faster sprint paddling allows for a greater entry speed as surfers first rise to their feet, allowing them to generate more speed sooner in the ride, making it easier for them to execute maneuvers in the most critical section of the wave and maximizing judging criteria.[8]

In addition, the selected athletes demonstrated significantly faster 400-m endurance time and endurance average velocity paddling (Table 2), which is in line with previously published research showing that elite juniors are significantly faster than a less competitive junior group.[12] Although these findings highlight the importance of aerobic capacity for surfing, Farley et al[7] reported there was no correlation ($r = -.02$, $P = .97$) between peak oxygen uptake and seasonal rank during an aerobic paddle test using a modified ergometer on dry land. In spite of the fact that time–motion analyses during an hour of surfing reported 44% to 54% devoted to paddling,[3–5] surfing is judged on wave riding. It may be that having greater aerobic capabilities will benefit surfers, as this would improve one's ability to withstand the demands of the paddling and delay the onset of fatigue. However, it may be that in-water time trials, rather than dry-land ergometer methods, are required to elucidate truly relevant performance differences in paddling for surfers. Nonetheless, it is important to note that surfing is likely best described as requiring intermittent paddling bouts[3–5] and that although an endurance-based time trial as we performed in the current study is clearly relevant to this population, a repeated-effort-style test that incorporates multiple, intensive paddling bouts may be considered even more applicable.

The current study highlights the importance of lower-body dynamic strength for surfing, since the S athletes demonstrated significantly greater jump height during countermovement jump than the NS athletes (Table 3). Although a vertical jump may not immediately appear specific to surfing, surfers do perform an absorption, braking, and propulsion phase when executing maneuvers. For example, in the bottom turn, surfers compress their body and hold the bottom position, then throw the arms forward and up as they maneuver the surfboard back to the lip of the wave. They then repeat this series for most maneuver types such as bottom turn to carve combinations on the face of the wave. In other words, high-level surfing is a series of compression and extension movements where the surfer produces and arrests force through the riding of a wave. Although jumping may not appear entirely similar, the fundamental neuromuscular action is likely relevant. Furthermore, with the increase in the execution of aerial surfing,[21] it stands to reason that the ability to have greater lower-body explosive power will enable surfers to launch themselves off the lip of the wave to gain greater height during an aerial.

An interesting finding was that there was no significant difference between the groups for lower-body absolute strength ($P = .10$, $d = 0.61$), particularly considering that maximal strength underpins power,[22,23] and such compelling differences were observed between the S and NS groups in the lower-body dynamic strength test. However, the selected athletes did demonstrate significantly greater relative strength, and this difference was practically meaningful when the magnitude was considered in light of our typical-error-of-measurement data from a similar population[9] and considering that the difference was of a moderate effect. Given that previous findings have demonstrated compelling differences between subelite and elite groups in maximal lower-body strength,[14] we suggest considering lower-body strength measures relative to body mass as being most insightful in a population of surfers. It is important to note that the nature of surfing requires athletes to transfer their body mass across the wave while performing high-risk maneuvers, thus requiring a certain amount of relative lower-body strength in combination with skill and dynamic postural stability.

The current study was limited to tests of anthropometry, paddling ability, power, and strength. Although our findings support the relevance of these tests of physical capability, surfing is a dynamic sport requiring high levels of sensorimotor ability. Future research efforts should investigate the importance of dynamic postural control and sensorimotor ability in surfers, as this measure might also discriminate among skill levels of surfers, thereby allowing for talent identification and detection of favorable training-induced changes.

Practical Implications

This study provides reference values of anthropometry, lower-body power and strength, and sprint and endurance paddling ability for S and NS elite junior surfers. These results, using a pool of elite junior surfers, distinguished differences in physical performance between the higher and lower level even among this very homogeneous group of surfers. As such, these measures can be used as performance tests in the sport. Furthermore, we recommend that competitive surfers incorporate strength-power and conditioning training in conjunction with surf training, as these qualities clearly have an association with superior surfing performance.

Conclusions

The purpose of this study was to measure and compare anthropometric characteristics and physical performance between S and NS elite junior male competitive surfers. While the difference was only borderline significant, the S athletes were leaner with significantly higher lean-mass ratio than the NS athletes. Furthermore, the S athletes demonstrated significantly greater relative vertical-jump peak force; vertical-jump height; relative lower-body maximum isometric strength; time to 5-, 10-, and 15-m sprint paddle; peak velocity sprint paddle; time to 400 m; and endurance average velocity paddling.

Acknowledgments

The authors would to thank all the surfing athletes for their time and participation in this study. In addition, the authors would like to thank all the surf coaches for their contribution and continuous support.

References

1. Mendez-Villanueva A, Bishop D. Physiological aspects of surfboard riding performance. *Sports Med*. 2005;35:55–70. PubMed doi:10.2165/00007256-200535010-00005
2. Eurich AD, Brown LE, Coburn JW, et al. Performance differences between sexes in the pop-up phase of surfing. *J Strength Cond Res*. 2010;24:2821–2825. PubMed doi:10.1519/JSC.0b013e3181f0a77f
3. Farley OR, Harris NK, Kilding AE. Physiological demands of competitive surfing. *J Strength Cond Res*. 2012;26:1887–1896. PubMed doi:10.1519/JSC.0b013e3182392c4b
4. Meir RA, Lowdon BJ, Davie AJ. Heart rates and estimated energy expenditure during recreational surfing. *Aust J Sci Med Sport*. 1991;23(3):70–74.
5. Mendez-Villanueva A, Bishop D, Hamer P. Activity profile of world-class professional surfers during competition: a case study. *J Strength Cond Res*. 2006;20:477–482. PubMed
6. Méndez-Villanueva A, Perez-Landaluce J, Bishop D, et al. Upper body aerobic fitness comparison between two groups of competitive surfboard riders. *J Sci Med Sport*. 2005;8:43–51. PubMed doi:10.1016/S1440-2440(05)80023-4
7. Farley O, Harris NK, Kilding AE. Anaerobic and aerobic fitness profiling of competitive surfers. *J Strength Cond Res*. 2012;26:2243–2248. PubMed doi:10.1519/JSC.0b013e31823a3c81
8. ISA International Judging & Officiating, International Judging Commission of Surfing. Association of Surfing Professionals (ASP). *ASP Rule Book 2012*. Available at: www.aspworldtour.com.
9. Sheppard JM, Osborne M, Chapman D, Andrews M, McNamara P. Technique adjustments influence the performance of sprint paddling in competitive male surfers. *Int J Sports Sci Coaching*. 2013;8:43–52. doi:10.1260/1747-9541.8.1.43
10. Barlow MJ, Findlay M, Gresty K, Cooke C. Anthropometric variables and their relationship to performance and ability in male surfers. *Eur J Sport Sci*. 2014;14(Suppl 1):S171–S177. PubMed
11. Loveless DJ, Minahan C. Peak aerobic power and paddling efficiency in recreational and competitive junior male surfers. *Eur J Sport Sci*. 2010;10:407–415. doi:10.1080/17461391003770483
12. Sheppard JM, Nimphius S, Haff GG, et al. Development of a comprehensive performance-testing protocol for competitive surfers. *Int J Sports Physiol Perform*. 2013;8(5):490–495. PubMed
13. Amonette WE, Brown LE, De Witt JK, et al. Peak vertical jump power estimations in youths and young adults. *J Strength Cond Res*. 2012;26:1749–1755. PubMed doi:10.1519/JSC.0b013e3182576f1e
14. Garhammer J. A review of power output studies of Olympic and powerlifting: methodology, performance prediction, and evaluation tests. *J Strength Cond Res*. 1993;7:76–89.
15. Haff GG, Stone M, O'Bryant H, et al. Force–time dependent characteristics of dynamic and isometric muscle action. *J Strength Cond Res*. 1997;11:269–272.
16. Sheppard JM, McNamara P, Osborne M, et al. Association between anthropometry and upper-body strength qualities with sprint paddling performance in competitive wave surfers. *J Strength Cond Res*. 2012;26:3345–3348. PubMed doi:10.1519/JSC.0b013e31824b4d78
17. Hopkins WG. How to analyze a straightforward controlled trial (Excel spreadsheet). *SportScience*. 2003.
18. Humberstone-Gough CE, Saunders PU, Bonetti DL, et al. Comparison of live high:train low altitude and intermittent hypoxic exposure. *J Sports Sci Med*. 2013;12:394–401. PubMed
19. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41:3–13. PubMed doi:10.1249/MSS.0b013e31818cb278
20. Cohen J. *Statistical Power Analysis for the Behavioural Sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum; 1988.
21. Lundgren L, Tran TT, Dunn M, Nimphius S, Sheppard JM. Analysis of manoeuvres and scoring in competitive surfing. *Int J Sport Sci Coaching*. 2014;9.
22. Sheppard JM, Chapman DW, Gough C, McGuigan M, Newton RU. Twelve-month training-induced changes in elite international volleyball players. *J Strength Cond Res*. 2009;23:2096–2101. PubMed doi:10.1519/JSC.0b013e3181b86d98
23. Nimphius S, McGuigan MR, Newton RU. Relationship between strength, power, speed, and change of direction performance of female softball players. *J Strength Cond Res*. 2010;24:885–895. PubMed doi:10.1519/JSC.0b013e3181d4d41d

Appendix 5: Study 3 Publication

International Journal of Sports Physiology and Performance, 2015, 10, 396-400
http://dx.doi.org/10.1123/ijspp.2014-0375

INTERNATIONAL JOURNAL OF
SPORTS PHYSIOLOGY
AND PERFORMANCE
www.IJSPP-Journal.com
ORIGINAL INVESTIGATION

Development and Evaluation of a Drop-and-Stick Method to Assess Landing Skills in Various Levels of Competitive Surfers

Tai T. Tran, Lina Lundgren, Josh Secomb, Oliver R.L. Farley, G. Gregory Haff, Robert U. Newton, Sophia Nimphius, and Jeremy M. Sheppard

The purpose of this study was to develop and evaluate a drop-and-stick (DS) test method and to assess dynamic postural control in senior elite (SE), junior elite (JE), and junior development (JD) surfers. Nine SE, 22 JE, and 17 JD competitive surfers participated in a single testing session. The athletes completed 5 drop-and-stick trials barefoot from a predetermined box height (0.5 m). The lowest and highest time-to-stabilization (TTS) trials were discarded, and the average of the remaining trials was used for analysis. The SE group demonstrated excellent single-measures repeatability (ICC = .90) for TTS, whereas the JE and JD demonstrated good single-measures repeatability (ICC .82 and .88, respectively). In regard to relative peak landing force (rPLF), SE demonstrated poor single-measures reliability compared with JE and JD groups. Furthermore, TTS for the SE (0.69 ± 0.13 s) group was significantly (*P* = .04) lower than the JD (0.85 ± 0.25 s). There were no significant (*P* = .41) differences in the TTS between SE (0.69 ± 0.13 s) and JE (0.75 ± 0.16 s) groups or between the JE and JD groups (*P* = .09). rPLF for the SE (2.7 ± 0.4 body mass; BM) group was significantly lower than the JE (3.8 ± 1.3 BM) and JD (4.0 ± 1.1 BM), with no significant (*P* = .63) difference between the JE and JD groups. A possible benchmark approach for practitioners would be to use TTS and rPLF as a qualitative measure of dynamic postural control using a reference scale to discriminate among groups.

Keywords: surfing, wave riding, dynamic postural control, time to stabilization, relative peak landing force

The ability to attenuate landing force and regain postural control as quickly as possible on landing, before transitioning to the next maneuver, is of great importance for the sport of surfing. This is due to the increasing complexity of maneuvers performed in competitive surfing.[1] As a result of these complex maneuvers, an important element of surfing is dynamic postural control on landing and rapid compression, which occurs during maneuvers such as bottom turns, reentries, aerials, and floaters. However, no known research to date has investigated these qualities in surfing athletes. Previously suggested variables to assess dynamic postural control are time to stabilization (TTS) and relative peak landing force (rPLF), which may be important for surfing athletes in relevant landing tasks.[2] Dynamic postural control involves a combination of the sensory, motor, and central integration to process information and produce appropriate neural responses to control posture and joint stability.[3,4] Recently, Paillard et al[5] reported that more-skilled surfing athletes possess greater postural control than less-skilled surfing athletes; however, Chapman et al[6] found no difference between skilled and less-skilled surfing athletes. Both studies had their participants perform the required tasks with either eyes open or eyes closed. The difference was that Paillard et al had their participants perform the tasks on an unstable seesaw device, whereas Chapman et al had their participants stand as still as possible on a balance platform while performing the tasks. Furthermore, the tasks used in both studies may not be ideal in re-creating athletic activities, as standing still may not challenge the neuromuscular system.[7] It is worth noting that different methods of assessing dynamic postural control have an effect on the current findings in the literature, therefore indicating that dynamic postural control needs further investigation, as the literature confounds the ability to draw clear conclusions.

Wikstrom et al[2] investigated the reliability and precision of TTS using a force plate to assess dynamic postural control, reporting fair reliability for TTS in the vertical direction. In another study, Flanagan et al[9] reported poor reliability for TTS landing after depth jumps from 0.3 m. Although these studies did not show promising results for the TTS variable, it is important to note that they used a complex protocol to quantify postural control. A more simple design would be to use a drop-and-stick (DS) test, where the athlete starts by standing on top of a standardized box height, then takes a forward step off the box and lands softly with both legs. Furthermore, using a DS test is more relevant for surfers to assess postural-control ability in such a manner where control must be regained after the drop. Collectively, these studies provided a significant contribution to the postural-control literature; however, different protocols will vary in results of the postural-control assessment and need to be modified depending on the age or level of the athletes for whom they are developed. An alternative method to quantify postural-control ability and landing force may be to implement a reference scale. Adopting a reference scale as part of a surfing-development curriculum may ensure that surfers are on path to effective development throughout their junior-to-senior elite level of competition. In addition, a reference scale may help surf coaches determine whether a surfer is physically ready and has earned the right for higher-demand training, in light of the fact that surfing criteria require surfers to perform more radical maneuvers to maximize scoring criteria. Aerials are high-risk maneuvers that maximize scoring when they are completed successfully. However, surfers with a low physical level may expose themselves to higher risk of injury when landing this high-risk maneuver.

According to Seegmiller and McCaw,[8] exposure to repetitive high-eccentric-load landings is one of the contributing factors to

The authors are with the Centre for Exercise and Sport Science Research, Edith Cowan University, Joondalup, Western Australia. Address author correspondence to Tai Tran at taitran151@yahoo.com.

injury in the lower extremity. Therefore, the ability of surfing athletes to repeatedly land in a stable and controlled posture with low impact force is critical to spare the joints and potentially reduce the likelihood of an injury to the lower extremity. While previous studies have used ground-reaction-force measurements to assess force production during the concentric phase of the vertical jump, TTS using the ground-reaction force during the landing phase has been recently used to quantify dynamic postural control among various populations.[2,9–12] The TTS method using the DS test measures the ability of an athlete to transition from a dynamic movement in a controlled environment to land and remain motionless as quickly as possible. Furthermore, rPLF may quantify how effectively various levels of surfing athletes use different landing techniques to attenuate eccentric load rather than allowing the force to transmit directly through the joints. For instance, it may be suggested that a surfer with the ability to efficiently attenuate the impact force in a landing and rapidly regain a stable position will be able to quickly transition to the next maneuver after a landing from an aerial maneuver or floater during wave riding. TTS and rPLF in a DS landing are likely important variables for a surfing athlete. Currently, there is no published research on a standardized postural-control assessment such as a DS off a standardized box or reference scale to assess TTS or rPLF in various levels of competitive surfing athletes. Therefore, the purpose of this study was to provide information on the measures of a DS assessment regarding TTS and rPLF. In addition, the results of this investigation might allow us to differentiate between various competitive levels of postural control.

Methods

Nine competitive senior elite (SE) male (n = 7) and female (n = 2), 22 junior elite (JE) male (n = 15) and female (n = 7), and 17 junior development (JD) male (n = 11) and female (n = 6) competitive surfers (overall mean ± SD age, mass, and stature for SE, 24.5 ± 3.8 y, 75.1 ± 9.2 kg, 175.0 ± 9.0 cm; for JE, 16.1 ± 1.0 y, 61.9 ± 6.7 kg, 171.0 ± 5.5 cm; and for JD, 14.7 ± 1.4 y, 56.3 ± 10.6 kg, 167.0 ± 9.5 cm, respectively) participated in this study. Body mass (BM) was measured on a scale with resolution to the nearest 0.1 kg with the participant barefoot. Stature was measured on a stadiometer to the nearest 0.5 cm with the participant barefoot, feet together, and head level. All athletes and parents of the minor athletes were informed in detail regarding all test procedures and risks for the study. Before participation, athletes voluntarily gave informed consent, and informed consent was obtained from the parents of those under the age of 18 years. All testing and data management were conducted according to the Declaration of Helsinki and approved by the university human ethics committee. After anthropometric measurements, athletes performed a standardized general and dynamic warm-up consisting of skipping, knee hug, squat, duck walk, lateral shuffle, thoracic rotation, hop-hop stick, and knee tuck.

DS Test

The DS test was performed on a portable force plate (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia) connected to a computer running data-collection and -analysis software (InnerBalance, Innervations, Perth, Australia) recording vertical ground-reaction force at a sample rate of 600 Hz. Force was not filtered, but the force threshold was set at 50 N. Athletes attended a single session and were familiarized with the DS test by performing 3 practice trials before data collection. However, if additional trials were necessary to be competent in the landing task, the athletes were provided additional trials. The athletes then performed 5 DS trials barefoot from a predetermined box height of 0.5 m (Figure 1[a]). They were instructed to step forward off the box with their preferred leg, "land soft" on both feet, and as quickly as possible squat to the final position (upper thighs parallel to the ground, Figure 1[b]). TTS was calculated from the time of initial landing contact until they stabilized within 5% of BM (Figure 2). For example, if an athlete's initial contact occurred at 1.5 seconds and stabilization to within 5% of their BM occurred at 2.1 seconds, TTS of 0.6 second was recorded. The rPLF was calculated from peak landing force divided by BM to account for individual differences. In the event that the upper thighs were not parallel to the ground, the trial was discarded and the athlete was given another trial. A minimum of 15 seconds of rest was provided between drop landings.[13]

Statistical Analyses

The lowest and highest TTS trials were discarded, and the remaining 3 trials were used to determine single-measures repeatability. The average of 3 trials was then used for further analysis and comparison between groups. One-way analyses of variance were used to identify any significant differences in TTS and rPLF between groups. Post hoc analyses of the effects of measure were conducted using least-significant-difference-adjusted 2-tailed *t* tests. All statistical analyses were completed using SPSS, version 22 software (SPSS Inc, Chicago, IL, USA) with criterion level of significance set at P .05. Reliabilities for TTS and rPLF were analyzed using intraclass correlation coefficient (ICC) with 95% confidence intervals (CI), and typical error expressed as coefficient of variation (CV). In addition, all reliability coefficients were classified as poor < .69, fair .70 to .79, good .80 to .89, and excellent .90 to 1.00.[14]

Results

The ICCs and CVs for TTS and rPLF are presented in Table 1. The SE group demonstrated excellent single-measures reliability in the TTS, whereas the JE and JD groups demonstrated good single0measures reliability. In regard to rPLF, the SE group demonstrated poor single-measures reliability compared with the JE and JD groups (Table 2). There was no significant (P = .41) difference between the SE (0.69 ± 0.13 s) and JE groups (0.75 ± 0.16 s) for TTS (Figure 3[a]); however, SE surfers' TTS (0.69 ± 0.13 s) was significantly

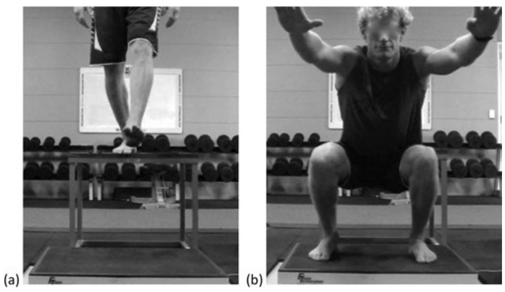


Figure 1 — Drop-and-stick from a box height of 0.5 m, (a) start and (b) end position.

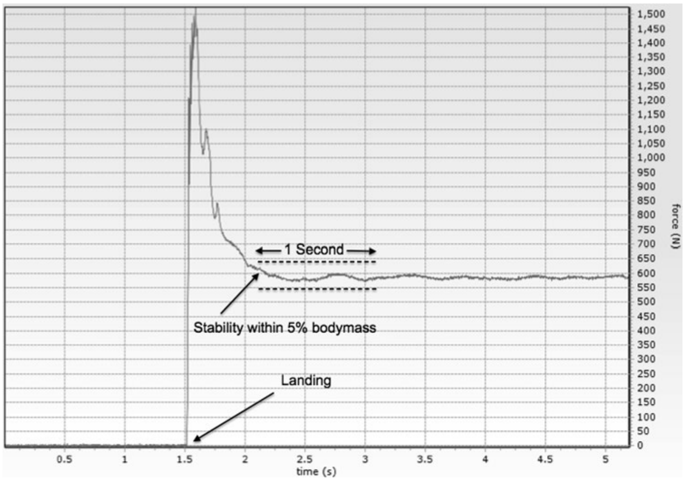


Figure 2 — Time to stabilization calculated from initial contact of the landing to the time the athletes stabilized within 5% of body mass.

Table 1 Reliability of Measures of Time to Stabilization (TTS) and Relative Peak Landing Force (rPLF) Showing Intraclass Correlation Coefficient (ICC) and Coefficient of Variation (CV%) From Senior Elite, Junior Elite, and Junior Development Competitive Surfers

				95% Confidence Interval		
Group	**n**	**Variable**	**ICC**	**Lower**	**Upper**	**CV, %**
Senior elite	9	TTS (s)	.90	.74	.98	5.3
		rPLF (body mass)	.62	.22	.88	10.4
Junior elite	22	TTS (s)	.82	.67	.91	8.0
		rPLF (body mass)	.76	.58	.88	16.2
Junior development	17	TTS (s)	.88	.75	.95	10.0
		rPLF (body mass)	.70	.45	.86	7.7

(P = .04) faster than that of the JD group (0.85 ± 0.25 s). There was no significant (P = .09) difference between the JE and JD groups for TTS. In regard to rPLF (Figure 3[b]), the SE group (2.7 ± 0.4 BM) landed with significantly less relative force than the JE (3.8 ± 1.3 BM; P = .02) and JD groups (4.0 ± 1.1 BM; P = .01). There was no significant (P = .63) difference in rPLF between the JE and JD groups. The DS test was able to discriminate between SE and JD groups for TTS and rPLF (Figure 3). Furthermore, the test was able to differentiate SE and JE groups and SE and JD for rPLF.

Discussion

The purpose of this study was to determine whether TTS and rPLF from a simple DS-test assessments of dynamic postural control differentiate between SE, JE, and JD competitive surfers. The results of this study demonstrated excellent single-measures reliability (ICC =

Table 2 Dynamic-Postural-Control Reference Scale for Time to Stabilization (TTS) and Relative Peak Landing Force (rPLF)

	Elite senior	**Elite junior**	**Junior development**
TTS			
excellent	<0.60 s	<0.65 s	<0.70 s
good	0.60–0.75 s	0.65–0.80 s	0.70–0.85 s
poor	>0.75 s	>0.80 s	>0.85 s
rPLF			
excellent	<3.0 BM	<3.5 BM	<4.0 BM
good	3.0–4.0 BM	3.5–4.5 BM	4.0–5.0 BM
poor	>4.0 BM	>4.5 BM	>5.0 BM

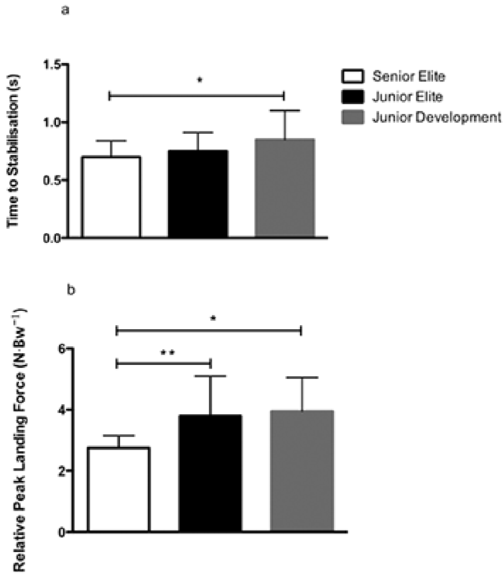


Figure 3 — Time to stabilization and relative peak landing force for competitive surfers. *Indicates senior elite competitive surfers were significantly ($P < .05$) different from junior development surfers. **Senior elite competitive surfers were significantly different from junior elite surfers.

.90; CV = 5.3%) for TTS in the SE group, with poor single-measures reliability for rPLF (ICC = .62; CV = 10.4%). JE and JD groups demonstrated good reliability for TTS (ICC = .82, CV = 8.0%, and ICC = .86, CV = 10.0%, respectively), with fair reliability for rPLF (ICC = .76, CV = 16.2%, and ICC = .70, CV = 7.7%, respectively). This provides new justification to believe that TTS is a measurable variable to assess dynamic postural control. Furthermore, TTS and rPLF demonstrated a significant difference between SE and JD, thus indicating that the DS test could differentiate between elite and junior-development level of ability.

Wikstrom et al[2] reported fair reliability (ICC .78, CI95 .59–.90) for TTS. However, they used a complex approach to assess TTS by having the participants perform a multistage single-limb task before the actual landing, whereas Flanagan et al[10] used a different approach by having the participants perform a depth jump, then land and stabilize with both feet as quickly as possible. Flanagan et al[10] reported low reliability (ICC = .68) for TTS using NCAA Division I track and field athletes. They also used a complex task before landing compared with the current study, which may explain differences in the results. We suggest that practitioners standardize and make the TTS assessment simple and suitable for all levels, as this will increase the reliability of a sensitive test. Furthermore, we recommend that the athletes be familiarized with the task to increase competency in an effort to repeatedly perform the test properly.

To overcome concerns for the reliability observed in these studies, one possible approach would be to use TTS as a qualitative measure of dynamic postural stability using reference values to categories an athlete's baseline value (eg, excellent < 0.6 s, good 0.60–0.75 s, poor > 0.75 s; Table 2), based on age groups or training age, to quantify TTS on landing. For instance, this reference scale could be used as a qualitative measure to discriminate among groups, as the results would be expected to vary due to different levels of ability. The method used in this study to assess dynamic postural control is a general landing task, and therefore it is possible to standardize for repeated trials; however, there are also some similarities to landing tasks that occur in surfing after aerial or floater maneuvers. In addition, using a standardized 0.5-m drop height will place loads that make high demand of the neuromuscular system, without eliciting any substantial injury risk.[8,15] Therefore, it is imperative that the athletes flex their ankles, knees, and hips on landing to ensure that the eccentric loads are absorbed by the muscles and that joint structures are spared, which is an important component to reducing injury risks on landing.[16]

Because landing skill is highly trainable variable,[17] it is expected that adults or higher-level athletes would be able to exhibit less landing force than adolescents or lower-level surfing athletes. This hypothesis is supported by the results of this study, as the SE group was able to efficiently attenuate the peak landing force compared with the junior groups. The rPLF for all 3 groups demonstrated ICCs ranging from .62 to .76 with a CV% ranging from 5.3% to 16.2%, with only rPLF in the JE group demonstrating unreliability at a CV cutoff of 10%.[18] However, before dismissing the utility of this measure, it may be an important variable to measure after a periodized resistance-training phase to assess whether athletes can efficiently use their muscles to attenuate a high landing force. For instance, if a surfing athlete lands from an aerial maneuver and his or her muscles cannot withstand the high landing force, the athlete will likely be at increased risk of injury.[19]

Another interesting finding was that the SE rPLF demonstrated poor single-measures reliability compared with the JE and JD groups; however, the SE group was able to land with significantly ($P < .05$) lower impact force than the other 2 groups. The greater variability in landing force might be due to the fact that the athletes were only instructed to land as softly as possible. It might be that some athletes will land with flat feet while others will land on their toes first, then transferring their weight to the heels. It was expected that the SE group would be able to attenuate the landing force better than the junior groups, and this was supported, with the SE group demonstrating 28.9% and 32.5% less landing force than the JE and JD groups, respectively, over an average of 3 trials. The JE group was able to land with 5.0% less impact force than the JD group; however, there was no significant ($P > .05$) difference observed. A possible explanation of the observed difference might be a lack of intermuscular coordination, which limits the ability of the younger or lower-level athletes to repeatedly attenuate the landing force. It has been reported that landing from a 0.5-m drop height produced landing forces ranging from 1.67 to 6.18 BM.[20] In a study involving a cohort of recreational and competitive male and female athletes age 13 to 19 years, it was reported that the landing force from a 0.3-m height ranged from 2.0 to 10.4 BM with a mean of 4.5 BM.[15] The current study demonstrated the SE group's rPLF was 2.7 ± 0.4 BM, with the JE and JD demonstrating 3.8 ± 1.3 BM and 4.0 ± 1.1 BM, respectively. In contrast, Seegmiller and McCaw[8] reported that female Division I gymnasts exhibited higher landing force from 0.6 m and 0.9 m than recreational females participating in sports that also involve repetitive landings. The higher landing forces in highly trained gymnasts compared with the highly trained surfers in the current study might be due to landing instructions given to the athletes. Seegmiller and McCaw instructed their gymnasts to land using their natural landing style, whereas the surfers

in the current study were instructed to land soft on both feet and move as quickly as possible to a squat position. The results from the Seegmiller and McCaw study raise awareness that high-level athletes may also benefit from landing-technique training. A simple altitude landing task such as dropping from a box with ankle, knee, and hip flexion and quiet landing should be monitored in a training program. Once an athlete demonstrates safe and effective landings with no valgus knees or minimal ankle, knee, and hip flexion, the athlete can progress to single-leg horizontal hop-and-stick. Landing is trainable and, if instructed properly, an athlete will exhibit less landing force[15,16,21,22] and reduce the likelihood of an injury from exposure to repetitive high landing forces.[19]

Practical Implications

The results of this study provided descriptive data for the DS test among competitive surfing athletes. ICCs revealed good to excellent single-measures reliability for the DS test via TTS to assess dynamic postural control. This suggests that the DS test using TTS is useful to assess dynamic postural control on landing across different levels of competitive surfing athletes. Although rPLF demonstrated greater variability, DS is an important measure to assess landing force and force-attenuation skills for surfing athletes. The distinctive differences for TTS and rPLF between the SE and JD athletes indicated that the DS is a useful test to assess dynamic postural control. We suggest that practitioners use both measures as an assessment of landing skills. A possible benchmark approach for practitioners would be to use the DS as a qualitative measure of dynamic postural control using a reference scale (eg, excellent < 0.6 s, good 0.60–0.75 s, and poor > 0.75 s) to quantify TTS for elite surfing athletes and rPLF (excellent < 3.0 BM, good 3.0–4.0 BM, and poor > 4.0 BM), which will be adjusted depending on the age and level of the athlete. Adopting a reference scale might be useful for coaches and practitioners to determine whether individual needs to work on stability, reduction of landing forces to spare the joints, or earn the right to perform high-risk maneuvers. Furthermore, it may be worthwhile to incorporate an intervention program in landing technique for lower-level athletes or those with low training age. This is due to the results from the current study revealing that lower-level surfing athletes were significantly slower to stabilize and also produced greater landing force.

References

1. Lundgren L, Tran TT, Dunn M, Nimphius S, Sheppard JM. Analysis of manoeuvres and scoring in competitive surfing. *Int J Sports Sci Coaching*. In press.
2. Wikstrom EA, Tillman MD, Smith AN, Borsa PA. A new force-plate technology measure of dynamic postural stability: the dynamic postural stability index. *J Athl Train*. 2005;40:305–309. PubMed
3. Lephart SM, Riemann BL, Fu FH. Introduction to the sensorimotor system. In: Lephart SM, Fu FH, eds. *Proprioception and Neuromuscular Control in Joint Stability*. Champaign, IL: Human Kinetics; 2000:17–24.
4. Granacher U, Muehlbauer T, Taube W, Gollhofer A, Gruber M. Sensorimotor training. In: Cardinale M, Newton RU, Nosaka K, eds. *Strength and Conditioning: Biological Principles and Practical Applications*. Oxford, UK: Wiley-Blackwell; 2011:399–409.
5. Paillard T, Margnes E, Portet M, Breucq A. Postural ability reflects the athletic skill level of surfers. *Eur J Appl Physiol*. 2011;111:1619–1623. PubMed doi:10.1007/s00421-010-1782-2
6. Chapman DW, Needham KJ, Allison GT, Lay B, Edwards DJ. Effects of experience in a dynamic environment on postural control. *Br J Sports Med*. 2008;42:16–21. PubMed doi:10.1136/bjsm.2006.033688
7. Colby SM, Hintermeister RA, Torry MR, Steadman JR. Lower limb stability with ACL impairment. *J Orthop Sports Phys Ther*. 1999;29:444–451. PubMed doi:10.2519/jospt.1999.29.8.444
8. Seegmiller JG, McCaw ST. Ground reaction forces among gymnasts and recreational athletes in drop landings. *J Athl Train*. 2003;38(4):311–314. PubMed
9. Ebben WP, Vanderzanden T, Wurm BJ, Petushek EJ. Evaluating plyometric exercises using time to stabilization. *J Strength Cond Res*. 2010;24:300–306. PubMed doi:10.1519/JSC.0b013e3181cbaadd
10. Flanagan EP, Ebben WP, Jensen RL. Reliability of the reactive strength index and time to stabilization during depth jumps. *J Strength Cond Res*. 2008;22:1677–1682. PubMed doi:10.1519/JSC.0b013e318182034b
11. Goldie PA, Bach TM, Evans OM. Force platform measures for evaluating postural control: reliability and validity. *Arch Phys Med Rehabil*. 1989;70:510–517. PubMed
12. Webster KA, Gribble PA. Time to stabilization of anterior cruciate ligament-reconstructed versus healthy knees in National Collegiate Athletic Association Division I female athletes. *J Athl Train*. 2010;45(6):580–585. PubMed doi:10.4085/1062-6050-45.6.580
13. Read MM, Cisar C. The influence of varied rest interval lengths on depth jump performance. *J Strength Cond Res*. 2001;15:279–283. PubMed
14. Portney LG, Watkins MP. *Foundations of Clinical Research: Applications to Practice*. Norwalk, CT: Appleton and Lange; 1993.
15. McNair PJ, Prapavessis H. Normative data of vertical ground reaction forces during landing from a jump. *J Sci Med Sport*. 1999;2:86–88. PubMed doi:10.1016/S1440-2440(99)80187-X
16. Scase E, Cook J, Makdissi M, Gabbe B, Shuck L. Teaching landing skills in elite junior Australian football: evaluation of an injury prevention strategy. *Br J Sports Med*. 2006;40:834–838. PubMed doi:10.1136/bjsm.2006.025692
17. Aerts I, Cumps E, Verhagen E, Meeusen R. Efficacy of a 3 month training program on the jump-landing technique in jump-landing sports. Design of a cluster randomized controlled trial. *BMC Musculoskelet Disord*. 2010;11:281. PubMed doi:10.1186/1471-2474-11-281
18. Cormack SJ, Newton RU, McGuigan MR, Doyle TL. Reliability of measures obtained during single and repeated countermovement jumps. *Int J Sports Physiol Perform*. 2008;3(2):131–144. PubMed
19. Dufek JS, Bates BT. The evaluation and prediction of impact forces during landings. *Med Sci Sports Exerc*. 1990;22:370–377. PubMed doi:10.1249/00005768-199006000-00014
20. Mizrahi J, Susak Z. In-vivo elastic and damping responses of the human leg to impact forces. *J Biomech Eng*. 1982;104:63–66. PubMed doi:10.1115/1.3138305
21. McNair PJ, Prapavessis H, Callender K. Decreasing landing forces: effect of instruction. *Br J Sports Med*. 2000;34:293–296. PubMed doi:10.1136/bjsm.34.4.293
22. Prapavessis H, McNaire PJ. Effects of instruction in jumping technique and experience jumping on ground reaction forces. *J Orthop Sports Phys Ther*. 1999;29:352–356. PubMed doi:10.2519/jospt.1999.29.6.352

Appendix 6: Conference Poster (Study 3)

RELIABILITY OF AN ALTERNATIVE METHOD TO ASSESS LANDING SKILLS IN ADOLESCENT SURFERS

Tai T. Tran[1,2], Lina Lundgren[1,2], Josh Secomb[1,2], Oliver Farley[1,2], Sophia Nimphius[2], Robert U. Newton[2], Jeremy M. Sheppard[1,2]

1. Hurley Surfing Australia High Performance Centre, Casuarina Beach, Australia
2. Centre for Exercise and Sport Science Research, Edith Cowan University, Joondalup, Western Australia

INTRODUCTION

Surfing demands a high level of physical qualities such as strength, power, and dynamic postural control to perform radical manoeuvres under control. An important feature of surfing that lacks research and needs further understanding is dynamic postural control during landing and rapid compression, which occurs during bottom turns, aerial manoeuvres and floaters etc. Two potentially important factors that might be critical when assessing dynamic postural control during landing are time to stabilisation (TTS) and relative peak force (rPF). Currently, there are no standardised methods or reference guides to assess dynamic postural control. Therefore the purpose of this study was to provide additional information on reliability measures of a novel dynamic postural control assessment via TTS and relative peak force upon landing.

METHODS

Fifty-nine male and female adolescent competitive surfers with a mean age, weight and height (mean ± standard deviation) of 16 ± 1.6 yrs, 57.9 ± 10 kg and 165.5 ± 18.16 cm respectively participated in this study. Participants performed five drop and stick trials from a pre-determined box height of 50cm. They were instructed to step forward off the box with their dominant leg, land soft, and as quickly as possible reach the position with the upper thighs parallel to the ground. To determine the average of three drop and stick trials, the trials with lowest and highest TTS were discarded. Time to stabilisation was calculated from initial contact of the landing to the time the participants stabilised within 5% of body mass. Time to stabilization and relative peak impact force were analysed using intraclass correlation (ICC) with a 90% confidence interval, CV% and TE to determine the repeatability of measures between trials.

RESULTS

Intra-class correlation coefficient (ICC), coefficient of variation (CV), typical error (TE) and smallest worthwhile changes (SWC) for TTS and rPF are presented in Table 1. Intra-class correlation coefficient revealed that TTS of the drop and stick was moderately reliable from trial to trial (ICC = 0.85), whereas relative peak impact force (ICC = 0.63) demonstrated greater variability (figure 1).

Table 1. Reliability of measures TTS and rPF showing ICC, CV%, TE, and SWC using data from adolescent competitive surfers

		90% Confidence limits				
Measure	ICC	Lower	Upper	CV %	TE	SWC
TTS (s)	0.85	0.78	0.89	26.2	0.07	0.04
rPF (N/kg)	0.63	0.49	0.75	24.9	0.99	0.32

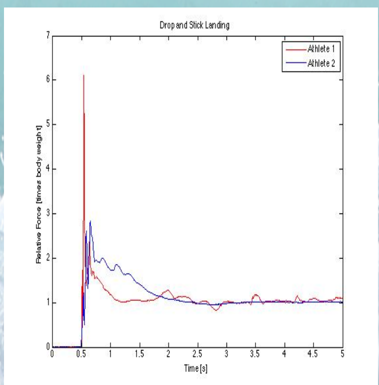


Figure 1. Graphical force trace of time to stabilization within 5% body mass. Comparison between two athletes weighing approximately 70kg, the difference is their ability to absorb the landing force.

CONCLUSION

The findings of this study investigating an alternative method to assess dynamic postural control via drop and stick off a 50cm box height demonstrated moderately reliable measures for time to stabilization with adolescent surfers. Although TTS was found to be moderately reliable, coefficient of variation for TTS was higher than the recommended value (≤ 10%) to detect changes in dynamic postural control. In addition, the results demonstrated a low reliability measure for rPF with a CV of 24.9%. Therefore, this alternative method to assess dynamic postural control would not be suitable for adolescent surfers. However, it may be appropriate to use reference values for time to stabilisation and relative peak force when measuring landing skills for adolescent surfers.

PRACTICAL APPLICATIONS

Time to stabilisation may be a useful indicator to detect dynamic postural control or joint instability upon landing; however, it was not a suitable measure for adolescent surfers in our study. Therefore, we suggest using the product of TTS and rPF to include both measures as an assessment of landing skills. Furthermore, the variables could be divided into reference groups, to avoid errors due to the moderate reliability shown in this study. For example for the TTS, <0.7s could be considered excellent, 0.7-1.2s good and >1.2s poor, of course depending on the age and level of the athlete.

CONTACT

Tai T. Tran
Hurley Surfing Australia
Lead Development Scholarship Surfers
Strength & Conditioning Coach
tai@surfingaustralia.com

Appendix 7: Conference Poster (Study 5)

EFFECT OF FOUR WEEKS DETRAINING ON POWER, STRENGTH, AND SENSORIMOTOR ABILITY OF ADOLESCENT SURFERS

Tai T. Tran[1,2], Lina Lundgren[1,2], Josh Secomb[1,2], Oliver R.L. Farley[1,2], G. Gregory Haff FNSCA[2], Sophia Nimphius[2], Robert U. Newton FNSCA[2], Lee E. Brown FNSCA[3], Jeremy M. Sheppard[1,2]

1. Hurley Surfing Australia High Performance Centre, Casuarina Beach, Australia 2. Centre for Exercise and Sport Science Research, Edith Cowan University, Joondalup, Western Australia 3. Department of Kinesiology, Center for Sport Performance, Human Performance Laboratory, California State University, Fullerton, California

PURPOSE

While there is a considerable amount of literature on the positive adaptations from acute and long-term resistance training in young athletes, it is uncertain whether adolescent surfers are able to maintain physical performance with surfing alone. Therefore, the purpose of this study was to determine the magnitude of changes in physical performance over a four-week detraining period during which the athletes completed no resistance training.

METHODS

Nineteen adolescent surfers with an overall mean age, mass, and stature (mean ± SD) of 14.1 ± 1.6 y, 54.0 ± 10.8 kg and 165.1 ± 9.0 cm, respectively, volunteered to participate in four weeks of detraining (surfing participation maintained but resistance training ceased) following seven weeks of periodized resistance training. Power (vertical jump height; VJH), maximal isometric strength (isometric mid-thigh pull; IMTP), and sensorimotor ability (time to stabilization during a drop and stick (DS); TTS) pre-test results were determined from the conclusion (post-test) of the first seven-week training block while post-test results were measured at the start (pre-test) of a second seven-week training block.

RESULTS

Four weeks of detraining significantly decreased the following variables: VJH by -5.3%, (p=0.037, *d*= 0.40), vertical jump peak velocity (VJPV) by -3.7% (p=0.001, *d*= 0.51), maximal isometric strength by -5.5%, (p=0.012, *d*= 0.22), and relative maximal isometric strength by -7.3% (p=0.003, *d*= 0.47). Furthermore, sensorimotor ability worsened, as assessed by TTS, with a significant increase of 61.4% (p=0.004, *d*= 1.01), indicating athletes took longer to stabilize from a dynamic landing task (Figure 1).

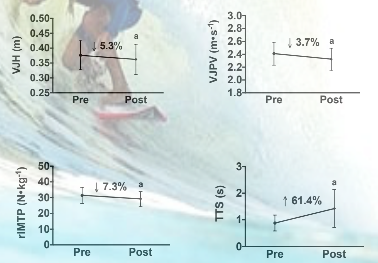


Figure 1. [a]Significantly different from pre-test values

CONCLUSION

In light of these findings, adolescent surfers experienced a reversal effect when resistance training was discontinued for four weeks. These results demonstrate that surfing, in the absence of resistance training, is not a potent enough stimulus to maintain performance parameters. The results of this study will increase awareness within the surfing community of the deleterious impact of detraining on power, strength, and sensorimotor ability.

PRACTICAL APPLICATIONS

Competitive adolescent surfers with a relatively low training age should strive to maintain consistent resistance training in conjunction with surf training to avoid the negative decrements in power, strength, and sensorimotor ability, as these are likely to reduce physical capabilities. Therefore, by continuing resistant training in adolescent surfers, training age increases and continued gains in power, strength and sensorimotor abilities can be continued and therefore more likely to be able to contribute to increased performance during surfing or decreased injury risk and ability to tolerate surfing training loads.

CONTACT

Tai T. Tran, MS, CSCS*D
Hurley Surfing Australia HPC
Lead Development S&C Coach
tai@surfingaustralia.com