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Gender differences in physical performance characteristics of competitive surfers

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This thesis is presented for the degree of
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ABSTRACT

Competitive surfing is judged on the performance and complexity of innovative and progressive manoeuvres. As such, surfers require the physical attributes of strength and power in both the upper and lower-body in order to facilitate performance. To date, there remains limited research pertaining to the physical performance characteristics of competitive female surfers, making it difficult to quantify the current gender gap in performance attributes. Therefore, the purpose of this thesis was fivefold: (1) to describe and compare the gender differences in physical performance characteristics of competitive surfers; (2) to investigate the reliability and validity of the isometric push-up (IPU), dynamic push-up (DPU) and force plate pop-up (FP POP) measures of upper-body strength qualities; (3) to examine the gender differences in the dynamic strength index (DSI) and dynamic skill deficit (DSD); assessing upper-body dynamic and sports-specific strength relative to maximal isometric strength; (4) to investigate the gender differences in kinetic and kinematic variables of the countermovement jump (CMJ) and squat jump (SJ); and (5) to assess the gender differences in resistance training self-efficacy (SE) and outcome expectancy (OE). The aforementioned studies provide strength and conditioning practitioners, as well as surf coaches, with the data to make evidence-based decisions in the application of training to the female surfers and bridge the gender gap that is apparent within competitive surfing. Study one informed competitive male surfers had more developed physical performance characteristics in the upper and lower-body than female surfers. The findings of this study highlighted the performance benefits that female surfers may experience if such physical qualities are targeted through structured and periodised training. Study two demonstrated the IPU, DPU and FP POP to be reliable

measure of upper-body isometric, dynamic and sports-specific strength. Furthermore, the results of this study identified maximal upper-body strength to be strongly associated with the ability to apply force dynamically (DPU and FP POP). These findings apply novel methodologies, in order to better understand the upper-body sports-specific strength qualities of surfers. Study three reported no gender differences in DSI or DSD ratios. However, competitive male surfers applied greater upper-body isometric and dynamic PF application, and greater sport-specific force application (FP POP). These findings, in conjunction with study two, suggest female surfers may benefit from improving their upper-body maximal strength, thus facilitating their ability to apply force in a sports-specific context. Study four demonstrated competitive male surfers achieved an increased jump height by applying a significantly larger normalised concentric impulse in both the CMJ and SJ. These findings may be attributed to the greater countermovement depth exhibited by males, enabling a greater distance over which force can be applied. Study five found no significant difference in resistance training SE or OE between competitive male and female surfers, with similarly high values being reported for both genders. Therefore, resistance training SE and OE in the examined cohort does not seem to be a confounding variable that interacts to elicit the physiological gender differences of competitive surfers.

DECLARATION

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

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

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

(iii) *Contain any defamatory material.*

[redacted]

Joanna R Parsonage

ACKNOWLEDGMENTS

Three and a half years ago, I decided to jump on a plane and embark on a once in a lifetime opportunity. A lot has happened in that time, of which it's hard to find the words. All I know for certain is that I couldn't have survived both the highs and lows without being surrounded by some incredible human beings.

I would firstly like to thank the three supervisors that have supported me throughout this journey. Dr Jeremy Sheppard, you provided me with this amazing opportunity of which I will forever be thankful. You allowed my life to take a path I could have only ever dreamt of. Dr Sophia Nimphius, I am extremely thankful for both your mentorship and friendship. I would not be finishing this PhD today without you taking me under your little Puerto Rican wings. You have encouraged and pushed me to go beyond what I ever thought I was capable of. Dr Josh Secomb, over the last three years you've been a friend, a colleague and a mentor all wrapped in one. I will be forever appreciative of the support you have provided me with. It has been a pleasure watching you grow and evolve as a coach, husband and father. To all the other scholars, Oliver, Lina, Brendon and Rebecca, you all provided support at different chapters of this journey, of which I am extremely thankful.

Surfing Australia, you have allowed me to experience something so unique it's hard to articulate. The professional opportunities I have been provided with will follow me throughout my whole career. To the team at Surfing Australia, you gave me all the encouragement and support I required in the last push to the finish line. The memories I've made here are priceless and will always bring a smile to my face. Surfing has become part of who I am, and that will never change.

On that note I cannot forget to thank all the surfers who kindly participated in my research, as this would not be possible without you. I have had the pleasure to coach some of you for the last three years, and see you grow as both athletes and people.

Josh, Belen and Akia Michael Fuller, there are no words. Two and a half years ago my guardian angels brought you into my life for a reason. You have been right beside me experiencing and tolerating all the highs and lows that the last few years have brought. You have given me the belief in my abilities, not just in regard to this PhD but in all walks of life. I can honestly say that I would not have survived the last few years without you. You are and will always be my family. I love you.

‘Find your tribe and love them hard’ Jena, Ellie, Fran, Mel and Candice, your support since I met you has been unwavering. You are all incredible and inspirational humans, with the biggest hearts, and I count myself extremely lucky to have you all in my life. I cannot wait to embark on the next chapter with you all.

Finally, and most importantly my family. Nana, the strength and courage you show every day is inspirational. As a child growing up, you repeatedly told me that as long as I did my best that’s all that mattered. I can look back over this journey and say, “I did my best”. Simon, big bro, you’ve been at the end of the phone whenever I’ve needed. You’ve always been there for me, and I know mum would be extremely proud of us supporting each other throughout life’s challenges. Although you are both on the other side of the world, you have been by my side every day, supporting and encouraging me. I love you both unconditionally and could never find the words that could truly explain how amazing you both are. I am blessed to call you my family.

DEDICATION

A year into this PhD, I lost the three people I cherished most in this world: Mum, Auntie Carole and Bampa Jones. I can unquestionably say that without these three-amazing people I would not be completing my PhD today.

Mum - You were and will always be my hero. You are my inspiration in everything I do and have shaped the person I've become today. As a strong and independent woman, you showed me that with hard work and a smile on your face, you can achieve anything.

Bampa Jones - My best friend, you taught me that the most important thing in life was to be happy, regardless of what I did or achieved. Your unconditional love, and amazing sense of humour, made you the most incredible Bampa a girl could have asked for.

Auntie Carole - You were the person that got me on that plane three and a half years ago. Whenever I have doubted myself on this journey, I've had your voice in my head saying "PARSONPOOPS……. you've got this". I will be forever thankful.

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LIST OF ABBREVIATIONS

1RM	One repetition maximum
2-D	Two-dimensional
3-D	Three-dimensional
95% CI	Ninety-five percent confidence interval
Ɵ	Angle
ANOVA	Analysis of variance
cm	Centimetres
CMJ	Countermovement jump
COM	Centre of mass
CV%	Coefficient of variation percent
DPU	Dynamic push-up
DSI	Dynamic strength index
DSD	Dynamic skill deficit
d	Cohen's d effect size
ES	Effect size
EV	Eccentric velocity
FP	Force plate
FPS	Frames per second
FP POP	Force plate pop-up
g	Hedges' *g*
GRF	Ground reaction force
H	Height
Hz	Hertz
IBP	Isometric bench press

ICC	Intraclass correlational coefficient
IMTP	Isometric mid-thigh pull
IPU	Isometric push-up
kg	Kilograms
m	Metres
m•s^{-1}	Metres per second
N	Newtons
n	Subject number
nPF	Normalised peak force
N•BW^{-1}	Newtons per kilogram of body weight
OE	Outcome expectancy
PF	Peak force
PP	Peak power
PV	Peak velocity
p	p-value
r	Correlation coefficient
***r*^{2}**	Coefficient of determination
ρ	rho
RFD	Rate of force development
ROM	Range of motion
SCT	Social cognitive theory
SE	Self-efficacy
SEM	Standard error of the mean
SD	Standard deviation
SJ	Squat jump

SMBT	Seated medicine ball throw
SWC	Smallest worthwhile change
TE	Typical error
TEM	Typical error of measurement
TTP	Time to pop-up
WCT	World Championship Tour
WSL	World Surf League
yrs	Years

PUBLICATION LIST

This thesis is submitted as a series of manuscripts. To date, three of these manuscripts have been accepted for publication in scientific peer-reviewed journals, with two under review at present.

Chapter 3

Parsonage, J., Secomb, J., Tran, T., Farley, O., Nimphius, S., Lundgren, L and Sheppard, J. (2017). Gender differences in physical performance characteristics of elite surfers. *Journal of Strength and Conditioning Research*. *31*(9), 2417-2422.

Chapter 4

Parsonage, J., Secomb, J., Sheppard, J., Ferrier, B., Dowse, R., and Nimphius, S. Upper-body strength measures and pop-up performance of stronger and weaker surfers. *Journal of Strength and Conditioning Research (In Press).* DOI: 10.1519/JSC.0000000000002377

Chapter 5

Parsonage, J., Secomb, J., Dowse, R., Ferrier, B., Sheppard, J., and Nimphius, S. The assessment of isometric, dynamic, and sports-specific upper-body strength in male and female surfers. *Sports (In Press).* DOI: 10.3390/sports6020053

Chapter 6

Parsonage, J., Secomb, J., Dowse, R., Ferrier, B., Sheppard, J., Andrews, M., and Nimphius, S. Gender differences in kinematic and kinetic performance variables of the countermovement jump and squat jump in competitive surfers.

Chapter 7

Parsonage, J., Secomb, J., Dowse, R., Sheppard, J., and Nimphius, S. Gender differences in resistance training self-efficacy and outcome expectancies in elite surfing athletes.

For consistency throughout this thesis, formatting and referencing of the published chapters have been amended. As a result, they may not conform to the journal styles in which they were published. However, no adjustments have been made to the content of these manuscripts (i.e. main body of text, tables and figures).

Conference Abstracts

In addition to the published chapters, three abstracts have been presented at the Australian Strength and Conditioning Association'. Copies of these can be found in the appendix.

Parsonage, J., Secomb, J., Tran, T., Farley, O., Nimphius, S., Lundgren, L. & Sheppard, J. (2015). The meaningful use of sprint paddling data to determine surfer's strengths and weaknesses: A gender comparison. *Journal of Australian Strength & Conditioning*. *23*(6**)** 79-82.

Parsonage, J., Secomb, J.L., Sheppard, J.M., Ferrier, B.K., Dowse, R.A., & Nimphius, S. (2016). The isometric push-up: What degree of elbow flexion elicits the greatest peak force. *Journal of Australian Strength & Conditioning. 24* (6.) 46.

Parsonage, J., Secomb, J.L., Sheppard, J.M., Ferrier, B.K., Dowse, R.A., & Nimphius, S. (2017). Comparison of 2-D and 3-D motion analysis in the calculation

of lower-body joint angle: a pilot study. *Journal of Australian Strength & Conditioning. 25*(6). 41

CHAPTER ONE

General Introduction and Aims of the Thesis

Sets out the research objectives and provides an overview of the thesis structure

1.1 Background

Surfboard riding (surfing) is an internationally established sport, with the World Surf League (WSL) recognised as the professional governing body. Competitive surfing consists of three critical phases; the sprint paddle onto the wave face, the pop-up from a prone paddling position to a surf specific stance, and the wave-ride. As part of the wave- ride, WSL scoring criteria requires competitive surfers to execute a combination of innovative and progressive manoeuvres, with speed, power and flow (WSL, 2017). Although the WSL scoring criteria is the same for male and female competitive surfers, there has been clear disparity in the scoring of similar manoeuvres between genders.

This was highlighted during the 2015 WSL season, when a competitive female surfer was awarded a 10-point (10.00 ± 0.00) ride for incorporating an aerial based manoeuvre (air reverse) into her wave-ride (WSL, 2015). In the same competitive year, performance analytics showed male surfers successfully executed 226 air reverses, with an average score of 6.58 ± 1.74 being awarded (Ferrier et al., 2018). As a result, it is evident that there is a greater disparity in the scoring of near identical performances during a wave-ride. Competitive males achieved a lower score for incorporating an innovative and progressive manoeuvre that they typically perform more frequently and successfully than their female counterparts. As such it is evident that there is a significant difference in perceived performance ability between genders.

Of the limited gender comparison studies that have been documented, male surfers have been shown to exhibit a quicker paddling performance (Secomb et al., 2013), apply significantly greater force application during the pop-up phase (Eurich et al., 2010) and display enhanced lower-body strength and power (Bruton, Adams, & O'Dwyer, 2017; Bruton, O'Dwyer, & Adams, 2013). Furthermore, male surfers have reported significant associations between lower-body strength and power, and the scoring of wave-riding manoeuvres (Secomb, Farley, et al., 2015). As a result, the combination of the above findings would allow a male surfer to paddle faster onto the face, enabling quicker entry speed into the first manoeuvre with potentially greater speed, power and flow. The combination of which increases the performance potential in competitive surfing.

Despite the aforementioned literature, the limited research investigating the physical performance characteristics of competitive female surfers makes it difficult to quantify the gender gap in physical development or perceived competence that may help explain the variance in the actual performance difference between genders. Thus, evidence-based research is required quantify the physical performance characteristics of both male and female surfers in an effort to provide strength and conditioning coaches with an evidence-base to optimise.

1.2 Aims of Research Studies

Due to the current gaps in the literature, the scientific aims of the current thesis were as follows:

1. To describe and compare the gender differences in upper- and lower-body physical performance characteristics of competitive surfers (Study 1);
2. To develop and evaluate the reliability of an upper-body isometric (IPU), dynamic (DPU) and sports-specific protocol (FP POP) to assess upper-body strength qualities, in competitive surfers (Study 2);
3. To examine the gender differences in upper-body isometric (IPU), dynamic (DPU) and sports-specific (FP POP) upper-body strength, in competitive surfers (Study 3);
4. To examine the gender differences in lower-body kinetic and kinematic performance variables during the countermovement jump (CMJ) and squat jump (SJ), in competitive surfers (Study 4);
5. To examine the gender differences in resistance training self-efficacy (SE) and outcome expectancy (OE), in competitive surfers (Study 5).

1.3 Research Questions and Hypotheses

Study 1

Research Question 1.1: Are there significant gender differences in the physical performance characteristics of competitive surfers?

Hypothesis 1.1: It was hypothesised that there would be significant gender differences in the physical performance characteristics of males and female surfers.

Study 2

Research Question 2.1: Are the IPU, DPU, and FP POP reliable measures of upper-body isometric and dynamic strength qualities in surfing athletes?

Hypothesis 2.1: It was hypothesised that the IPU, DPU and FP POP would be reliable measures of upper-body isometric and dynamic strength, reporting acceptable coefficient of variation percentage (CV %) and intraclass correlation coefficient (ICC) values.

Research Question 2.2: Are there significant differences in time to pop-up (TTP) between stronger and weaker surfers, and is there a relationship between upper-body isometric strength and dynamic performance measures?

Hypothesis 2.2: It was hypothesised that there would be significant differences in TTP between stronger and weaker surfers, with an association between upper-body isometric strength and dynamic performance reported.

Study 3

Research Question 3.1: Are there significant gender differences in the dynamic strength index (DSI), aimed at assessing a surfer's upper-body dynamic strength, in relation to their maximal isometric strength?

Hypothesis 3.1: It was hypothesised that there would be a significant gender difference in the DSI between male and female competitive surfers. Furthermore, it was hypothesised that there would be significant gender differences in normalised upper-body isometric and dynamic strength.

Research Question 3.2: Are there significant gender differences in the dynamic skill deficit (DSD) index, aimed at assessing gender differences in sports-specific dynamic strength, in relation to maximal isometric strength?

Hypothesis 3.2: It was hypothesised that there will be a significant gender difference in the DSD. Furthermore, it was hypothesised that there would be a significant gender difference in normalised sports-specific dynamic strength.

Study 4

Research Question 4.1: Are there significant gender differences in both kinetic and kinematic performance variables of the CMJ and SJ in competitive surfers?

Hypothesis 4.1: It was hypothesised that there would be significant gender differences in both kinetic and kinematic performance variables of the CMJ and SJ.

Study 5

Research Question 5.1: Are there significant gender differences in resistance training SE and OE in competitive surfers?

Hypothesis 5.1: It was hypothesised that there would be significant gender differences in resistance training SE and OE scores.

1.4 Significance of Research

In the last few years, competitive female surfing has undergone considerable progression. Despite this, research within surfing has frequently only investigated and reported the physical performance characteristics of competitive male surfers. Furthermore, the limited research conducted on physical performance characteristics of female surfers has largely focused on the recreational cohort. This is a common trend, not just within surfing, but across other competitive sports that females are under-represented within scientific literature. Thus, the current lack of research makes it difficult for strength and conditioning practitioners to prescribe evidence-based programmes to meet the specific needs of not just the competitive female surfer, but the female athlete in general. Through conducting the aforementioned research, there is now an enhanced understanding of the specific physical performance qualities that are required to enhance the performance capabilities of competitive female surfers. Therefore, the current thesis is significant in many novel measurements and methods of evaluation but also through the social significance of contributing to advancing more equitable evaluation amongst the genders within scientific literature in sport and exercise science.

1.5 Limitations

The limitations of the studies of the current thesis were as follows:

Study One

a) Kinetic performance variables only

Study one only reported kinetic performance variables of the SJ, focusing on the force that causes motion, not the kinematic performance variables that describe motion. The practical application of gross kinetic variables to improve performance is limited, with other previous research documenting the benefits of kinematic analysis (Comfort et al., 2017; Gheller et al., 2015).

Study Two

a) Participant numbers

The participant numbers for both male (n = 9) and female (n = 8) competitive surfers were low. The high competitive level of surfers recruited (delimitation stated below) for this study resulted in the population available for the study being relatively small. This is similar to other research studies involving competitive level surfers (Secomb, Farley, et al., 2015; Secomb et al., 2016).

b) GoPro sampling frequency

The GoPro, which was used to film TTP had a lower sampling frequency than lab-based applications (100 frames per second). However, this is consistent with other research using the same sampling frequency in a field-based setting (Hunter, Angilletta Jr, Pavlic, Lichtwark, & Wilson, 2018; Panoutsakopoulos, Vujkov, Kotzamanidou, & Vujkov, 2016; Wagner et al., 2014).

Study Three

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The participant numbers for both male (n = 9) and female (n = 8) competitive surfers were low. The high competitive level of surfers recruited (delimitation stated below) for this study resulted in the population available for the study being relatively small. This is similar to other research studies involving competitive level surfers (Secomb, Farley, et al., 2015); Secomb et al. (2016).

b) Sports-specific training age

The study did not record sports-specific training age in relation to years surfing. With a large standard deviation in the age of both competitive male and female surfers, this may have highlighted potential motor skill contributions to TTP.

c) GoPro sampling frequency

The GoPro used to film TTP had a lower sampling frequency than lab-based applications (100 frames per second). However, this is similar to other researchers who have used the same sampling frequency in a field-based setting (Hunter et al., 2018; Panoutsakopoulos et al., 2016; Wagner et al., 2014).

Study Four

a) Participant numbers

The participant numbers for both male (n = 10) and female (n = 10) competitive surfers were low. The high competitive level of surfers recruited (delimitation stated below) for this study resulted in the population available for the study being relatively small. This is similar to other research studies involving competitive level surfers (Secomb, Farley, et al., 2015; Secomb et al., 2016).

b) iPad *sampling frequency*

The iPad used to film TTP had a low sampling frequency of 120 frames per second. However, this is similar to other research that has used the same sampling frequency in a field-based setting (Hunter et al., 2018; Panoutsakopoulos et al., 2016; Wagner et al., 2014).

Study Five

a) Resistance training history

The resistance training history of the participants was not documented in this study. Thus, future research should aim to examine if resistance training history influences SE and OE variation between genders.

b) Likert scale

Likert scales are unidimensional, providing the participant with five points of response. However, the intervals between points on such scales do not present equal changes in attitude for all individuals, and thus may not provide a true representation of the participant's SE and OE. Despite this, the likert scale used in the current study was previously implemented (Lubans, Aguiar, & Callister, 2010), providing a reliable measure of SE and OE towards resistance training.

1.6 Delimitations

The delimitations set for each study of the thesis were as follows and were set in order to evaluate a specific cohort with unique characteristics or to ensure the evaluation performed in the research could be considered practically applicable in the applied sport environment (e.g. enhance ecological validity):

Study One

- *The current study delimited participants to competitive male and female surfers*

As a result, this was the first research study to report both upper- and lower-body physical performance characteristics of competitive female surfers. More specifically, it was the first study to document gross measures of vertical jump performance in competitive female surfers.

Study Two

- *The current study delimited the pop-up assessment to be measured only in the natural environment.*

The in water pop-up assessment allowed for field-based data collection, facilitating the ecological validity of the study. This was the first time pop-up performance was measured in the ocean.

Study Three

- *The current study delimited the pop-up assessment to be measured only in the natural environment.*

The in water pop-up assessment allowed for field-based data collection, facilitating the ecological validity of the study. This was the first time pop-up performance was measured in the ocean.

Study Four

a) *The current study delimited the measurement to only two-dimensional analysis*

Study four utilised two-dimensional video analysis, which provided reliable lower-body kinematic data. This methodology may be favourable to many strength and conditioning coaches, providing coach-friendly, cost-effective technologies in comparison to some three-dimensional means.

Study Five

a) *The current study delimited participants to elite competitive male and female surfers*

The competitive surfers that partook in this study were all at the elite level of their sport, competing on the WCT or World Qualifying Series (WQS) level. As these were all elite athletes, the sample size was large, with data collected from 14 male and 14 female surfers.

1.7 General Overview of the Following Chapters

The thesis includes a total of eight chapters. Chapter two provides an extensive literature review on gender differences in physical performance characteristics of competitive surfing athletes. However, due to the limited research in this specific context, the review will also present literature from a multitude of different athlete cohorts across a number of competitive sports. Chapter three reports the results of the first study, providing comparative data for both upper- and lower-body physical performance characteristics of competitive male and female surfers. Chapter four presents the findings of study two, examining the reliability of novel isometric (IPU) and dynamic (DPU) upper-body strength measures in relation to the sports-specific pop-up performance (TTP). Chapter five details the findings of study three, examining gender differences in both the DSI and DSD, assessing maximal upper-body strength in association with dynamic and sports-specific upper-body strength. Chapter six presents the findings of study four, examining both kinetic and kinematic performance variables during the CMJ and SJ in competitive male and female surfers. Chapter seven reports the findings of study five, which examines the differences in resistance training SE and OE in competitive male and female surfers. Finally, chapter eight provides a summary and conclusion of the key findings identified in this thesis.

CHAPTER TWO

Review of the Literature

Discusses the main emphasis of prior research and summarises key findings that underpin the design and implementation of the current research

2.1 Introduction

This thesis outlines a series of studies investigating the gender differences in performance characteristics of competitive surfers. In order to provide rationale for the subsequent chapters this review initially outlines the sport of competitive surfing, the physiological demands of the sport, and the existing literature pertaining to the gender differences in physical performance characteristics. However, due to the limited research in the area of gender differences in surfing, the literature review will also explore the gender differences across a range of competitive sports.

Specifically, the review will be split into several sections that examine various topics pertaining to the overall theme of the thesis. Gender differences in physical performance characteristics have been separated into the upper-body and lower-body and examined independent of each other. Gender differences in isometric and dynamic assessments of upper-body strength have been explored, with particular focus on their reliability and validity in relation to a competitive surfing cohort. Furthermore, gender differences in the lower-body kinetic and kinematic characteristics of males and female athletes when executing explosive lower-body movements, such as the squat jump (SJ), and countermovement jump (CMJ) have been examined. Finally, as the term 'gender' pertains to the socially constructed characteristics of males and females (Oliffe & Greaves, 2011), this review will also examine the potential socio-cognitive and psychosocial influences on the physical performance characteristics of male and female athletes.

A common theme that will be emphasised throughout this review will be the gender disparity in the scientific literature. Original research published in three major sports journals (*Medicine and Science in Sport and Exercise, British Journal of Sports Medicine* and *American Journal of Sports Medicine*), was analysed, with data from 1,382 articles, involving 6,076,580 participants considered (Costello, Bieuzen, & Bleakley, 2014). It was reported that absolute female participation numbers were significantly lower than males, with the average male to female ratio per article being almost two-fold greater (~65:35) (Costello et al., 2014). These data highlight the current under-representation of female participants in published scientific research, which inherently limits the ability to compare genders in physical performance characteristics. In summary, the literature review provides valuable empirical evidence regarding the gender differences in physical performance characteristics among surfers and other athlete cohorts. In addition, the current gaps within the literature are highlighted and future research directions are explored.

2.2 The Competitive Sport of Surfing

Surfing is a popular water-based sport, characterised by the riding of waves by an individual. The World Surf League (WSL) is the sport's professional governing body, and is responsible for the World Championship Tour (WCT), World Qualifying Series (WQS), and Pro Junior Series (WSL, 2017). Within these competitions, a competitive heat can range from 20 - 35 minutes and have two-four competitors. Each wave-ride is scored out of a possible 10 points by a panel of five WSL accredited judges, with the two best waves contributing to a surfer's final heat score out of 20 (WSL, 2017). The judges analyse and score each wave based on the following five criteria: i.

commitment and degree of difficulty, ii. innovative and progressive manoeuvres, iii. combination of manoeuvres, iv. variety and v. speed, power and flow (WSL, 2017). This scoring criteria is the same for both the male and females, for all levels of competitive surfing. Prior to the wave-ride a surfer is required to paddle on to the wave face and perform a pop-up from prone to a surfing specific stance. As such, surfing can be categorised into three broad and distinct phases of activity: paddling, pop-up and wave-riding, all of which require well-developed physical capacities.

2.2.1 The Physiological Demands of Competitive Surfing

The physical demands of paddling

Paddling is the forward propulsion of a surfboard using alternate-arm paddling action (Meir, Lowdon, Davie, Geebng, & Victoia, 1991). Previous research reported that during a two-hour surfing training session, 42.6% ± 9.9% of total time was spent paddling (Secomb, Sheppard, & Dascombe, 2015). This is slightly lower than the 54% ± 6.3% previously reported by Farley, Harris, and Kilding (2012a). However, the study of Secomb et al. (2015) analysed a surfing training session, whereas Farley and colleagues (2012a) reported on a competitive surfing heat. The discrepancy between these two studies may be attributed to the fact that during a surfing heat, competitors will have greater opportunity to paddle for and catch more waves. This will result in the need for surfers to paddle back to the take-off zone more frequently, than during a training session. In contrast, time spent sprint paddling for a wave only made up 4.0% ± 1.5% of total paddle time in competition (Farley, Harris, & Kilding, 2012b). This is similar to the 4.1% ± 1.2% of sprint paddling reported during a training session

(Secomb, Sheppard, et al., 2015). It can be seen that paddling is a major determinant of surfing performance, characterised by both repeated measures of low-intensity paddling (aerobic) and intermittent high-intensity sprint paddling (anaerobic).

Previous research has emphasised the importance of both aerobic and anaerobic physical capacity, to meet paddling demands and optimise surfing performance (Farley et al., 2012a; Loveless & Minahan, 2010; Mendez-Villanueva et al., 2005). Meir et al. (1991) reported a surfer's mean heart rate to be 80% of their peak heart rate during a one hour surf, thus highlighting aerobic contribution as an important physiological variable. A such, a well-developed aerobic system is required to allow the surfer to perform at this intensity for a prolonged period of time, with interspersing near-maximal efforts. Sheppard et al. (2013), designed a 400 metre (m) endurance paddle in order to reflect their endurance capabilities in a surf specific context. It was reported that internationally competitive junior surfers demonstrated a faster endurance paddle velocity (d = 0.90, p = 0.008) than age matched nationally competitive junior surfers (Sheppard et al., 2013). These findings were supported by Tran, Lundgren, et al. (2015) who reported a significant difference in 400 m endurance paddle time between surfers who were selected for the national team and those who were not (d = 0.70, p = 0.04). As paddle battles between competitive surfers usually occur over an extended time period at a point break location, a quicker endurance paddle would allow surfers to out-paddle their opponent when returning to the take-off zone, and subsequently give them priority for the next wave.

In regard to anaerobic ability, comprehensive testing protocols have measured a surfer's sprint paddle ability over 5, 10 and 15 m (Sheppard et al., 2013), with competitive surfers reported to be significantly quicker over all three distances than their recreational counterparts (Coyne et al., 2016). Anaerobic peak power (PP) output was also measured during a 10 second (s) maximal sprint paddle using a modified ergometer, with a significant relationship between competitive surfer's season ranking and anaerobic PP output (r = -0.55, p = 0.02) (Farley, 2011). Peak velocity (PV) during a sprint paddle has also been measured, with senior surfers recording significantly higher peak paddling velocities over 15 m than youth surfers (d = 2.30, p < 0.001) (Sheppard, Osborne, Chapman, & Andrews, 2012). A faster sprint paddling time would enable a surfer to take off earlier at the peak of the wave, allowing the first manoeuvre to be executed earlier and in a more critical section of the wave, which can be a key factor in wave-score. In addition, a greater PV attained during a sprint paddle to catch a wave, will increase the speed a surfer enters the wave face with, enabling a greater entry speed into the first manoeuvre.

Furthermore, Sheppard, McNamara, Osborne, Andrews, and Chapman (2012) reported strong associations between normalised upper-body pull-up strength and sprint paddle time to 5, 10 and 15 m (r = 0.94, 0.93, 0.88, 0.66, respectively, p < 0.05) in competitive male surfers. It was reported that normalised upper-body strength was significantly greater in the faster paddlers (d = 1.88, p = 0.03). Therefore, it would seem beneficial for surfing athletes with poorer sprint paddle ability to improve upper-body maximal strength. Coyne et al. (2017) investigated this hypothesis, implementing a five-week upper-body maximal strength training intervention in competitive and recreational male surfers. The training group increased their sprint paddle speed over 5, 10 and 15 m (d = 0.71, d = 0.51, d = 0.40, respectively), with a concomitant increase in one repetition maximum (1RM) pull-up strength of 6.17% (d

= 0.42) (Coyne et al., 2017). The application of these findings is promising, with sprint paddling improvements being elicited during a short period of upper-body maximal strength training, mirroring the timeline a competitive surfer would have in-between competitions. As such it is suggested that in order to enhance sprint paddling performance in surfing athletes, highly developed upper-body pulling strength is a key requirement. An increase in maximal upper-body pulling strength, may allow a competitive surfer to enter a wave sooner and with greater speed, enabling them to perform the first manoeuvre with increased speed and power.

The Physical Demands of the Pop-Up

The second phase of surfing is the pop-up and is defined as the change from a prone paddling position to standing in one explosive movement (Everline, 2007a). More specifically the pop-up requires a surfer to move around 75% of their body weight in less than a second (Eurich et al., 2010). A quicker pop-up would allow a surfer to get to their feet faster, commence wave-riding earlier, and execute their first turn sooner. Research investigating the pop-up phase of surfing is extremely sparse, with only one research group publishing their findings in regard to gender differences (Eurich et al., 2010). The gender differences reported in this study will be articulated in the following section, however the importance of upper-body maximal and dynamic strength were identified as key physical performance determinants in pop-up performance. The limited research in this area, warrants further investigation to better understand the physical capacities that underpin pop-up performance.

The Physical Demands of the Wave-Ride

Finally, wave-riding is defined as the total time from when a surfer initiates the pop-up to either riding off the back of the wave or loosing contact with their board (Secomb, Sheppard, et al., 2015). The wave-ride is the only phase of surfboard riding which is scored, and therefore an in-depth understanding of the physical performance characteristic that underpin this is crucial. Time motion analysis has shown that wave-riding time makes up only 8% ± 2% of a 20 minute surf heat (Farley et al., 2012b). This is higher than recorded during a two-hour surfing training session, with wave-riding time accounting for only 2.5% ± 1.9% (Secomb, Sheppard, et al., 2015). The discrepancy between duration of wave-riding time in competition and training is possibly due to the competition for waves, with only two to four surfers in the water during a competitive heat.

Within a competitive heat a surfer is required to execute a variety of innovative and progressive maneuverers with speed, power, and flow, as stipulated by the WSL scoring criteria (WSL, 2017). In order to maximise scoring potential, lower-body strength and power have been documented as important physical performance determinants of wave-riding (Sheppard, Chapman, & Taylor, 2011; Tran, Lundgren, et al., 2015). Previous research identified a significant difference in vertical jump peak force (PF) and jump height in those junior surfers selected for the national team and those not selected (Tran, Lundgren, et al., 2015). Furthermore, a significant association has been identified between the ranking of turning manoeuvres and PF applied in the CMJ ($\rho = -0.73$, $p < 0.01$), SJ ($\rho = -0.85$, $p < 0.01$) and isometric mid-thigh pull (IMTP) ($\rho = -0.68$, $p < 0.01$) in competitive male surfers (Secomb, Farley, et al., 2015). Together, the aforementioned findings highlight that lower-body strength and power are necessary physical performance characteristics for enhanced performance in competitive surfers.

2.2.2 Gender Differences in the Physiological Performance Characteristics of Competitive Surfers

As already highlighted, the WSL scoring criteria is the same for both male and female surfers (WSL, 2017). However, the scores awarded for similar manoeuvres successfully executed has demonstrated extreme variability across genders. During the 2015 WSL competitive season, a female surfer was awarded a 10-point (10.00 ± 0.00) ride for incorporating an aerial based manoeuvre (air reverse) into her wave-ride (WSL, 2015). In the same competitive year performance analytics showed that the average score for an air reverse completed by a male surfer was 6.58 ± 1.74 (Ferrier et al., 2018). It is therefore of interest to investigate and quantify the current physiological gap between male and female surfers to provide an indication of the variance in skill-based performance between genders.

An online search was conducted in *Google Scholar*, using the terms "surfboard riding", "performance", "male" and "female". Of the 26 relevant scientific manuscripts noted, only four were found to include female participants (Bruton et al., 2017; Bruton, O'Dwyer, et al., 2013; Eurich et al., 2010; Secomb et al., 2013). Firstly, large significant gender differences in sprint paddling performance have been identified, with males recording significantly quicker times to; 5 m (d = 1.40, $p < 0.001$), 10 m (d = 1.30, $p < 0.001$), and 15 m (d = 1.30, $p < 0.001$) (Secomb et al., 2013). Secomb et al. (2013) also noted male surfers to record greater peak velocities (d = 1.30, $p < 0.001$) over 15 m compared to their female counterparts. As male and female surfers train in the same environment at the same times, a slower sprint paddle time may compromise a female's ability to compete for the best waves, which would reduce the number of waves they can catch, and hence, reduce the opportunity to practice technical skills during wave-riding.

In addition to significantly faster sprint paddle ability, it has also been reported that male surfers produce significantly greater normalised PF and PP ($p < 0.05$) when performing a surfing specific explosive pop-up (Eurich et al., 2010). These results suggest that female surfers maybe at a disadvantage, when aiming to move 75% of their body weight in less than a second, as decreased force application would limit the acceleration of the mass of the body. However, the sports-specific performance outcome of time to pop-up was not reported in this study. Further research would be warranted to see if force application during a simulated pop-up was associated with a quicker performance outcome in time to pop-up. This would provide a greater insight into the ability of male and females to transfer from a prone paddling position to their surf specific stance, in one explosive movement.

As previously stated, lower-body strength and power are key physical performance determinants of wave-riding performance. Research focused on the gender differences in the lower-body has shown male surfers to exhibit significantly greater leg press power at 75%, 100% and 125% of body weight ($F_{1,36}$ = 56,5, 47.4, 16.5, $p < 0.05$) (Bruton, O'Dwyer, et al., 2013). Bruton, O'Dwyer, et al. (2013) noted that the leg press was chosen to eliminate the use of a countermovement. However, in order to generate speed along the wave face a surfer completes continuous cycles of compression and extension, flexing through the hip, knee and ankle joints during the countermovement phase. Therefore, it would be of interest to examine the gender differences in lower-body power when a countermovement is adopted, as this may affect the ability to generate speed during wave-riding, which is a major component of the WSL scoring criteria. To date no research has been published regarding the lower-body explosive strength of female surfers, measured using a CMJ. As the aforementioned literature highlights the research pertaining to gender differences in competitive surfing is minimal, and so the subsequent sections will examine the scientific literature pertaining to gender differences across a range of competitive sports.

2.3 Gender Differences in Sport Performance

Gender differences in sport performance can pertain to a number of different contexts, including, but not limited to; physiological, biomechanical, socio-cognitive and psychosocial. It is important to note that the aforementioned contexts should not always be regarded as independent constructs, but rather as interdependent. In all professional sports males and females compete in different competitive classifications. In sports where objective results can be analysed there is still a significant gender gap in performance. For example; in sprint running (100 m, 200 m and 400 m), there has been a consistent 10 - 12% difference in performance times since the 1980's (Sandbakk, Solli, & Holmberg, 2017). In upper-body dominant sports such as kayaking, larger gender differences in performance sprint times have been documented ($\geq$ 12%) (Sandbakk et al., 2017). Importantly, although a significant difference in performance still exists, some sports have observed a narrowing of the gender gap. For example, at the 1980 Olympic Games, in the 100 m freestyle race, the male and female winners recorded a time of 49.36 s and 54.98 s, respectively. Since this period males have taken 1.25 s off the aforementioned time compared to the females reducing their time by 2.30 s at the 2014 commonwealth games ("Glasgow Commonwealth Games 2014. Offcial results book. ,"). In normalised terms this results in a 4.6% reduction by females compared to only a 2.5% reduction by males. Together, these statistics demonstrate that female athletes have reduced the performance gap in certain sports.

The main rationale for the significant difference in performance is the advantageous biological, anatomical and physiological characteristics of males. However, the sociocultural opportunities of women (i.e. length of cumulative experience, money and social norms) cannot be overlooked as critical influences on the anatomical and physiological adaptions that may influence performance. It has long been reported that males are heavier, leaner and possess greater muscular strength, when compared to females (Maughan, Watson, & Weir, 1983; Miller, MacDougall, Tarnopolsky, & Sale, 1993). Greater muscular strength of both the lower and upper-body have been attributed to a larger skeletal muscle mass (Janssen, Heymsfield, Wang, & Ross, 2000), larger muscle fibres (Miller et al., 1993) and greater muscle cross sectional area (Kanehisa, Ikegawa, & Fukunaga, 1994; Maughan et al., 1983). A greater muscle cross sectional area has been positively correlated to absolute and normalised strength, in both male and females (Maughan et al., 1983). However, when analysing the upper and lower-body independent of each other, disparity between genders have exhibited variation. Bishop et al. (1987) reported gender differences in strength to be larger in the upper-body than the lower-body, in equally trained male and females, of which was almost entirely accounted for by the difference in muscle size. This is further supported by Miller et al. (1993) who identified women to have a lower proportion of fat free mass in the upper-body than the lower-body. Based on the aforementioned literature, females maybe at a physiological disadvantage, due to the innate biological gender differences, particularly in the upper-body. In order to investigate the biological, anatomical and physiological differences on performance, physical performance tests are frequently implemented by sports science professionals. Physical performance tests can generate sport-specific normative data and performance standards for a specific athlete cohort, as well as providing strength and conditioning coaches with baseline measures, in which to facilitate individualised exercise prescription (McGuigan, Cormack, & Gill, 2013). However, in order for physical performance tests to be meaningful for the coach and athlete, they must be reliable, valid and take into consideration the physical requirements of the sport (McGuigan et al., 2013). The following two sections of this review will outline a variety of upper-body and lower-body physical performance tests, and their ability to quantify and report gender difference in physical performance characteristics.

2. 4 Gender differences in upper-body physical performance characteristics

Sports from Olympic weightlifting and rugby to handball and surfing have been shown to require both maximal and dynamic upper-body strength to facilitate performance (Baker & Nance, 1999; Haff et al., 2005; Sheppard, McNamara, Osborne, Andrews, & Chapman, 2012; Ziv & Lidor, 2009). As such, strength and conditioning practitioners are required to assess an athlete's upper-body strength and power capabilities, in order to attain baseline measures that can be used to guide training interventions. The purpose of this upper-body review is to analyse the current research available in relation to the use of reliable and valid isometric and dynamic upper-body assessments, in both male and female athlete cohorts.

2.4.1 Isometric Measures

Muscular contractions are best described based on two variables, length and force, and are categorised into either isotonic or isometric contractions. Isometric contraction involves a maximal voluntary contraction at a specific joint angle against an unyielding resistance (Wilson & Murphy, 1996). Strength assessments utilising a single isometric contraction have been frequently used to assess athletic qualities in a multitude of sport populations (Baker, Wilson, & Carlyon, 1994; Haff et al., 2005; Stone et al., 2004; West et al., 2011), and occupational health (Das & Forde, 1999; Le Bozec & Bouisset, 2004).

Maximal upper-body strength has been previously assessed using a 1RM bench press protocol (Baker et al., 1994; Paulsen, Myklestad, & Raastad, 2003). However, due to the potential injury risk associated with the 1RM, as well as time efficiency, coaches have more recently opted for the use of isometric testing protocols (Bellar, Marcus, & Judge, 2015; Comfort, Jones, McMahon, & Newton, 2014; Young, 2013). At present the implementation of upper-body isometric protocols to assess the force-producing ability of the neuromuscular system is limited. Possible reasons for the limited implementation of these tests include: technology may not have allowed for a standardised protocol that can be easily and quickly implemented within a gym/applied laboratory environment, fewer sports consider maximal upper-body strength measures to be a significant performance indicator for their athlete cohort and there may not be enough literature to support the use of such tests. Despite these limitations there is reliable and valuable research available within the literature, pertaining to the isometric bench press (IBP) (Young, Haff, Newton, Gabbett, & Sheppard, 2015; Young, Haff, Newton, & Sheppard, 2014) and isometric push-up (IPU) (Bellar et al., 2015).

The IBP has become one of the more commonly implemented upper-body isometric testing protocols and has been shown to represent a reliable isometric assessment when measuring upper-body PF (Kilduff et al., 2002; Murphy, Wilson, Pryor, & Newton, 2010; Young et al., 2014). Kilduff et al. (2002) reported an ICC = 0.95 for test-retest reliability of the IBP, similar to Young et al. (2014) who reported an ICC = 0.89 - 0.97, and CV% = 1.2 - 1.6. In comparison, the rate of force development (RFD) was not as reliable a measure, at varying degrees of elbow flexion (ICC = 0.56 – 0.65, CV% = 0.5 – 7.6) (Young et al., 2014). It should be noted that the participant cohort in the two aforementioned studies were elite/resistance trained males. No research study involving the IBP has been found with female subjects, and therefore, no comparisons can be drawn between genders.

Similar to the bench press, the push-up has been widely implemented in the assessment of upper-body maximum strength. However, in comparison to the IBP, there is only one documented study that has measured isometric upper-body strength implementing a prone push-up (Bellar et al., 2015). Beller et al. (2015) assessed a novel isometric push-up (IPU) test, involving both male and female participants who adopted a fixed push-up position, using a strap placed over the thoracic spine to restrict elbow joint flexion to 90°. This protocol was found to be a reliable measure of isometric PF (ICC

= 0.98) with a multiple regression model identifying isometric PF as a significant predictor of 1RM bench press ($r^2 = 0.86$, $p < 0.001$). Despite this study involving male and female participants, no direct gender comparisons were reported in relation to the raw IPU values. Applying these findings to a surf specific cohort, the isometric push-up may be a favourable test in the assessment of maximal upper-body strength, with the prone push-up being a familiar closed kinetic chain exercise adopted by surfers, in a similar plane to the surf specific pop-up. The encouraging findings of Beller et al. (2015) warrants further research into the reliability and validity of the IPU within a surfing cohort, and at varying degrees of elbow flexion.

Isometric contractions involve a maximal voluntary contraction at a specific joint angle, and as such the joint angle at which the isometric contraction is initiated needs to be considered. Murphy et al. (2010) investigated the relationship of the IBP with elbow flexion fixed at both 120° and 90° in weight trained males. They identified that 120° elbow flexion elicited greater PF, however 90° elbow flexion exhibited a large magnitude and significant association with 1RM bench press performance ($r = 0.78$, $p < 0.01$). Kilduff et al. (2002) found that a fixed elbow flexion angle of 90° was reliable when collecting PF measures in male rugby players. More recently, Young (2013) investigated four different elbow flexion angles (60°, 90°, 120° and 150°) and found that both 120° and 150° elicited greatest PF. Young concluded that either 120° or 150° of elbow flexion can be adopted in the IBP as there was no statistically significant difference between angles ($p = 0.08$). Taking into account the large range in recommended elbow flexion (90° - 150°), Murphy et al. (2010) suggest that the best angle for isometric contraction to occur may be the joint angle that elicits the maximum PF in the performance of interest. The current findings provide evidence that a change in joint angle could significantly alter PF production and test retest reliability, emphasising the need to investigate a variety of joint angles for different athlete cohorts.

2.4.2 Dynamic Measures

Pertinent to surfing, upper-body dynamic strength is required for the transition from a prone paddling position to a surf specific stance, in one explosive movement (Everline, 2007a). In sports that require upper-body dynamic strength, the three most commonly implemented physical performance measures are the ballistic bench throw (BBT) (Alemany, Pandorf, Montain, & Castellani, 2005; Cronin & Owen, 2004; Marques, Van Den Tillaar, Vescovi, & González-Badillo, 2007; Young et al., 2014), seated medicine ball throw (SMBT) (Harris et al., 2011; Marković, Sekulić, Harasin, & Šimić, 2009; Murphy & Wilson, 1996), and dynamic push-up (DPU) (Koch, Riemann, & Davies, 2012; Wang et al., 2017). Comprehensive research by Young et al. (2014) investigated the reliability of upper-body performance measures using a BBT at 45% of 1RM in elite male athletes. It was reported that PF, PV, and PP exhibited high levels of reliability (ICC = 0.89 - 0.97, CV% = 1.7-3.3), with PRFD exhibiting poor levels of reliability (ICC = 0.43, CV% = 4.1) (Young et al., 2014). Young et al. (2014) suggests further familiarisation sessions maybe required to see an improvement in the reliability of PRFD. They also speculate that if athlete is not mentally prepared, their ability to produce force as quickly as possible may be compromised, negatively effecting PRFD. Specific to the female athlete, Cronin and Owen (2004) investigated the reliability and validity of a standardized 10 kg BBT. They reported good reliability

(CV% = 0.14 - 3.50) for PF, PP and impulse, with PP and impulse most highly correlated to the sports-specific chest pass (*r* = 0.77 - 0.81).

The SMBT has shown high levels of test-retest reliability using both a 1.5 kg (ICC = 0.99) and 3 kg (ICC = 0.98) medicine ball (Harris et al., 2011). In addition, validity of the SMBT has been assessed, and found to be positively correlated to an explosive push-up for both 1.5 kg (*r* = 0.64) and 3 kg (*r* = 0.61), respectively (Harris et al., 2011). However, the cohort used in the aforementioned research study, had an average age of 72.4 ± 5.2 yrs, significantly older than that of an athlete specific population. In a student population of males and females, significant differences in absolute (~ 30%) and normalised (~ 10%) upper-body explosive strength, as measured using a SMBT was reported (Marković et al., 2009). Interestingly to note, when both fat free mass and 1RM bench press were controlled for, gender differences were no longer apparent.

Finally, the DPU has frequently been used as a training modality for a range of athletes (Kraemer et al., 2001; Vossen, Kramer, Burke, & Vossen, 2000). Within the literature, a push-up incorporating a dynamic concentric component has been referred to as a plyometric push-up (Hogarth, Deakin, & Sinclair, 2013; Koch et al., 2012; Miller & Kennedy, 2015), a ballistic push-up (Wang et al., 2017), and an explosive push-up (Miller & Kennedy, 2015). Koch et al. (2012) reported within-day reliability of the plyometric 'clap' push-up in both the dominant and non-dominant hand when measuring PF (ICC = 0.85 - 0.91, SEM = 0.03 - 0.01). Furthermore, research by Hogarth et al. (2013) reported moderate-high levels of between-day test-retest reliability for PF (ICC = 0.80, 95%CI = 0.37 - 0.94) (CV% = 7.6, 95%CI = 5.5 – 12.0), in fourteen strength trained rugby league players. Although a high ICC was reported for RFD (ICC = 0.84, 95%CI = 0.50 - 0.95), the within-in subject CV% indicated poor test-retest reliability (CV% = 11.0, 95%CI = 8 - 18) (Hogarth et al., 2013). It has previously been documented that the method adopted to calculate RFD, may determine its reliability (Haff et al., 2015). For example; average RFD failed to meet reliability standards compared to that calculated from pre-determined time bands (Haff et al., 2015). As such the findings of Haff et al. (2015) should be taken into account when interpreting RFD reliability. More recently, Miller and Kennedy (2015) investigated the test-retest reliability of an explosive push-up, in seven highly strength-trained males. They reported high between-day reliability for PF (CV% = 7.6, TE = 0.64), PP (CV% = 3.1%, TE = 0.31) and PV (CV% = 2.2%, TE = 0.32) (Miller & Kennedy, 2015). Due to the high reliability identified in previous research, and the similarity in movement pattern between the DPU and surf specific pop-up, it would be of benefit to undertake similar testing in surfers.

The three aforementioned methodologies allowed for a countermovement, prior to the concentric contraction. In contrast, Wang et al. (2017) reported the reliability of a ballistic push-up, that excluded the countermovement; requiring participants to initiate an entirely concentric contraction from the bottom of the push-up. This methodology reported moderate to high reliability of PF (ICC = 0.97, 95%CI = 0.95 - 0.98), PP (ICC = 0.93, 95%CI = 0.89 - 0.96) and RFD (ICC = 0.84, 95%CI = 0.75 - 0.90) in sixty recreational males (Wang et al., 2017). In relation to the sport of surfing, the sports-specific pop-up does not allow for a countermovement action prior to the concentric push. Instead an individual is required to transition from a prone to standing position, in one explosive concentric action. Therefore, the application of a methodology mirroring that of Wang et al. (2017) would be more specific to the force production required when executing a surf specific pop-up. The cohort recruited by Koch, Hogarth, Miller and Wang, all comprise of recreational or strength trained males. To date no research has examined the reliability of the upper-body dynamic push-up strength in females, and therefore comparisons cannot be made between genders.

2.4.3 The Transfer of Isometric Upper-Body Strength to Dynamic Performance

As the aforementioned sections highlight, both maximal isometric and dynamic testing protocols can be implemented to assess upper-body strength and power. Furthermore, the results of such assessments, have helped strength and conditioning practitioners better understand the relationship between maximum strength and dynamic performance. It has previously been documented that maximum strength underpins dynamic strength capabilities, with the majority of the literature drawing from the lower-body (Baker & Nance, 1999; Baker et al., 1994; McGuigan & Winchester, 2008; McGuigan, Winchester, & Erickson, 2006).

In contrast to the plethora of lower-body research, there is limited research into the relationship between upper-body maximal isometric strength and dynamic performance. Despite their contrasting findings, the following manuscripts have begun to provide valuable data in an area of limited research. Baiget et al. (2016) identified a significant positive association between maximal isometric shoulder internal rotation strength and serve velocity (r = 0.67, p = 0.02) in competitive professional tennis players (Baiget et al., 2016). This is in contrast to Murphy et al. (1994) who reported a poor association between IBP PF and seated shot put performance (r = 0.38).

Interestingly to note no research has yet examined a relationship between maximal isometric strength and dynamic performance assessed using an IPU. Such investigation would be warranted in a surfing cohort, to further explore the relationship between maximal isometric upper-body strength, and the dynamic surf specific pop-up.

2.4.4 Dynamic Strength Index

In order to determine an athlete's dynamic force capabilities in relation to their maximal isometric strength, a ratio of dynamic PF to isometric PF has been calculated (Sheppard, Chapman, et al., 2011; Thomas, Dos'Santos, & Jones, 2017; Thomas, Jones, & Comfort, 2015; Young et al., 2015). This ratio is referred to as the dynamic strength index (DSI) and has been implemented by strength and conditioning practitioners to highlight an athlete's area of weakness, and subsequently guide training interventions. Existing literature provides normative DSI values for various populations including; rowers (Sheppard, Chapman, et al., 2011), soccer players (Comfort et al., 2017; Thomas, Dos'Santos, et al., 2017) and rugby players (Comfort et al., 2017). However, only two scientific manuscripts have reported DSI values in relation to PF attained in upper-body isometric and dynamic strength measures (Young et al., 2015; Young et al., 2014).

Young et al. (2014) reported an upper-body DSI to be a reliable tool (ICC = 0.93, CV% = 3.5) in assessing an athlete's dynamic force capabilities in relation to their maximal isometric strength, adopting the IBP and BBT testing protocols (Young et al., 2014). Furthermore, Young et al. (2015) investigated if the upper-body DSI could be effectively used to highlight areas of weakness and guide specific training prescription. Participants were assigned to either a high load (80 - 100% 1RM) bench press or, moderate load (40 - 50% 1RM) BBT training group based on baseline DSI values. The results showed that both high load and moderate load groups significantly improved their isometric (bench press) and dynamic PF (BBT), respectively, coupled with a significant increase in DSI. As a result, Young et al. (2015) provided the following practical guidelines: A DSI ≥ 0.75, suggests a need to increase maximum strength, with a DSI < 0.75 indicating that adequate levels of maximum strength are present, and as such ballistic training is recommended. It should however be noted that the DSI is a ratio and in order to interpret and apply this ratio correctly, analysis of both isometric and dynamic values need to be considered. For example; two athletes could have the exact same ratio of 0.80, but one is able to produce double the force in both the isometric and dynamic push-up."

In summary, the comprehensive research by Young et al. (2015) demonstrated that the DSI could be used to guide training interventions and was sensitive to training-induced changes. No research has yet reported an upper-body DSI of any female athlete cohort, and thus gender comparisons can once again not be made. The investigation of an upper-body DSI in both male and female surfers, could help better understand the contribution that maximal upper-body strength plays in relation to upper-body dynamic performance.

2.4.5 Summary of the Upper-Body Considerations

The scientific research pertaining to the upper-body is still relatively limited within the literature. More specifically, the literature pertaining to gender differences in both isometric and dynamic upper-body strength is scarce. Explanations for this are multifactorial including; methodological issue and the fact that the majority of research is performed on sports which are characterised by lower-body performance variables (e.g. soccer, volleyball, cycling, Australian rules football, rugby). Specific to competitive surfing, there remains a significant gap in research pertaining to upper-body isometric and dynamic assessments of strength, and their relationship to sports-specific performance. More specifically, the implementation of the IPU and DPU within a surfing population may be favourable to better understand the contributions of both maximal and dynamic upper-body strength to the surf specific pop-up in competitive male and female surfers.

2.5 Gender Differences in Lower-Body Physical Performance Characteristics

As stated earlier, lower-body strength and power have been documented as important physical performance determinants of wave-riding performance in competitive male surfers, with greater lower-body strength associated with higher scoring potential for turning manoeuvres (r = -0.68, p < 0.01) (Secomb, Farley, et al., 2015). Furthermore, as part of the WSL scoring criteria surfers are judged on their inclusion of innovative and progressive manoeuvres (WSL, 2017), which has led to a significant increase in the occurrence of high-risk aerials above the lip of the wave (Ferrier et al., 2018). The completion of such manoeuvres, are more frequently and successfully executed by competitive male surfers, resulting in speculation by spectators, coaches and strength and conditioning coaches as to why this is the case. Is it that females do not poses the skill level to execute such manoeuvres, or may it be attributed to greater lower-body strength and power by competitive male surfers. As such further investigation and quantification of both male and female surfers lower-body strength and power is warranted.

The CMJ and SJ have been documented as reliable and valid measurement tools in the assessment of lower-body power across a plethora of athlete cohorts, with jump height the primary performance variable of interest (Cormack, Newton, McGuigan, & Doyle, 2008; Cronin, Hing, & Mcnair, 2004; Markovic, Dizdar, Jukic, & Cardinale, 2004). A significant difference in jump height has been reported between genders, with males jumping significantly higher than their female counterparts when performing both the CMJ (Laffaye, Wagner, & Tombleson, 2014; McMahon, Rej, & Comfort, 2017) and SJ (Riggs & Sheppard, 2009). Comprehensive research by Riggs and Sheppard (2009) investigated gender differences in the jump height of international beach volleyball players. It was documented that male volleyball players jumped significantly higher than female players for both CMJ and SJ by 8.3 cm and 8.1 cm respectively (Riggs & Sheppard, 2009). These findings are similar to those reported in male and female national soccer players, with men jumping 10.3 cm higher in the CMJ, and 8.5 cm higher in the SJ (Castagna & Castellini, 2013). To date, no research examining gender differences in CMJ and SJ performance in surfers has been reported. Further analysis into the key kinetic and kinematic variables that contribute to vertical jump performance are warranted in order to better understand why there is such a large disparity in jump height between genders. Throughout the subsequent sections, the three distinct phases of the CMJ will be analysed, with particular focus on the eccentric and concentric phases (Figure 2.1) (McMahon, Murphy, Rej, & Comfort, 2016).

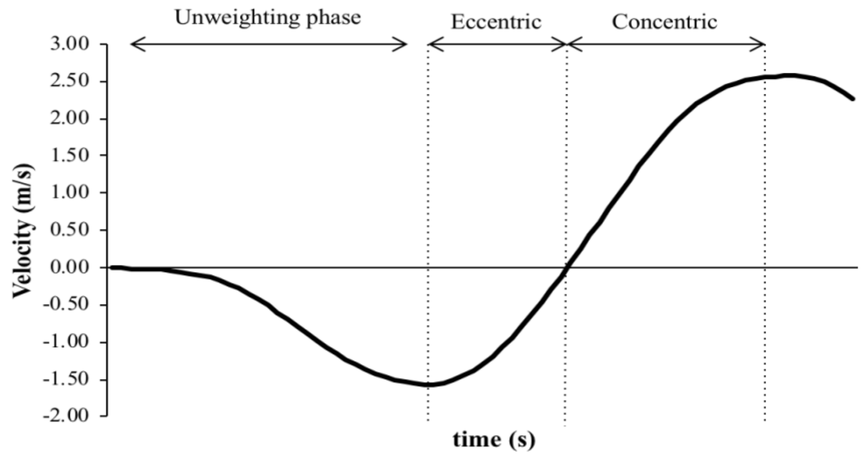

Figure 2.1: Countermovement jump velocity-time curve. Adapted from McMahon et al. (2016)

2.5.1 Kinetic Characteristics

Kinetics refer to the forces that cause motion, with impulse, with peak force (PF), and peak power (PP) being discrete kinetic variables of interest (Winter, 1990). The analysis of these three variables throughout different phases of a vertical jump has proved to be beneficial for sports scientists, to investigate and understand the potential mechanisms behind the disparity in performance differences between genders.

There has been contrasting research reporting the difference in applied force between male and females in the CMJ and SJ. Research has identified males produce significantly greater normalised PF in the concentric phase of a CMJ than their female counterparts (Laffaye et al., 2014). This is in contrast to previous findings by McMahon et al. (2017) who found no significant difference in normalised PF between genders ($p = 0.61$). The findings of McMahon et al. (2017) have been supported by Riggs and Sheppard (2009) who found no significant difference in normalised PF between male and female volleyball players when performing a CMJ (d = 0.07, $p = 0.71$). However, when analysing the SJ, Riggs and Sheppard (2009) reported significant differences between male and female volleyball players for all variables of interest, including normalised PF (d = 0.49, $p < 0.01$). To date, a number of studies have been published in regards to male surfers, and their force application during the CMJ and SJ (Secomb et al., 2016; Sheppard, Chapman, et al., 2011). However, only one study has included female participants, in which lower-body strength and power data of male and female surfers was combined and analysed as one group (Secomb, Nimphius, Farley, et al., 2015). Therefore, comparison of force application between genders in competitive surfers cannot yet be made.

Although gender differences in PF production have been investigated and reported, there has been discussion regarding the use of normalised PF as a reliable performance measure. Some research groups have shown normalised PF to be strongly correlated with CMJ height (Laffaye et al., 2014; Riggs & Sheppard, 2009). However, Nuzzo et al. (2008) and Sheppard et al. (2008) found no association between CMJ PF and jump height. Further, Kirby et al. (2011) have advocated net vertical impulse to be a more accurate predictor of CMJ performance as would be expected mathematically.

Impulse is defined as force production over time and has been calculated for both the eccentric and concentric phases of the CMJ, as well as the SJ (Kirby et al., 2011; McMahon et al., 2016) (Figure 2.2). Kirby et al. (2011) reported a positive association between CMJ height and normalised net vertical impulse (concentric phase only) for the SJ ($r = 0.93$, $p < 0.001$) and CMJ ($r = 0.92$, $p < 0.001$) in ten males, with two years jumping experience. These results are not unforeseen as velocity of the centre of mass at take-off was used to calculate jump height, and velocity of the centre of mass is determined by the net vertical impulse. Furthermore, this positive association remained regardless of different squat depths adopted. McMahon et al. (2016) investigated CMJ phase characteristics in senior and academy rugby league players. They reported senior players to report a larger normalised concentric impulse (d = 0.86, $p = 0.004$), which in turn facilitated a greater vertical velocity of their centre of mass (COM). The relevance and application of this finding will be discussed in more detail in the following section. Of particular interest was the finding that although there was a larger concentric impulse was found in senior players, there was no significant difference in normalised PF between groups (d = 0.08, $p = 0.35$).

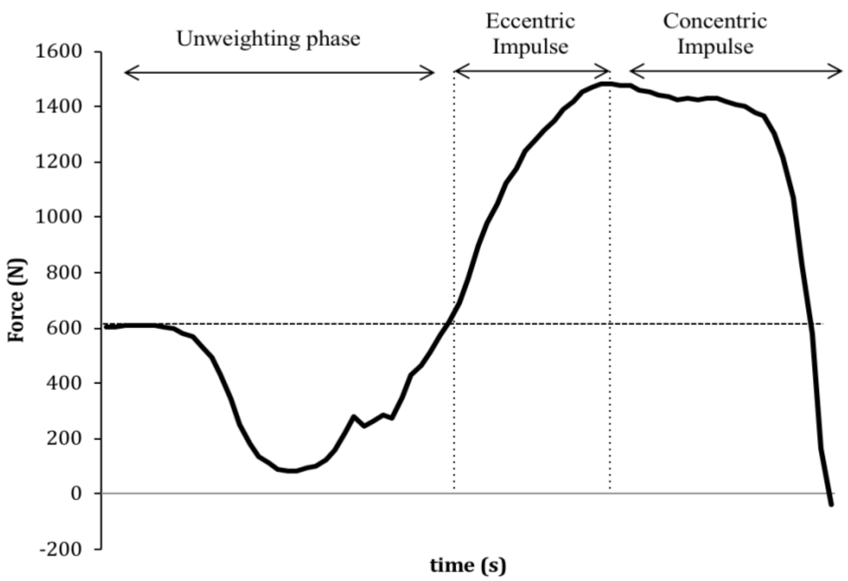

Figure 2.2: Countermovement jump force-time curve. Adapted from (McMahon et al., 2017)

McMahon et al. (2017) investigated gender differences in both the eccentric and concentric impulse of a CMJ. It was reported that impulse was significantly higher in males, in both the eccentric (g = 0.82, $p = 0.04$) and concentric (g = 1.56, $p < 0.001$) phases. However, normalised PF for both phases were not significantly different between genders. With males jumping 24% higher than females, it seems that the significantly larger impulse applied by males is an underpinning factor in CMJ performance, and not that of PF application. As research within surfing has only ever reported the gross measure of PF, the aforementioned literature provides future research directions, with impulse being a variable of significant importance.

Similarly, to PF and impulse, PP has been documented as an important variable in vertical jump performance (Cormie, McBride, & McCaulley, 2008; Riggs & Sheppard, 2009; Stone et al., 2003). Riggs and Sheppard (2009) reported normalised PP to strong predictor of SJ height for both male ($r = 0.94$, $p < 0.05$) and females ($r = 0.90$, $p < 0.05$), with a significant difference in PP between genders ($p < 0.01$). They also reported normalised PP to be a strong predicator of CMJ height in males ($r = 0.83$, $p < 0.05$) and females ($r = 0.65$, $p < 0.05$) (Riggs & Sheppard, 2009), however in contrast to the SJ no significant difference was reported between genders ($p = 0.38$). The aforementioned findings differ from those of McMahon et al. (2017) who reported significant gender difference in CMJ PP, with males rugby league players recording 16.9% greater PP than females netballers (d = 1.24, $p = 0.001$). These opposing findings could be attributed to specific cohorts used; with Riggs and Sheppard recruiting elite level beach volleyball players with an extensive jump training history.

Of particular interest are the recent findings of Rice et al. (2017) in strength matched male and female basketball players. In analysing both the force- and power-time curve of a CMJ, they found gender differences in PF was not significantly different when normalised to body mass (d = 0.00, p = 0.92). However, PP was significantly different during the concentric phase, when analysed in both absolute (d = 0.49, p = 0.002; d = 0.25, p = 0.05) and normalised terms. This is one of the first studies to compare strength matched males and females, highlighting that gender is not always a determining factor in PF application. In contrast, PP exhibits significant gender differences, independent of strength levels.

In summary, the kinetic variables of interest include PF, impulse and PP, of which all have been shown to explain the variance in vertical jump performance. The aforementioned literature highlights the current gender differences in lower-body strength and power. The exception occurs when values are expressed normalised to body weight, with a substantial narrowing of the gender gap. The contrasting findings reported when different cohorts of athletes were recruited, reinforce the importance of sports specificity. Thus, further research is warranted to provide baseline values for both male and female competitive surfers.

2.5.2 Kinematic Characteristics

Kinematics describe movement, without reference to the forces that cause such movement (Winter, 1990). Velocity, describes the rate of change of an object, and has been reported in both eccentric and concentric terms (Linthorne, 2001). Bobbert (2001) highlights that during the concentric phase of a vertical jump, peak linear velocity of the COM is the variable of primary importance. Bobbert's (2001) statement is reinforced by the use of take-off velocity in the calculation of jump height, regardless of the methodology adopted (e.g. flight time method, impulse-momentum method, and the work energy method) (Linthorne, 2001). It is for this reason that concentric PV is a significant predictor of jump height in both the CMJ ($r = 0.97$, $p < 0.01$), and SJ ($r = 0.95$, $p < 0.01$) (Pupo, Detanico, & Santos, 2012).

During the concentric phase of the CMJ, Floria et al. (2016) reported rugby players with significantly greater concentric velocity, demonstrated increased vertical jump height (d ≥ 0.80, $p = 0.03$). When examining gender differences, peak concentric and eccentric velocity have been reported to be significantly higher in male rugby league players (2.67 ± 0.18 m•s-^{1}, 1.19 ± 0.21 m•s-^{1}), compared to female netballers (2.32 ± 0.20 m•s-^{1}, 1.02 ± 0.19 m•s-^{1}) (McMahon et al., 2017). Furthermore, during the eccentric phase of the CMJ, males have been shown to demonstrate a greater vertical displacement of their COM (31.4 ± 5.9 cm) than female netballers (25.1 ± 5.6 cm) (McMahon et al., 2017). These findings are supported by research specific to surfing, with stronger male surfers shown to record a significantly higher eccentric PV (d = 1.40, $p < 0.01$), in addition to exhibiting a greater vertical displacement of the COM (d = 1.41, $p < 0.01$), than weaker male surfers (Secomb et al., 2016). Secomb et al. (2016) suggests that strength coupled with a greater eccentric velocity, may allow an athlete to brake more effectively during the eccentric phase of a CMJ, thus enabling greater PF application during the concentric phase. These findings provide strength and conditioning practitioners with practical data, in which to interpret and apply in the physical preparation of male surfers. However, with no such data pertaining to the female surfers, the same assumptions cannot be made, providing rationale for another area of future research. Through examining these variables in a female cohort of surfers, a better understanding of the mechanism that limit vertical jump performance in females maybe identified and provide direction in their physical preparation programming.

Superior jumpers have been shown to displace their COM lower, subsequently maximising the vertical distance the COM can travel in the concentric phase of the CMJ (Floría et al., 2016). Previous research has shown that a greater displacement of the COM, allows for a larger distance over which force can be produced, increasing net vertical impulse, enhancing take-off velocity, and consequently increasing jump height (Bobbert, Gerritsen, Litjens, & Van Soest, 1996; Floría et al., 2016). The displacement of an individual's COM, requires the hip, knee and ankle joints to move through their full range of motion. Surfers require their hips, knee and ankles to perform a combination of flexion and extension, to not only ensure speed is maintained across the wave face, but to achieve pop above the lip when attempting an aerial manoeuvre. Research has documented that with an increase in surfing experience, comes the ability to crouch lower to the board, through greater flexion of the hip, knee and ankle joint ($F_{1,36} \geq 19.1$, $p < 0.01$) (Bruton, O'Dwyer, et al., 2013). Interestingly, this trend was more apparent when comparing recreational with competitive female surfers. These lab-derived findings of Bruton, O'Dwyer, et al. (2013), align with the opinion of surf coaches, with the failure of female surfers to produce adequate knee flexion the most common flaw highlighted. The lack of knee flexion would compromise a female surfers ability to generate speed along the wave face and limit their scoring potential.

Although not specific to surfing, Hsieh and Cheng (2016) examined the kinematic differences in vertical jump performance, between skilled (competitive) and non-skilled (recreational) female volleyball players. Hsieh and Cheng (2016) reported skilled players to exhibit significantly greater CMJ height than non-skilled players. The kinematic variables that were significantly associated with jump height in skilled players were, greater eccentric PV ($r = -0.32$, $p < 0.05$), maximum eccentric vertical displacement of the COM ($r = -0.41$, $p < 0.01$) and minimum joint angle of the hip ($r = -0.63$, $p < 0.01$), knee ($r = -0.64$, $p < 0.01$) and ankle ($r = 0.50$, $p < 0.01$) (Hsieh & Cheng, 2016). Together these variables accounted for 64% of variance in jump height during the preparation phase of a CMJ for skilled players. To summarise, they found that the further and faster the COM was displaced in the preparation phase of the CMJ, resulted in greater VJ height in a female cohort.

A number of studies have examined the effect of squat depth, as determined by hip, knee and ankle flexion on jump height in male athletes. Gheller et al. (2015) found that a deeper squat position, with a knee flexion < 90° resulted in a greater CMJ height in male volleyball and basketball players ($p < 0.01$). Ghellar et al. (2015) investigated the effect of three different knee flexion angles (70°, 90°, 100° and a preferred position) on SJ performance. Results showed that greater jump height was attained from the greatest knee flexion angle (70°), highlighting the significance of initial starting position in vertical jump performance. This is in contrast to Domire and Challis (2007), who found no significant difference in jump height when a deeper squat was adopted. Reasons for the contrasting findings may be methodological, with Domire and Chaliis allowing participants to self-select their deeper squat position.

In conjunction with investigating joint ROM, and COM displacement, angular velocity of the hip and knee have been examined within the literature (Bobbert, 2001; Gheller, Dal Pupo, Lima, Moura, & Santos, 2014; Hsieh & Cheng, 2016). For example; when a knee flexion < 90° was adopted, angular velocity of the hip was significantly higher, resulting in a greater linear velocity of the COM. This is in agreement with Vanrenterghem et al. (2008) and Bobbert et al. (1996) who stated that a greater angular velocity of segments, results in greater velocity of the COM. As concentric velocity is a significant predictor of vertical jump height, it would seem favourable for targeted training interventions to focus on increasing the angular velocity of the lower-body joints. Previous research has shown assisted jumping to be a favourable training modality in increasing take-off velocity, and subsequently jump height (Sheppard, Dingley, et al., 2011; Tran et al., 2011). Therefore, through quantifying the aforementioned variables in both competitive male and female surfers, strength and conditioning practitioners may be able to apply such training modalities to facilitate performance.

Applying the findings of Ghellar et al. (2014) using recreational male volleyball players, and Hsieh and Cheng (2016) using recreational female volleyball players allows comparisons between genders to be made. The primary performance variable of CMJ height was greater in recreational males (0.37 ± 0.05 m) than their female counterparts (0.24 ± 0.04 m). In regard to joint angular velocities, male players produced greater peak hip (665.10 ± 96.18 °/s) and peak knee (978.69 ± 104.19 °/s) angular velocities than female players (604.43 ± 72.04 °/s, 792.61 ± 76.17 °/s). The most interesting finding reported by Hsieh and Cheng (2016) was that peak hip and knee joint angular velocity was a significant predictor of jump height in recreational females ($r = 0.48$, $p < 0.01$, $r = 0.32$, $p < 0.05$), suggesting angular velocity of the lower-body joints may be influencing factors in vertical jump performance specifically in females.

In summary, the kinematic variable of interest includes both displacement and velocity (eccentric and concentric), in relation to an individual's COM. Based on the aforementioned literature, there seems to be a discrepancy between genders in relation to the distance and velocity of which the COM is displaced, with males producing favourable results. Of particular interest is the range of motion that the hip, knee and ankle joints move through and subsequent angular velocities, and accelerations of these joints. Future research should aim to quantify such variables for both male and female surfers; as such variables can be changed through training. For example; if it is found that female surfers displace their COM over a shorter distance than males, training that incorporates movements that require the hip, knee and ankle joint to move through a larger range could be favourable.

2.5.3 The Transfer of Isometric Lower-Body Strength to Dynamic Performance

In regards to the lower-body the, IMTP is a frequently implemented assessment, with PF the main performance variable of interest (Beckham et al., 2013; Comfort et al., 2014). As already stated in the upper-body subsection, it is well documented that maximal strength underpins dynamic strength capabilities (Baker & Nance, 1999; Baker et al., 1994). West et al. (2011) demonstrated a significant association between IMTP normalised PF and dynamic performance (CMJ, 10 m sprint time) in male rugby league players ($r = 0.43$, $r = -0.68$). Furthermore, Thomas, Jones, Rothwell, Chiang, and Comfort (2015) reported absolute IMTP measures to be significantly associated with CMJ PF in trained male participants (*r* = 0.45, $p < 0.05$). However, no significant associations were found for both absolute and normalised IMTP measures and jump height in both the CMJ and SJ (Thomas, Jones, Rothwell, et al., 2015). In a female cohort of netball players, normalised IMTP PF, vertical jump performance and sprint speed was reported (Thomas, Comfort, Jones, & Dos' Santos, 2017). Despite associations between vertical jump performance and sprint speed being made, no associations were reported between IMTP PF and jump height. With a limited number of studies including female participants, it is difficult to draw conclusions with a number of cofounding factors that may be contributing to the disparity between genders (i.e. training age and normalised maximal strength level).

Specific to surfing, Secomb et al. (2015) previously reported IMTP data for competitive male surfers (3.3 ± 0.5 N•BW^{-1}), with a significant association between surfing performance and maximal isometric strength. Furthermore, the same research group documented male surfers with a higher normalised IMTP to record a significantly higher eccentric PV (d = 1.40, $p < 0.01$), in addition to exhibiting a greater vertical displacement of the COM (d = 1.41, $p < 0.01$) in the CMJ (Secomb et al., 2016). A wide range of normalised IMTP data for female cohorts has been documented; i.e. adolescent netballers recording IMTP PF values of 3.07 ± 0.53 N•BW^{-1} (Thomas, Comfort, et al., 2017), and senior Olympic weightlifters recording values between 3.9 - 4.5 N•BW^{-1} (Haff et al., 2008). Despite this, no IMTP normative data is available for female surfers and thus the transfer of maximal strength to dynamic performance cannot be quantified.

2.5.3 Summary of the Lower-Body Considerations

The recent influx of aerial manoeuvres by male surfers, suggest that males maybe possess a physiological advantage in order to pop above the waves lip with speed and power. However, to date, there is no empirical evidence documenting gender differences in lower-body power, as measured by the CMJ and SJ in competitive surfers. The lack of normative kinetic and kinematic data in this area, may limit the effectiveness and implementation of tailored programming by practitioners, thus compromising wave-riding performance. The simultaneous investigation of both kinetic and kinematic variables contributing to lower-body performance will provide a critical insight into not just the forces that cause motion (i.e. PF and PP), but more specifically describe the movement that's occurring (i.e. PV and displacement).

2.6 Gender Differences in Self-Efficacy and Outcome Expectancy

As stated previously in this review, gender differences in sport are multifactorial and can be discussed in a number of different contexts. In addition to the physical and biomechanical performance characteristics, social cognitive models of behaviour have also been implemented to investigate gender differences in sport (Bandura, 2001). Previous research has shown significant associations between social cognitive factors and sports-specific performance, with gender differences reported (Beauchamp, Bray, & Albinson, 2002; Bruton, Mellalieu, Shearer, Roderique-Davies, & Hall, 2013; Chang et al., 2014; Gomez Paloma, Rio, & D'Anna, 2014; Spence et al., 2010). However, prior to providing the empirical evidence in regard to the social cognitive factors and their application in a competitive sport setting, a basic understanding of the theory that underpins the research is required.

2.6.1 The Social Cognitive Theory

The social cognitive theory (SCT) proposes that human actions are viewed as the product of dynamic interplay of personal, behavioural and environmental factors (Bandura, 2001). The SCT outlines a number of critical factors that influence behaviour, with the two core behaviours identified as; perceived self-efficacy (SE) and outcome expectations (OE) (Figure 2.3) (Bandura, 2001)

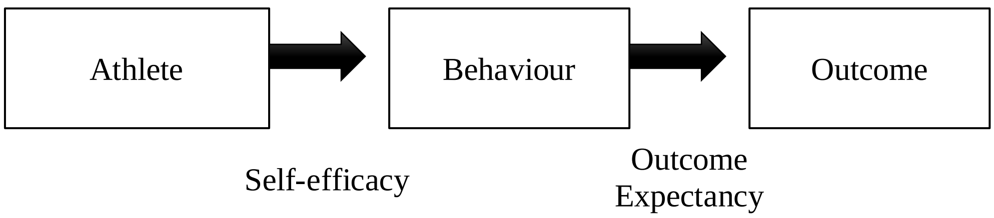

Figure 2.3: Illustration of Banduras social cognitive theory (Bandura, 1977)

Albert Bandura has been a leading researcher in the area of thoughts and their effect on behaviour, specifically looking at an individual's belief in their abilities (SE) to perform a given task (Bandura, 1977, 1993, 2001). Bandura (2006) highlights that SE is not concerned with the skill an individual may possess but the judgment of what the individual can do with the skill they possess. An individual's belief in their efficacy influences the choices they make, how much effort they apply in a given task, their perseverance in the face of difficulty, the goals they set and how they perceive causes of success and failure (Bandura, 2001). Bandura (1977) further outlines that expectations of SE are based on four major sources of information; mastery experiences, vicarious experiences, verbal persuasion and emotional arousal, of which mastery experiences are considered to be the strongest source of SE.

Peoples' beliefs concerning the likely consequences of their behaviour are referred to as outcome expectancies (Bandura, 1977). In contrast to SE, OE doesn't focus on the behavioural performance itself, but instead focuses on the result of the given behaviour. Bandura (1977) further outlines that OE can take three major forms: physical outcomes of the given behaviour, social reactions to the behaviour and self-evaluative reactions to behaviour.

2.6.2 Self-Efficacy and Outcome Expectancy Scales in Sports

Based on his theory, Bandura constructed a 22 item questionnaire in which to assess total physical SE, perceived physical ability and confidence in physical self-presentation (Bandura, 1977). Since then numerous physical activity scales have been constructed using his 'guide for constructing SE scales' in order to measure situation specific SE (Bandura, 2006) (Table 2.1).

Table 2.1: Physical activity self-efficacy and outcome expectancy scales

Authors	Questionnaire Implemented	Items	Participants	Cronbach alpha
Ryckman et al. (1982)	Physical self-efficacy scale (PSE)	22 items	University students (n = 363)	0.81
Holloway et al. (1988)	Physical strength and self-efficacy scale	11 items	Untrained adolescent females (n = 59)	0.75 - 0.90
Lubans et al. (2010)	Resistance training outcome expectancy scale Resistance training self-efficacy scale	5 items 4 items	Untrained secondary school participants (Female = 52, Male = 56)	0.83 0.75
Resnick and Jenkins (2000)	Self-efficacy for exercise scale (SEE)	12 items	Sedentary elderly adults (n = 182)	0.92
Covey et al. (2012)	Self-efficacy for upper-body resistance training questionnaire	8 items	Adults with moderate to severe chronic obstructive pulmonary disease (n = 64)	Not reported
Gilson et al. (2012)	Self-efficacy questionnaire for athletes	3 items	Division 1 male American football players (n = 250)	0.92

In a sports-specific setting, gender differences in SE and OE measures have been measured and discussed in a number of different contexts, including participation, adherence and motivation (Martin & Gill, 1991; Spence et al., 2010). For example; gender has been reported as being a key moderator between SE and participation in physical activity (Spence et al., 2010). To further elaborate, Spence et al. (2010) reported the magnitude of association between physical activity and SE to be greater in youth males, with males having significantly higher levels of SE ($F_{1,4225} = 64.2$, $p < 0.01$). These findings are further supported by Singh et al. (2009) who implemented Bandura's SE questionnaire in adolescent male and females, at both an interschool and national school level. They reported national level athletes perform better in regard to total physical SE, perceived physical ability and confidence in physical self-presentation. More specifically, male athletes regardless of level, were found to perform better in both physical self-presentation and total physical SE than females (Singh et al., 2009). Despite the aforementioned findings being highlighted in adolescent youths, they provide a thought provoking rationale for gender playing a significant role in athlete's behaviours (SE and OE) at a competitive senior level.

2.6.3 Resistance Training Self-Efficacy and Outcome Expectancy

Although research has focused on SE and OE in relation to physical activity, there is a paucity of research in regard to an individual's SE towards resistance training, specifically at an elite level. Resistance training is almost always implemented within athletic populations and can incorporate multiple training modalities (e.g. free weights, machine weights, elastic tubing and body weight loading). The physiological and performance benefits of resistance training for an athletic population have been frequently documented within the literature, with different types of resistance training being tailored to the specific needs of the athlete (Kraemer et al., 2003; Secomb et al., 2017; Tran, Nimphius, et al., 2015). However, for resistance training to be effective, athlete motivation and adherence to the programming would play significant roles in program success.

Based on Bandura's (1977) theory, resistance training SE refers to an individual's beliefs in their abilities to complete resistance training, while OE refers to their beliefs about the likely consequences of resistance training. Of the few studies that have investigated resistance training SE and OE, the majority have been conducted using a recreational cohort. Early research by Holloway et al. (1988) developed and implemented the physical strength and SE scale, designed to measure situation specific SE and OE measures of weight training in females. They investigated the hypothesis that a gain in SE towards resistance training in adolescent girls, would transfer to other areas of life and positively affect self-esteem. Untrained adolescent females were tested before and following 12 weeks of strength training, with the treatment group recording significant increases in strength and weight training SE. Simultaneously, perceived physical ability, physical self-presentation confidence and overall physical SE improved significantly ($p < 0.05$) (Holloway et al., 1988). This was the first study to associate behavioural intentions with resistance training, highlighting not only the physiological improvements of such an intervention, but the social-cognitive benefits in adolescent females.

More recently, Gao et al. (2007) investigated the relative contributions of SE and the three types of OE in predicting student behavioural intention and behaviour in a beginner weight training class. It was reported that physical SE and OE were positive predictors of both behavioural intentions and actual behaviours in both males and females (Gao et al., 2007). Interesting to note, was that only physical OE was a significant predictor, with social reaction and self-evaluative reactions not playing a substantial role in behaviours towards resistance training. Finally, resistance training SE and OE constructs have been assessed using two scales combing to a form a nine-item questionnaire. The SE and OE scales demonstrated acceptable reliability with Cronbach alpha, $\alpha = 0.83$ and $\alpha = 0.75$, respectively (Lubans et al., 2010). Although change in SE was not significant following eight weeks of free weight training in recreational males and females, there was a large magnitude increase in outcome expectancy among females. The importance of physical OE in females is an interesting point to note in relation to the competitive sport of surfing. Surfing is a sport where females have noted the pressure to maintain an 'aesthetic' body shape in order to maximise their opportunity for sponsorship (Franklin, 2009). It has been reported that social physique anxiety was 4.5 times higher in individual aesthetic sports compared to non-aesthetic sports (Gay, Monsma, & Torres-McGehee, 2011). Therefore, it would be of interest to investigate possible gender differences in resistance training physical OE in male and female surfers.

In regard to an elite cohort, only one study has investigated the relationship between SE and physical performance. Gilson et al. (2012) reported SE to be positively related to 1RM squat performance in Division One American Football players. More specifically, they reported that improvement in SE over time corresponded with changes in 1RM squat performance when previous accomplishments were controlled. This finding supports Bandura's theory that an individual's belief in their efficacy influences how much effort they apply in a given task (Bandura, 1977). To date, no research has examined gender differences in SE and OE towards resistance training at a competitive level. With previous research in a recreational cohort highlighting gender as a key moderator towards an individual's SE, it would seem pertinent to further examine gender differences at a competitive level. However, regardless of gender this may be an extremely important performance variable that is currently overlooked within the profession. If an athlete does not have belief in their resistance training abilities, or the relevant outcome expectations, they may not apply themselves to a given task, subsequently hindering any physical performance outcomes that are targeted.

2.6.4 Summary of Self-Efficacy and Outcome Expectancy Considerations

In comparison to other professional sports, the adoption of a high-performance environment is still in its infancy within surfing and as a result resistance training for surfing athletes is still a relatively new area of importance. Therefore, research investigating sociocultural behaviours towards resistance training may provide strength and conditioners with greater insight into current attitudes amongst surfers. In addition, quantifying SE and outcome expectancies in a surf specific population may aid in providing rational for the current gender gap in physical performance characteristics.

2.7 Conclusion

The scientific literature presented in this review has provided rationale for the subsequent chapters. A lack of research pertaining to the competitive female surfers is highlighted, with the need to examine and quantify the current gap in physical performance characteristics justified. It is apparent that gender differences are multifactorial, with this review examining the physiological, biomechanical and socio-cognitive contexts of such differences. This review has emphasised current gaps in the literature, with upper-body strength assessments, and their associations with sport-specific performance measures, an area of research that could benefit the competitive surfer, regardless of gender. Furthermore, the examination of both kinetic and kinematic variables on vertical jump performance, will provide strength and conditioning coaches with additional information pertaining to the variables that describe movement, and not just the forces that cause it. Finally, the unique investigation, into the gender differences in socio-cognitive attitudes of competitive surfers, will provide greater insight into the different attitudes of male and female surfers towards resistance training.

CHAPTER 3

Gender Differences in Physical Performance Characteristics of Elite Surfers

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3.1 Abstract

The purpose of this study was to describe and compare the gender differences in physical performance characteristics of elite surfers. Twenty competitive female surfers and twenty competitive male surfers performed a battery of physical performance tests: squat Jump (SJ), isometric mid-thigh pull (IMTP), 15 m sprint paddle and 400 m endurance paddle) during a single testing session. All performance measures were significantly different between competitive male and female surfers ($p < 0.01$). Specifically, male surfers produced greater peak force production (28.5%) and jumped higher (27.7%) in the SJ and produced greater normalised peak force during the IMTP (18.9%) compared to females. For paddling performance, male surfers were faster over 5, 10 and 15 m (12.4%, 9.7% and 10.9%), possessed a higher peak paddling velocity (11.3%), and recorded faster paddle times over 400 m (11.8%). The results of this study suggest that competitive male surfers exhibit superior physical performance characteristics than competitive female surfers, in relation to both the lower and upper body. Strength and conditioning practitioners should therefore implement a structured and periodised program to facilitate strength qualities that underpin surfing performance for all participants but as highlighted in the current investigation, female surfers that may have a greater window for adaptation, and therefore vast benefit of targeting their underdeveloped physical qualities.

Key Words: surfing, testing, comparisons, paddling, strength.

CHAPTER 4

Upper-Body Strength Measures and Pop-Up Performance of Stronger and Weaker Surfers

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4.1 Abstract

The primary purpose of this study was to investigate the reliability of the isometric push-up (IPU), dynamic push-up (DPU), and force plate pop-up (FP POP) as measures of upper-body isometric and dynamic strength qualities in surfing athletes. Furthermore, the study aimed to compare pop-up performance between stronger and weaker surfers. Eighteen female (n = 9) and male (n = 9) surfers (age = 28.1 ± 6.4 yrs, mass = 69.6 ± 10.4 kg, height = 172.5 ± 6.7 cm) completed a battery of upper-body strength assessments, of which exhibited high between-day reliability: (IPU, (CV% = 4.7, ICC = 0.96), DPU (CV% = 5.0, ICC = 0.90), FP POP (CV% = 4.4, ICC = 0.90). Participants were subsequently split into stronger (n = 9) and weaker (n = 9) surfers based on normalised peak force (PF) attained in the IPU. Pop-up performance was measured both in the water and during the FP POP and was referred to as time to pop (TTP). Significant between group differences were observed for normalised PF during IPU (d = 1.59, $p < 0.01$) and DPU (d = 0.94 $p = 0.04$). Although not significant, there was a large magnitude difference in FP POP (d = 0.80, $p = 0.08$) and FP TTP (d = 0.85, $p = 0.07$). Significant correlations were identified between normalised IPU PF and normalised DPU FP ($r = 0.69$, $p = 0.03$) and FP TTP ($r = 0.73$, $p = 0.02$) in the stronger group. The weaker group exhibited a significant inverse correlation between normalised IPU PF and in water TTP ($r = -0.77$, $p < 0.01$). The results suggest improvements in pop-up performance may be elicited by improving dynamic strength for stronger surfers, whereas pop-up performance in weaker surfers may be elicited by improving maximum strength. The upper-body strength assessments provided a novel insight into strength qualities that are associated with in water performance of surfers (TTP).

CHAPTER 5

The Assessment of Isometric, Dynamic, and Sports-Specific Upper-Body Strength in Male and Female Competitive Surfers

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5.1 Abstract

The primary purpose of this study was to investigate gender differences in the dynamic strength index (DSI): an assessment of upper-body dynamic strength relative to maximal isometric strength. The secondary purpose was to investigate gender differences in the dynamic skill deficit (DSD): an assessment of sports-specific dynamic strength relative to maximal isometric strength, and its association with a sports-specific performance measure in surfers. Nine male (age = 30.3 ± 7.3 yrs) and eight female (age = 25.5 ± 5.2 yrs) surfers undertook three upper-body assessments: isometric push-up, dynamic push-up and a force plate pop-up to determine the DSI and DSD. The performance measure of time taken to pop-up (TTP) was recorded. No gender differences for the DSI (d = 0.48, $p = 0.33$) or DSD (d = 0.69, $p = 0.32$) were observed. Normalised peak force (PF) of the isometric push-up, dynamic push-up, and force plate pop-up were significantly greater in males ($p < 0.05$), with males recording significantly quicker TTP (d = 1.35, $p = 0.01$). The results suggest that male and female surfers apply a similar proportion of their maximal strength in sports-specific movements. However, greater normalised isometric and dynamic strength in males resulted in greater sports-specific PF application and a faster TTP. It would appear favorable that female surfers improve their maximal strength, to facilitate sports-specific pop-up performance.

Keywords: Assessment; Skill; Performance; Pop-up; Gender

CHAPTER 6

Gender Differences in Kinetic and Kinematic Performance Variables of the Countermovement Jump and Squat Jump in Competitive surfers

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CHAPTER 7

Gender Differences in Resistance Training Self-Efficacy and Outcome Expectancies in Elite Surfing Athletes

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CHAPTER EIGHT

Summary and Conclusion

Provides a summary of the research findings and poses suggestions for future research

8.1 General Summary

The overall purpose of this thesis was to examine the gender differences in physical performance characteristics of competitive surfers and the socio-cognitive factors that may influence them. The limited literature pertaining to the physical performance characteristics of competitive female surfers, warranted further investigation, with the need to quantify the current gender gap. The previous chapters have provided strength and conditioning practitioners with valuable empirical data, of which is summarised below.

Study One (**Chapter Three**) described the gender differences in physical performance characteristics of competitive surfers. In agreement with the studies hypothesis, significant gender differences were reported, with competitive male surfers jumping 27% higher, applying 18.9% greater normalized peak force in the IMTP, and paddling significantly faster over 5, 10 and 15 m (12.4%, 9.7%, 10.9%). This study was the first to quantify the gender gap of both upper- and lower-body physical performance characteristics of competitive surfers. The results highlight that male surfers possess advantageous physical characteristics specific to the sport of surfing. For example; male and female surfers train in the same environment, in which a faster sprint paddle would enable males to out paddle their female counterparts onto the wave face and result in an increased number of wave-rides, and hence provide greater opportunity for technical practice. Applying this knowledge, strength and conditioning coaches can now tailor training interventions to the specific needs of the female surfer, in order to optimise surfing performance. Based on the associations between 1RM upper-body pull-up strength and sprint paddle performance (Sheppard, McNamara, Osborne, Andrews, & Chapman, 2012) competitive female surfers should partake in training focused on increasing their pulling strength in order to improve their sprint paddle, allowing them to compete alongside their male counterparts when paddling onto the wave face.

Study Two (**Chapter Four**) investigated the reliability of an isometric push-up (IPU), dynamic push-up (DPU) and force plate pop-up (FP POP), as a measure of upper-body strength qualities, in competitive surfers. In line with the stated hypothesis, all three measures exhibited high between-day reliability, providing valuable data in an area of research that still lacks depth. In addition, the significant association between the FP TTP and in water TTP, illustrates that the lab-based performance measure is a valid assessment of in water performance. The study also aimed to compare upper-body strength and sports-specific pop-up performance between stronger and weaker surfers. A quicker pop-up by a competitive surfer, would allow for a more critical take-off, and an earlier transition onto the wave face. The finding that greater isometric and dynamic strength capabilities were significantly associated with a quicker TTP, provides a novel insight into the maximal and dynamic strength qualities that underpin a competitive surfer's pop-up performance. As such pop-up performance in weaker surfers may benefit from resistance training that targets an increase in maximal upper-body push strength, prior to dynamic force capabilities being of focus.

Study Three (**Chapter Five**) examined the gender differences in both the DSI and DSD, aimed at assessing upper-body dynamic and sport-specific strength, relative to maximal isometric strength. This was the first study to report an upper-body DSI in a female cohort, once again adding to an area of research that is still lacking depth.

Contrary to the study's hypothesis, no significant difference in either DSI or DSD was reported. However, the isometric and dynamic strength qualities underpinning both ratios were significantly greater in male surfers, facilitating sports-specific performance (TTP). The novel calculation of a DSD in this population, provides greater understanding of the strength qualities that underpin sports-specific performance, with an inverse association between DSD and maximal isometric strength identified in females. As such, competitive female surfers may be at a physical disadvantage with reduced maximal upper-body strength, resulting in a slower TTP. Together, the findings of Study Two and Three, suggest that competitive female surfers should aim to improve their maximal upper-body push strength, to enable greater sports-specific force application in the pop-up. Such increases in maximal upper-body push strength have been documented using both open and closed kinetic chain exercise, with closed kinetic chain exercises shown to increase throwing velocity in softball players (Prokoby et al., 2008).

Study four (**Chapter Six**) investigated the gender differences in both the kinetic and kinematic variables of the CMJ and SJ, in competitive surfers. In partial agreement with the hypothesis male surfers jumped higher in the CMJ and SJ, applying greater normalised concentric impulse. However, gender was not a determining factor in normalised PF, with no significant difference noted between male and female surfers. This was the first study to examine CMJ and SJ kinematics in competitive surfers. It was identified that competitive male surfers exhibited a greater countermovement depth, as characterised by greater hip and knee joint flexion, when compared to female surfers. Furthermore, the greater lower-body maximal strength of males, was found to increase SJ peak hip angular velocity. The varying jumping technique between genders warrants further investigation with the implementation of training modalities that encourage females to adopt a greater countermovement depth. An example of these modalities includes; traditional full ROM squat patterns and eccentric flywheel training, combined with lower body explosive strength training methods. However, it is noted that such change may occur with an increase in strength which poses a future area of particular research interest.

Study Five (**Chapter seven**) was the first study to explore gender differences in competitive surfers SE and OE towards resistance training. Moreover, this was the first study to report resistance training SE and OE in a competitive athlete cohort. The physiological adaptations evoked from resistance training have been well documented in the literature. However, if an athlete's SE and OE towards such training is low, engagement may be compromised, and therefore, the magnitude of positive adaptations will likely be limited. Contrary to the hypothesis, no significant difference in aggregated resistance training SE or OE were reported between the genders. However, competitive female surfers did exhibit a larger range in both scores, as apparent by the visible outliers being frequently females. Although these outliers were the minority, this is more often than not depicted as the "female experience" when questioning a female athlete's behavioural intention towards resistance training. Nonetheless, competitive surfer's resistance training SE and OE cannot be seen as global contributing factors in the gender differences in physical performance characteristics, in this cohort.

The collective findings of these five studies have provided valuable data in which to quantify the gender gap in the physical performance characteristics of competitive surfers. Analysing the gender differences in upper-body physical performance characteristics, it can be seen that male surfers paddle faster and at a greater PV, apply a greater normalised PF in a surf specific pop-up, and exhibited a quicker TTP. All of which would enable competitive male surfers to catch more waves, paddle faster onto the wave face, pop-up quicker and commence their wave-ride earlier. Based on these findings competitive female surfers would benefit from an increase in upper-body pull and push strength, to improve both sprint paddle and pop-up performance, respectively.

Examining the gender differences in lower-body physical performance characteristics, it can be seen that male surfers possess significantly greater lower-body maximal and dynamic strength, as displayed by increased IMTP PF, and a greater vertical jump height in both the CMJ and SJ. Further analysis of the CMJ and SJ indicate that competitive male surfers adopt a different jumping strategy compared to their female counterparts, with greater countermovement depth facilitating an increase in concentric impulse, and thus jump height. It appears that maximal lower-body strength may be an important factor in allowing the males to perform with a more efficient jumping strategy. The significant association previously reported between lower-body maximal and dynamic strength and the scoring of turning manoeuvres (Secomb, Farley, et al., 2015), further emphasises the important of these lower-body physical performance characteristic in competitive surfing performance. Moreover, the increased jump height by males may be a contributing factor in the greater frequency and completion of innovative and progressive manoeuvres above the lip of the wave. Interpretation of these findings, would suggest that competitive female surfer would benefit from improving maximal lower-body strength, through the implementation of training modalities that would enable them to undergo a greater countermovement depth and increase jump height.

It should be acknowledged that in every one of the aforementioned comparison studies there was as much within gender variability as between gender variability and specifically there was a substantial amount of overlap between genders, even when significance was discovered. Interpretation of these results highlights that gender may not always be a determining factor in strength and sport-specific performance differences between competitive male and female surfers. Overreaching generalization based on gender should likely be replaced with knowledge and interpretation of individual strength-training age or motor skill as potential cofounding variables instead of a relative vague assumption of these based on gender. With that stated however, it is apparent that many competitive female surfers still have a significant window for adaptation. As such, the implementation of targeted training programmes aimed at improving the physical performance characteristics required for competitive surfing could result in a substantial narrowing of the performance gap between genders but more importantly can maximise the overall competitive level and performance of female surfers.

8.2 Future Research

The aforementioned research has begun to address the current gaps within the literature. Despite this, there remains areas of research that warrant further investigation. The key areas highlighted are:

- The need to investigate if a structured resistance training programme facilitates upper-body strength capabilities and sports-specific performance. Study three (Chapter five), reported significant inverse associations between the DSD and normalized IPU PF in competitive female surfers (r = -0.73, p = 0.03), suggesting maximal isometric strength to underpin sports-specific dynamic strength capabilities. Thus, the implementation of a resistance training programme targeted at increasing maximal upper-body strength in competitive female surfers, may be favourable in eliciting meaningful changes in pop-up performance.

- The perceived gender differences in increased lower-body compression by competitive male surfers was validated by the findings of study four (Chapter six). Therefore, the competitive female surfers may benefit from the application of a tailored training programme incorporating training modalities that emphasise hip and knee joint ROM. Furthermore, future research efforts should examine if an increase in maximal lower-body strength in female surfers, will facilitate lower-body joint kinematics and thus vertical jump performance.

- Although no significant difference in resistance training SE and OE in elite competitive surfers, this is an area of research that is still limited and warrants further investigation regardless of gender. As strength and conditioning practitioners, we are focused on physical performance assessments, periodised programming, and measurable outcomes. However, research investigating the interplay of behavioural intentions, outcome expectancies and performance is sparse. Future research in surfing may benefit from continuing to investigate this, from a youth level to elite, identifying those with low resistance training SE and OE and applying the required intervention. It would also be of interest to examine how strength and conditioning coaches can most effectively deliver resistance training to athletes with low SE and OE.

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APPENDICES

Conference Abstract One

The meaningful use of sprint paddling data to determine surfer's strengths and weaknesses: A gender comparison

Parsonage, J., Secomb, J., Tran, T., Farley, O., Nimphius, S., Lundgren, L. & Sheppard, J. (2015). The meaningful use of sprint paddling data to determine surfer's strengths and weaknesses: A gender comparison. *Journal of Australian Strength & Conditioning*. *23*(6**)** 79-82.

Conference Abstract Two

The Isometric Push Up: What Degree of Elbow Flexion

Elicits the Greatest Peak Force

Parsonage, J., Secomb, J.L., Sheppard, J.M., Ferrier, B.K., Dowse, R.A., & Nimphius, S. (2016). The isometric push-up: What degree of elbow flexion elicits the greatest peak force. *Journal of Australian Strength & Conditioning. 24* (6.) 46.

Conference Abstract Three

Comparison of 2-D and 3-D Motion Analysis in the Calculation of Lower-Body Joint Angle: A Pilot Study

Parsonage, J., Secomb, J.L., Sheppard, J.M., Ferrier, B.K., Dowse, R.A., & Nimphius, S. (2017). Comparison of 2-D and 3-D motion analysis in the calculation of lower-body joint angle: a pilot study. *Journal of Australian Strength & Conditioning. 25*(6). 41.