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Master of Science (Sports Science)

Influence of Anthropometric and Upper Body Strength Qualities on Surfboard Paddling Kinematics

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ABSTRACT

Influence of Anthropometric and Upper Extremity Strength Qualities on Surfboard Paddling Kinematics

Joseph O.C. Coyne

Competitive surfing is an international professional water sport of which a key factor in performance appears to be surfboard paddling ability. Research on surfing performance is relatively novel and there is very limited data as to how anthropometric and upper extremity strength variables influence not just surfboard paddling but also surfing ability.

PURPOSE: The purpose of this research was threefold. The first purpose was to evaluate the reliability of Pull Up and Dip 1RM strength assessments, the ratio between the two exercises, and a surfboard endurance paddle assessment. The second purpose was to establish if there were discriminative factors between competitive and recreational surfers on these measures, and correlations between anthropometric, strength and paddling variables. The final purpose was to determine if upper extremity maximal strength training would improve surfboard paddling performance.

METHODS: Thirty-six male surfers (29.7 ± 7.7 years, 177.4 ± 7.4cm, 76.7 ± 9.9kg) participated in this research. Subjects performed a tempo and range of motion controlled 1RM Pull and Dip assessment followed by a timed

400m endurance paddle on 2 days with 7 days separating testing sessions. Reliability was assessed by Intra-Class Correlation (ICC), Percent Coefficient of Variation (%CV) and Typical Error (TE). These tests along with a 15m sprint paddle test and additional anthropometric assessments were evaluated to determine if correlations between tests existed and if there were any differences between competitive and recreational surfers. Subjects were then placed into either intervention or control groups with the intervention group training the Pull Up and Dip exercises three times per week for 5 weeks.

RESULTS: All performance measures were considered reliable (ICC 0.96, 0.97 and 0.99; %CV 2.22, 2.41 and 2.01 for Relative 1RM Pull Up, Dip and 400m paddle respectively). A relative 1RM dip : pull up ratio of 1.11 was established. Fat mass and relative arm span were both correlated with paddling speed across sprint ($p=0.02$ to 0.04 and 0.01 respectively) and with even greater statistical power for endurance ($p=0.01$ and <0.01 respectively) paddle bouts. Sprint paddling ability was correlated with relative 1RM Pull Up performance in the full cohort ($r=-0.41$ to -0.43) and with relative 1RM Dip performance in competitive surfers ($r=-0.71$ to -0.76). Significant differences between competitive and recreational surfers exist in relative arm span ($p<0.01$) and endurance paddle ability ($p<0.01$). Paddling performance in both sprint and with even greater statistical power for endurance efforts

improved as a result of maximal strength training with weaker subjects appearing to obtain greater benefits than stronger subjects (92-100% likelihood of practically meaningful difference; *d*=0.62-1.05).

CONCLUSIONS: Performance measures of 1RM Pull Up and Dip strength and endurance paddling are reliable when assessing upper extremity strength qualities in male surfers. Relative strength in the Pull Up and Dip are both correlated with sprint paddling ability. Significant differences in relative arm span and endurance paddling ability between competitive and recreational surfers appear to exist. Further, upper extremity maximal strength training can improve paddling ability in surfers; and especially so in weaker surfers.

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load strength training is tough even for experienced strength athletes and all subjects acquitted themselves superbly. Again without the staff and subjects who volunteered their time, this series of studies would not have been possible.

Lastly my wife Daegan is deserving of my most heartfelt love and appreciation. Without her belief and support, I would be half the man I am today.

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LIST OF ABBREVIATIONS AND DEFINITIONS

1RM: One repetition maximum.

UE: Upper Extremity

CKC: Closed kinetic chain

OKC: Open kinetic chain

Sum7: Sum of 7 skinfolds as measured by ISAK qualified practitioner

Reliability: The degree of consistency of a measurement.

Validity: Whether or not a test is actually measuring what it is supposed to measure.

CHAPTER 1: INTRODUCTION

1.1 Purpose of the Study

Surfboard paddling appears to be an important aspect of surfing competition. A high paddling velocity enables surfers to gain positional advantages over competitors during heats and ensures a fast entry speed into waves. This enhances the opportunity for the execution of a greater amount of manoeuvres that will increase the judges' score (Loveless & Minahan, 2010; Mendez-Villanueva & Bishop, 2005; Mendez-Villanueva et al., 2005; J. M. Sheppard et al., 2012). The outcomes of this research will help inform sport scientists and strength and conditioning coaches to structure physical testing and preparation of both elite and non-elite surfers for surfboard paddling performance. It will also provide a logical foundation to base further research for other upper extremity (UE) closed kinetic chain (CKC) dominant sports such as swimming and kayaking. At present, reliable testing procedures for UE CKC maximal strength have not yet been established, nor has the reliability of endurance measurement in the specific context of surfboard paddling been determined. As such best practice guidelines for testing and determining strength and conditioning priorities based on diagnostic ratios such as pressing and pulling strength from tests for surfers has not been fully developed. The outcomes from this study will help establish a basis for all three of these elements.

1.2 Background to the Research

A reliable and accurate assessment of speed, strength and endurance are key factors in strength and conditioning and sport science. Subsequently, it is of utmost importance that an appropriate testing system be used to i) assess performance on a reliable and meaningful basis and ii) through these assessments, evaluate the effectiveness of particular strength and conditioning interventions.

However, there seems to be a paucity of information regarding the assessment of UE maximal strength (especially in consideration of CKC strength exercises like the Pull Up and Dip) and the translation of these measures into appropriate training prescriptions for athletes. Therefore, the initial phase of this research was the determination of specific protocols for two UE CKC strength assessments: i) the Pull Up and ii) the Dip. Furthermore, because strength and conditioning for surfing as a sport is a relatively new phenomenon, the establishment of reliable testing protocols to appraise performance in a surfing specific context have not been fully established. The second phase of this research was assessment of the reliability of an endurance measure of surfboard paddling (400m paddle time trial). The third phase of this study was an investigation of the relationships between anthropometric, UE strength and surfboard paddling variables in competitive

and recreational surfers and to assess if any meaningful differences exist between the two levels of ability. The final phase of this research was an examination of the influence that improvements in UE CKC maximal strength brought about by a specific training intervention have on surfboard paddling in both competitive and recreational surfers.

1.3 Significance of the Study

Upper Extremity (UE) pressing and pulling strength are both vital for success in many sports. Therefore testing UE strength is considered an integral component of a complete athletic testing profile. Although open kinetic chain (OKC) UE strength tests and associated protocols are common, CKC UE tests are less so.

OKC exercises may be described as a combination of successively arranged joints where the terminal segment can move freely e.g. when an athlete applies force, the segment will move (Ellenbecker, 2001). Specific exercise examples of this relating to UE in strength & conditioning include the lat pulldown and bench press. CKC exercises are the opposite of OKC exercises in that the terminal segment cannot move freely or is restrained e.g. where an athlete applies force does not move (Ellenbecker, 2001). Examples of this relating to the UE include the pull up and dip. A CKC strength exercise assessment may possess greater context validity for some sports that

predominately involve CKC neuromuscular activity (Bulgakova NZ, 1990). Hence it is worthwhile to examine the utility of the pull up and dip as CKC measures of UE maximal strength.

In regards to the surfboard paddling specific context of this study, sprint and endurance paddling ability is highly likely to be a very relevant physical quality when assessing paddling ability for surfing performance. Although a sprint paddle assessment has been established(Coyne, 2011), a reliable and valid measure of endurance paddling ability is worthwhile to examine. In regard to strength context of this study, paddling actions (surfboard, paddleboard, swimming) the athlete 'pulls' and then 'pushes' their body over and through the water surface. This means that their distal segment (e.g. hand) is fixed. By definition, this makes it a CKC activity (Ellenbecker, 2001; Kibler, 2000) or at the very least a quasi-CKC activity when accounting for fluid movement around the hand. As mentioned above, CKC strength exercises may be more appropriate for both assessment and training purposes in surfing due to the greater context validity.

The analysis of correlations and differences in anthropometric, UE strength and surfboard paddling variables alongside the impact that increases in UE maximal strength has on surfboard paddling speed and endurance can be

used as a theoretical basis for the development of training interventions that concentrate on specific areas of deficiencies in athletes.

1.4 Research Questions

1) Will performance measures in the CKC UE maximal strength tests and the endurance paddling (400m time trial) test be reliable?
2) Do anthropometric and UE strength variables correlate with paddling ability (both speed and endurance) and are there significant differences between competitive and recreational surfers in anthropometric, UE strength and paddling abilities?
3) Does an UE CKC maximal strength training intervention provoke improvements in paddling speed and endurance in competitive and recreational surfers?

1.5 Hypotheses

The following hypotheses were tested:

1) Assessing UE strength qualities has been shown to be reliable (Cotten, 1990; McMaster, Gill, Cronin, & McGuigan, 2014; Pallares, Sanchez-Medina, Perez, De La Cruz-Sanchez, & Mora-Rodriguez, 2014; Pate, Burgess, Woods, Ross, & Baumgartner, 1993; Peyer, Pivarnik, Eisenmann, & Vorkapich, 2011a; Young,

Haff, Newton, & Sheppard, 2014) as has assessing surfboard paddling sprint performance (Coyne, 2011). Therefore, it is theorized that performance variables in UE strength tests (i.e. pull up and dip) and a surfboard paddling endurance test (i.e. 400m time trial) will all be reliable. Additionally, it is hypothesized that the surfboard paddling endurance test will have a greater discriminative ability to distinguish between surfers of different abilities than previous surfboard paddling tests (e.g. stationary paddle ergometer) (Loveless & Minahan, 2010; Meir, Lowdon, & Davie, 1991; Mendez-Villanueva et al., 2005) due to a higher context validity and replication of the kinetic chain used in paddling (e.g. CKC). If so, this test will be demonstrated to be superior and preferable for assessment of surfing athletes.

2) Anthropometric research on surfing athletes has shown arm span, body fat and mesomorphy to be related to surfing ability and surfboard sprint paddling ability (Barlow, Findlay, Gresty, & Cooke, 2014; J. M. Sheppard, McNamara, P., Osborne, M., Andrews, M., Oliveira Borges, T., Walshe, P., & Chapman, D.W., 2012). Therefore it is hypothesized that there will be high correlations with surfboard paddling ability (in both endurance

and sprint ability) and anthropometric variables. It is also hypothesized that there will be significant differences in anthropometric variables between competitive and recreational surfers. Previous researchers have also found correlations between relative UE strength and paddling speed (J. M. Sheppard et al., 2012). Combined with the high correlation between muscular strength and power and freestyle swimming performance (Costill et al., 1985; Hawley & Williams, 1991; Hawley, Williams, Vickovic, & Handcock, 1992; Sharp, Troup, & Costill, 1982; Swaine, 2000; Zampagni et al., 2008) (which possesses a number of biomechanical similarities with surfboard paddling (Carter J.E.L. and Ackland, 1994; Carter, 1982; Zampagni et al., 2008)) it is postulated that surfers who possess higher relative UE maximal strength will paddle faster than those who have less relative UE maximal strength.

3) Improving muscular strength qualities has been demonstrated to have a positive impact on freestyle swimming performance across a range of distances (Aspenes, 2009; Girold, Maurin, Duguâ, Chatard, & Millet, 2007; Halet, Mayhew, Murphy, & Fanthorpe, 2009; Tanaka & Swensen, 1998; Toussaint & Vervoorn, 1990; Trappe & Pearson, 1994). Due to the

aforementioned biomechanical similarities between surfboard paddling and freestyle swimming performance (Carter J.E.L. and Ackland, 1994; Carter, 1982; Zampagni et al., 2008) and the high correlations with relative UE strength and surfboard paddling ability(J. M. Sheppard, McNamara, P., Osborne, M., Andrews, M., Oliveira Borges, T., Walshe, P., & Chapman, D.W., 2012), it is hypothesized that the use of an UE CKC maximal strength intervention will improve surfboard paddling ability; particularly in sprint paddle performance.

CHAPTER 2: LITERATURE REVIEW

2.1 *Introduction*

This literature review is comprised of four sections. The first section is an exploration of the literature focusing on the nature of competitive surfing and determinants of performance in competition; in particular paddling ability. The second section is a review of studies focusing on establishing reliability and validity for new testing procedures and the ensuing influence they can have on training programs. The third section is an examination and critique of current research relating to the potential influence of anthropometry and strength on surfboard paddling ability. Research supporting the need to implement strength training in athletes will also be reviewed in this section. In the final section a framework is provided detailing how previous research has provided a basis of rationale for the completion of the present research project.

2.2 *Competitive Surfing and Determinants of Performance*

Competitive surfing is an international professional water sport. Competitive surfing success is determined by judging criteria that evaluates the surfer's ability to catch and ride the best waves while executing innovative and athletic manoeuvres in the most critical parts of the wave (i.e. closest to where the wave is breaking). Surfing competitions take place in a variety of

ocean conditions. The type of wave (i.e. reef, sand, point, beach), the weather and tide conditions at the time of each heat all influence the surfing activity significantly (Farley, Harris, & Kilding, 2011b; Meir et al., 1991; A. Mendez-Villanueva, D. Bishop, & P. Hamer, 2006). This is especially true of factors including the amount of waves caught, time spent riding waves, and time spent paddling.

Despite the variability of conditions, Time and Motion Analysis (TMA) of both competitive and recreational surfing reveals that surfing can be characterized as an intermittent sport (Farley et al., 2011b; Meir et al., 1991; Mendez-Villanueva & Bishop, 2005; A. Mendez-Villanueva, D. Bishop, & P. Hamer, 2006; A. Mendez-Villanueva et al., 2006; J. Sheppard, 2011). Reports from researchers analysing competitive surfing reveals paddling dominates the activity duration of competitive surfing heats with actual time spent wave riding to be surprisingly low (Farley et al., 2011b; Meir et al., 1991; Mendez-Villanueva & Bishop, 2005; A. Mendez-Villanueva et al., 2006; A. Mendez-Villanueva et al., 2006; J. Sheppard, 2011). For instance, Mendez-Villanueva (Mendez-Villanueva & Bishop, 2005) found wave riding duration to be only 3.8% of total surfing time in competition, whilst Meir's and colleagues (Meir et al., 1991) reported 5% in un-structured surfing (i.e. 'free surfing) and Farley's research (Farley et al., 2011b) 8% in competition. Meanwhile

paddling accounted for 44% (Farley et al., 2011b), 51.4% (Mendez-Villanueva & Bishop, 2005) and 54% (Meir et al., 1991) of heat time and no activity (i.e. stationary lying or sitting on board) represented 35% (Farley et al., 2011b), 42.5% (Mendez-Villanueva & Bishop, 2005) and 28% (Meir et al., 1991), respectively, of total time. Considering the three previous studies (Farley et al., 2011b; Meir et al., 1991; Mendez-Villanueva & Bishop, 2005) together, it appears that although competitive surfers are judged on their wave riding, it accounts for only a small portion of total activity, with about half of an entire competitive heat spent paddling.

The majority (~60% in Mendez-Villanueva's research (Mendez-Villanueva & Bishop, 2005) and ~80% in Farley's research (Farley et al., 2011b)) of the paddling bouts, are less than 20 seconds. Mendez-Villanueva & Bishop (Mendez-Villanueva & Bishop, 2005) found that ~25% of all paddling bouts were less than 10 seconds and ~35% between 10-20 seconds duration. Interestingly, Farley's research (Farley et al., 2011b) found that ~60% of all paddling bouts were less than 10s and ~20% between 11-20 seconds duration. The substantial differences in these two findings can be attributed to the aforementioned factors affecting competitive surfing heats (e.g. type of wave such as reef, sand, point, beach-break, as well as weather and tide conditions). However, in common is the large amount of relatively short,

repeated bouts of paddling, suggesting that surfing can be considered a sport requiring multiple short duration intermittent paddle efforts (Farley et al., 2011b; Meir et al., 1991; A. Mendez-Villanueva et al., 2006).

Reasons for such a high percentage of time spent paddling less than 20s is that competitive surfing involves paddling between the sets of broken waves (i.e. "getting out the back"), paddling to reposition in the take-off area, paddling to out-manoeuvre competitors or paddling to catch the waves. Sprint paddling appears to be an important aspect of surfing competition. High paddling velocity enables surfers to gain a positional advantage over other competitors during a heat and ensures fast entry speed into waves, enhancing the opportunity for the execution of a greater amount of manoeuvres that will increase the judges' score (Loveless & Minahan, 2010; Mendez-Villanueva & Bishop, 2005; Mendez-Villanueva et al., 2005; J. M. Sheppard et al., 2012). This has been reinforced by studies demonstrating competitive adult surfers being superior in sprint paddling when compared to competitive junior surfers (J. M. Sheppard, McNamara, P., Osborne, M., Andrews, M., Oliveira Borges, T., Walshe, P., & Chapman, D.W., 2012). It has also been demonstrated that peak sprint paddle power is a reliable discriminator between surfers of differing ability (Farley, Harris, & Kilding, 2011a; Mendez-Villanueva et al., 2005). This is likely because short

intermittent paddle bouts dominate activity characteristics of competitive surfing, sprint paddling power and speed, along with lower lactate levels at moderate and high paddle speeds, can differentiate between competitive and recreational surfers (Loveless & Minahan, 2010; Mendez-Villanueva et al., 2005) and between elite competitive surfers (Cámara, 2011; Farley et al., 2011a).

Bearing in mind the repeated effort and prolonged nature of surfing activity (Farley et al., 2011b; Meir et al., 1991; Mendez-Villanueva & Bishop, 2005), endurance paddling ability is also very likely to be a highly relevant physical quality (Mendez-Villanueva et al., 2005) when assessing paddling ability. Interestingly, the majority of previous studies have determined that neither maximal oxygen uptake nor endurance paddling measures are valid in discerning between competitive and recreational surfers (Loveless & Minahan, 2010; Mendez-Villanueva et al., 2005) nor between end of season rank in competitive surfers (Farley et al., 2011a). In opposition to these findings, Sheppard (J. M. Sheppard et al., 2013) found that endurance paddling (400m water based time trial) was a highly effective discriminator between an elite junior group of international competitors and competitive junior group of domestic surfing competitors ($p=0.08$, $d=0.9$). The disparity between the findings of Sheppard's group (J. M. Sheppard et al., 2013) and

others (Loveless & Minahan, 2010; Mendez-Villanueva et al., 2005) may be due to the method of assessment. A potential limitation in the previous investigations that did not find significant difference in endurance paddling ability between surfers of different abilities is that all used stationary paddle ergometers (i.e. Open Kinetic Chain and low context validity), whereas Sheppard (J. M. Sheppard et al., 2013) used a paddling time-trial in water (i.e. Closed Kinetic Chain and strong context validity) .

With this in mind, it could be suggested that competitive surfing is a sport requiring diverse physical qualities for explosive wave-riding manoeuvres. Competitive surfing also contains repeated bouts of sprint and moderate bouts of endurance paddling and these efforts appear to effect competitive outcome (J. Sheppard, 2011).

2.3 Assessment of Physical Qualities

Physical assessments can be used for a number of purposes. These may include talent identification, monitoring of training progress, and identifying specific physical qualities that are deficient relative to one another. With these lagging physical qualities, it appears to be crucial to address these in individual training programs to maximise athletic performance (G. J. Wilson & Murphy, 1996). A number of different tests can be used to diagnose i)

physical qualities that are deficient; ii) magnitude of deficiency in physical qualities; iii) physical qualities that are important for performance in the certain sport and iv) which physical qualities are changeable as a result of specific training (G. J. Wilson & Murphy, 1996). Different sports will require different levels of each physical quality and different athletes may also require different physical qualities (even within the same sport) due to an athlete's inherent capacities, current periodization or stage of athletic career.

The ability to accurately measure these physical qualities (i.e. strength, endurance) and determine meaningful performance changes in them requires assessment protocols to be valid, reliable and sensitive to any variations in performance influenced by training (Jeremy M. Sheppard, Chapman, & Taylor, 2011). Reliability can be described as the repeatability or reproducibility of a tested measure (William G. Hopkins, 2000). Whether an assessment can be deemed reliable depends upon the range of the practical measurement error (Thomas, Nelson, & Silverman, 2011; Vincent, 1995). There is significant discussion in the research as to the best approach to determining reliability. Test-retest reliability is the ability of a particular test to generate the same test results at different times under the same controllable conditions (William G. Hopkins, 2000). When evaluating variations in performance influenced by training, a test result must be interpreted with

respect to good relative (ICC) and absolute reliability measures (Typical Error of Measurement, TEM, and TEM expressed as percentage co-variance, % CV). While it is important to have high levels of both relative and absolute reliability, absolute measures of reliability may be more clearly understood by a strength and conditioning practitioner. For example, if variations in performance are greater than the TEM of a particular test then these variations could be considered worthwhile to note, giving the practitioner confidence that the change may be due to training or de-training, and unlikely to be attributable to measurement variability.

Validity can be described as the degree to which a test measures what it is designed to measure (R Enoka, 1988). Isoinertial tests are typically used to assess a physical quality like maximal strength because they involve exertion against gravity and so have high specificity to the real environment and are simple and inexpensive to implement. These tests allow strength and conditioning practitioners to accurately assess strength capabilities in movements that are biomechanically comparable to many athletic activities. Isoinertial tests normally require an acceleration and deceleration of a particular load (e.g. the subject's bodyweight and any external load in a 1 repetition maximum (1RM) pull up test). Isoinertial tests are seen as effective measures of an athlete's force producing capability, and because they

measure the desired assessment quality, these tests are generally deemed to be valid (Jeremy M. Sheppard et al., 2011; Tanner & Gore, 2012).

2.3.1 Upper Extremity Strength Assessments

Evaluation of upper extremity (UE) strength has long been considered an integral component of a complete testing profile for a large proportion of sports (D. Baker, 2001a, 2002a; D. G. Baker & Newton, 2004a; Pate et al., 1993). Many sports require athletes to be able to use the UE to apply large forces in both pressing and pulling actions. Certain sports demand sufficient strength to press and pull large external resistances in an open kinetic chain (OKC). An example of an UE OKC in sports is an athlete putting (throwing) the shot or wrestler throwing their opponent to the floor. Other sports entail athletes to possess significant strength in a closed kinetic chain (CKC) to move their own body around an implement or fixed point. Examples include a gymnast performing a manoeuvre on the high bar or a freestyle swimmer stroking through water. Therefore, both OKC and CKC pressing and pulling strength are vital for success in many sports; including endurance sports (Aagaard & Andersen, 2010; Hawley & Williams, 1991; Hawley et al., 1992; Storen, Helgerud, Stoa, & Hoff, 2008; Sunde et al., 2010b). Strength training seems to improve economy, efficiency and time to exhaustion at set work rates (e.g. maximal aerobic power) because the neuromuscular system is working at a lower relative load if strength is increased (Hoff, Gran, &

Helgerud, 2002; Hoff, Helgerud, & Wisloff, 1999; Millet, Jaouen, Borrani, & Candau, 2002; Storen et al., 2008; Sunde et al., 2010a), which aids endurance performance. Significant differences in UE strength in either movement could also limit the success of the athlete in these sports or could increase the chances of injury, such as muscle strains or tendon impingement e.g., bicep or rotator cuff (D. G. Baker & Newton, 2004b; McKean & Burkett, 2010). The magnitude of strength difference between movements may indicate a lack of functional range of motion around the shoulder joint, biomechanical stresses, lack of shoulder stabilisation through dynamic movement and/or poor antagonist-agonist strength ratios. All of these predispose the shoulder to injury and are normally considered and attended to by sports medicine professionals when trying to prevent or rehabilitate shoulder injuries (Cook, Gray, Savinar-Nogue, & Medeiros, 1987; Edouard et al., 2013; Escamilla & Andrews, 2009; Fleck & Falkel, 1986; Kibler, McMullen, & Uhl, 2001; Kolber, Beekhuizen, Cheng, & Hellman, 2009; Niederbracht, Shim, Sloniger, Paternostro-Bayles, & Short, 2008; Tonin, Strazar, Burger, & Vidmar, 2013). As such, it would seem advisable for strength and conditioning coaches and sports medicine professionals to assess UE strength when appropriate and correlate this with injury factors like history. It may also be appropriate to assess UE strength in the kinetic chain that is predominant in the athlete's chosen sport.

In strength and conditioning practice, OKC exercises can be defined as a combination of successively arranged joints in which the terminal segment can move freely e.g. when an athlete applies force, the segment will move (Ellenbecker, 2001). Exercise examples of this include leg extension, hamstring curl or DB bicep curl. Perhaps the most common UE maximal strength test is the barbell bench press (Alcaraz, Sanchez-Lorente, & Blazevich, 2008; D. Baker, 2001a; D. G. Baker & Newton, 2004b; D. G. Baker & R. U. Newton, 2006; Clemons & Aaron, 1997; Doan et al., 2002; McMaster et al., 2014; Pallares et al., 2014; Peyer, Pivarnik, Eisenmann, & Vorkapich, 2011b; Prestes et al., 2009; Segerstrom et al., 2011; Young et al., 2014). This test involves lowering a barbell resistance to the chest and then pressing the barbell back to arm's length.

CKC exercises are the opposite of OKC exercises in that the terminal segment cannot move freely or is restrained e.g. where an athlete applies force does not move (Ellenbecker, 2001). Examples of this in strength and conditioning include squat, push up or gluteal-hamstring raise. A CKC strength exercise and assessment may possess greater context validity for some sports. For example in swimming and paddling actions (surfboard, paddleboard) the athlete 'pulls' and then 'pushes' their body over the water surface e.g. their distal segment is fixed. This makes it a CKC activity (Ellenbecker, 2001; Kibler, 2000). As such, CKC strength exercises may be

better suited for athletes in these sports for both assessment and training purposes (Bulgakova NZ, 1990).

The most familiar CKC pressing exercise for testing maximal strength is possibly the parallel-bar dip. The dip involves an athlete supporting themselves on the parallel bars with extended arms and then lowering their body with elbow flexion and shoulder extension to a specified point before pressing their body and any external load back to the starting support position. Although the dip is used extensively by strength and conditioning professionals in the training of athletes, results for strength in the dip seem to be normally expressed as the maximum number of repetitions that can be performed with body weight (Collins, Silberlicht, Perzinski, Smith, & Davidson, 2014). As athletes in certain sports can perform a considerable number of repetitions in the dip with bodyweight, these types of tests may become tests of strength-endurance rather than maximum strength. As such, the author could not find any research on the reliability or protocols for use of the dip as a maximal strength test.

In regards to UE pulling, pull ups are one of the most commonly used UE exercises to develop and test pulling strength (D. G. Baker & Newton, 2004a; Cotten, 1990; Halet et al., 2009; McKean & Burkett, 2010; Negrete et al., 2010; J. M. Sheppard et al., 2012). Similar to the dip, the pull up is performed as a CKC. The pull up involves an athlete hanging off a bar in a

pronated grip (supinated variation for 'chin ups') and pulling a portion of their body up and over the height of the bar e.g. they may have to place their chin over the bar or even more demanding, touch their chest to the bar. Likewise for the dip, results for upper body pulling strength in the pull up are often stated as the maximum number of repetitions that can be performed with body weight (Peyer et al., 2011a; Trappe & Pearson, 1994) and as such become tests of strength-endurance rather than maximum strength (Collins et al., 2014; Peyer et al., 2011b).

The author was unable to find any research involving the assessment of maximal strength (e.g. 1RM) with the dip exercise. However, research using the pull up as an assessment of maximum strength has been performed with an array of protocols (D. G. Baker & Newton, 2004b; McKean & Burkett, 2010; J. M. Sheppard et al., 2012). There are important considerations to standardize in order to promote reliability. For example, differences in testing protocols include whether the test begins from a hanging position or from a flexed position i.e. beginning with an eccentric action or a concentric action (D. G. Baker & Newton, 2004a; J. M. Sheppard, McNamara, P., Osborne, M., Andrews, M., Oliveira Borges, T., Walshe, P., & Chapman, D.W., 2012), whether a controlled tempo or hold in the lengthened or flexed position was enforced, and different descriptors to determine the achievement of the flexed position. To the investigators' knowledge, no research has been

published which examines these factors, especially tempo of execution, in either the pull up or dip exercises.

2.3.2 Surfboard Paddling Assessments

Assessments that give meaningful insight into sporting performance and have high context validity are needed to assist sports and strength and conditioning coaches in their respective roles. Tests can help determine appropriate training regimes for an athlete or evaluate the effectiveness of a particular block of training.

In regards to surfboard paddling kinematics, Coyne and Sheppard (Coyne, 2011) have established a reliable protocol to assess sprint paddle ability. The sprint paddle test is performed in an outdoor 25m swimming pool. This allows for a simple outline of distances to the subjects, and for control of any potential effect of ocean conditions like tides and currents. Each subject performs the test on their own surfboard that they compete with and wears surfing board-shorts.

Subjects execute a paddling warm-up consisting of 200 m of low-intensity paddling, followed by a specific sprint paddling warm-up of 4 x 15 m sprint paddling efforts at 60, 70, 80, and 90% volitional effort on ~two minute intervals. After two minutes rest, the subjects complete two maximal effort

sprint-paddling time-trials (i.e. 2 x 15 m) to determine maximum sprint paddling performance. The sprint paddle efforts are commenced from a stationary, prone lying floating position.

Using a purpose-built horizontal position transducer (I-REX, Southport, Australia) attached to the back of each subject's boardshorts, kinematic data is gathered and stored for analysis. The position transducer data is stored as a time-stamp for each 0.02 m of displacement, thereby allowing determination of sprint times from the start to 5 m, 10m, and 15m, and by differentiation to calculate peak sprint paddle velocity. This procedure has been extensively validated (J. M. Sheppard et al., 2013).

As mentioned in Section 2.2, the majority of previous studies have used stationary paddle ergometers (Farley et al., 2011a; Loveless & Minahan, 2010; Mendez-Villanueva et al., 2005) to measure endurance paddling ability with only one study completing an endurance paddling test in the water(J. M. Sheppard et al., 2013). Of interest is that researchers using a water based 400m time trial paddle were able to effectively separate higher and lower performing surfers (J. M. Sheppard et al., 2013). The 400m time trial was performed over a 20m up and back course in the same pool, using 2 pool lane widths, so that non-stop paddling of 400m could be accomplished. The

paddling test was conducted with small buoy markers at both ends of the 20m distance. This meant subjects paddled 20m and completed a 180 degree turn at each end around the buoy, until 400m was completed. The time to finish the endurance paddle test was used for calculation of each subjects' average velocity and was intended to reveal endurance capabilities in the specific context of surfboard paddling. Just like the sprint paddle, each subject performs the test on their own surfboard and wears surfing boardshorts.

By definition, surfboard paddling is considered a CKC activity (Ellenbecker, 2001; Kibler, 2000; Sciascia & Cromwell, 2012) (i.e. the surfer 'pulls' their body over the water surface) rather than pulling the water surface toward them and remaining stationary. The OKC nature and low context validity of lab based endurance paddling ergometer assessments, along with the inability to separate higher and lower performing surfers, suggest limitations to non-water based endurance paddling tests. On the other hand, limitations to the water based endurance paddling test (400m time trial) used in previous research include a lack of reliability statistics which would allow a greater insight into determination of smallest worthwhile change data (J. M. Sheppard et al., 2013).

2.4. The Influence Of Physical Factors on Surfing

Physical qualities have been shown to have a number of influences on surfing and surfboard paddling performance. The qualities relevant to these series of studies can be broken down into anthropometrical and strength sections.

2.4.1 The Influence of Anthropometry on Surfing

As research on surfing performance is relatively novel, there is very limited data as to how anthropometric variables influence not just surfboard paddling but also surfing ability. In one of the first recorded studies investigating anthropometry and surfing ability, the researchers were unable to determine any significant correlations with anthropometric variables of competitive surfers and competition rank in the 1978 Bells Beach Surfing Championships (Lowdon, 1980). Similar research also found that male surfers (n=76) were predominately mesomorph or ectomorph somatotypes but there was no significant correlation between somatotype and competitive rank (Lowdon, 1983). More recent work from Barlow (Barlow et al., 2014) found significant correlations between ability, somatotype and skinfold measurements in a mixed ability level cohort (n=79, United Kingdom professional, national junior and intermediate as assessed by the Hutt scale (Hutt, 2001)), of surfers. This data suggests higher levels of muscularity and lower levels of body fat are associated with higher surfing skill. However when isolated to professional and junior national level surfers (e.g.

competitive surfers), these correlations with surfing ability were not significant (Barlow et al., 2014). These studies are in contrast to research by Sheppard (J. M. Sheppard et al., 2013) which found lower total skinfold sum and a higher Lean Mass Index (LMI) (Slater, Duthie, Pyne, & Hopkins, 2006) in Australian elite international junior competitors versus domestic junior competitors.

Although several researchers have suggested higher fat mass may be advantageous to surfers for thermal effect in cold water (Felder, Burke, Lowdon, Cameron-Smith, & Collier, 1998; Lowdon, 1980), a lower fat mass would seem to provide a more logical advantage in surfing due to a more efficient sequence of force production and absorption which relies on physical capabilities relative to body-mass (J. M. Sheppard et al., 2013). This has been demonstrated in many other sports (Gore, 2000). Other surfing anthropometric research has been carried out with the 2D:4D digit ratio. The 2D:4D measures the length of the second digit compared to the fourth and a low ratio is related to high prenatal testosterone and low prenatal estrogen. Significant associations between competitive surfing ability and a low 2D:4D ratio have been demonstrated in research (Kilduff, Cook, & Manning, 2011).

In regard to surfboard paddling ability, there is even less data on the effects of anthropometric variables on paddling speed and endurance. In the lone

study located that investigated these variables, Sheppard (J. M. Sheppard, McNamara, P., Osborne, M., Andrews, M., Oliveira Borges, T., Walshe, P., & Chapman, D.W., 2012) found arm span to have a significant correlation ($p<0.05$) with paddling speed over 5m and 10m ($r= 0.77$ and 0.67 respectively). Other variables including LMI and bodyfat skinfold measurements did not have strong associations with surfboard paddling ability. However, the authors of this study do note that the anthropometric correlations must be considered in the context of the study, which had a small range of skinfold thicknesses and LMI, and had a relatively low number of subjects ($n=10$). These factors are noted by the authors as possibly reducing the likelihood of finding an association between these measures and sprint paddling performance (J. M. Sheppard, McNamara, P., Osborne, M., Andrews, M., Oliveira Borges, T., Walshe, P., & Chapman, D.W., 2012).

To further the scope of the literature reviewed in regards to anthropometry, it is worthwhile considering freestyle swimming as it shares biomechanical similarities to surfboard paddling (Lavoie & Montpetit, 1986; Toussaint & Beek, 1992) and as mentioned, there is very little anthropometric studies completed on surfers. Height, arm span, body fat, seated height, brachial index (ratio of forearm to upper arm length), crural index (ratio of lower leg to thigh length), biacromial width, somatype and 2D:4D ratio have all been assessed with varying correlations to freestyle swimming performance (Carter

J.E.L. and Ackland, 1994; Carter, 1982; Zampagni et al., 2008). Of these height and arm span seem to be the most influential variables associated with freestyle swimming performance (Carter J.E.L. and Ackland, 1994; Carter, 1982; Zampagni et al., 2008).

2.4.2 The Influence of Strength on Surfing

It is generally accepted that success in most sports relies upon the achievement of a minimum level of maximum strength, power and speed (Newton & Kraemer, 1994). Examining this concept further, an athlete's strength level has been shown to be not only a valid discriminator between performance levels in sports and disciplines ranging from rugby league to ice hockey (D. Baker, 2001a, 2001b, 2002b; D. G. Baker & R. U. Newton, 2006; Peyer et al., 2011b) but also improving or maintaining strength is very influential in improving performance in sports; even in experienced athletes (Aagaard & Andersen, 2010; D. Baker, 1996; Hermassi, Chelly, Tabka, Shephard, & Chamari, 2011; J. M. Sheppard et al., 2007; Yamamoto et al., 2010). Of interest is that, improving strength levels in limbs not predominately used in the sport (e.g. increasing upper body strength in cycling) can still benefit sporting performance (Segerstrom et al., 2011). Of further note is strength training has a beneficial influence on endurance in a number of different exercise modalities and sports (Hoff et al., 2002; Hoff et

al., 1999; Ronnestad, Hansen, & Raastad, 2010; Storen et al., 2008; Sunde et al., 2010b; Yamamoto et al., 2008).

As surfing paddle speed (in both sprint and endurance) seems to be important for competitive outcome, there is a strong rationale to establish adequate levels of strength before developing other power and speed qualities (Cormie, McGuigan, & Newton, 2010a, 2010b, 2011; Nuzzo, McBride, Cormie, & McCaulley, 2008). This is especially pertinent to competitive surfing that has a relatively short history of strength training with most competitive surfers, even World Championship Tour competitors, having a very low strength training age (e.g. <1-2 years), if any at all.

To the author's knowledge, there are very few studies on correlations between strength and surfing ability. When developing a comprehensive testing protocol for competitive surfers, Sheppard's research (J. M. Sheppard et al., 2013) found a significant difference in the Isometric Mid-Thigh Pull (IMTP) peak force ($p=0.041$, $d=0.7$) between junior groups of international competitors (1802 ± 351 N) and domestic competitors (1531 ± 308). Only one study to date has examined any potential relationship between upper body strength and surfboard paddling speed. Sheppard et. al. (J. M. Sheppard, McNamara, P., Osborne, M., Andrews, M., Oliveira Borges, T., Walshe, P., & Chapman, D.W., 2012) found high correlations between

relative UE strength (1RM pull up) and paddle speed over 5 (r=0.94), 10 (r=0.93) and 15m (r=0.88) and peak velocity (r=0.66). In this study, UE relative pulling strength was also found to be superior when comparing the faster paddling group to the slower paddling group ($p \leq 0.05$), with a large effect size (*d*=1.88)(J. M. Sheppard, McNamara, P., Osborne, M., Andrews, M., Oliveira Borges, T., Walshe, P., & Chapman, D.W., 2012). We were unable to find any research investigating an UE pushing strength movement (e.g. dip) correlation with sprint paddling performance. Also no research on potential associations between UE strength and surfboard endurance paddling ability were found. It is also logical to acknowledge that there is a consistently high correlation between muscular strength and power and freestyle swimming performance (Costill et al., 1985; Hawley & Williams, 1991; Hawley et al., 1992; Sharp et al., 1982; Swaine, 2000; Zampagni et al., 2008), bearing in mind the considerable biomechanical similarities between freestyle swimming and surfboard paddling (Lavoie & Montpetit, 1986; Toussaint & Beek, 1992).

However despite the apparent strong correlation between strength and sprint paddling performance, this still does not indicate cause and effect. As yet it remains to be investigated whether improving strength qualities in the upper body will in turn improve surfboard paddling speed.

2.5 Summary and Implications of Literature Review

Competitive surfing can be described as a sport requiring a range of physical abilities for explosive wave-riding manoeuvres and repeated bouts of sprint and endurance paddling. Of note is that sprint and endurance paddling ability seem very likely to impact competitive outcome (J. Sheppard, 2011) and surfing ability (J. M. Sheppard et al., 2013).

There seems to be certain anthropometric variables (e.g. arm span, skinfold thickness) that are associated with higher surfing ability and faster paddling speeds. Of the other factors that influence paddling ability, UE strength seems to have a very high correlation with faster paddling speeds (J. M. Sheppard et al., 2012). This is consistent with studies on a number of other sports and athletic activities. However there is minimal research examining the effects UE strength has on surfboard paddling ability and this area requires more investigation.

It is important to examine UE strength with reliable and valid testing protocols. To give the UE tests as much context validity as possible, a replication of the biomechanics and kinetic chain used in surfboard paddling (e.g. CKC) would be desirable. This involves testing athletes with UE CKC exercises in both a push and a pull motion. Of the major UE exercises, the

pull up and dip best encompass the desired attributes of the test. Unfortunately, there is a lack of reliability data on testing maximal strength (e.g. 1RM) with the pull up and dip.

The next step is to discover or establish a valid and reliable testing protocol for surfboard paddling ability. Sprint paddling ability tests have been established as being reliable and effective in differentiating surfers of higher and lower ability. Most of the research on surfing paddling endurance has used laboratory tests on dry land using stationary paddling ergometers. This research has failed to demonstrate significant differences between surfers of greater or lesser talent. However when an endurance-paddling test is conducted in a pool (which replicates the kinetic chain movement and has high context validity), there seems to be reasonable effectiveness in discriminating ability amongst competitive surfers. However, the reliability of the pool-based endurance protocol is unknown.

The existing research on correlations between surfing, anthropometry and UE strength is limited and more investigations in this area seem worthwhile. Research examining the effects of maximal UE strength training on surfboard paddling speed is also required to examine if a causal relationship exists. Improvements in UE strength positively influences performance in a host of

other sports, including activities that are very similar to surfboard paddling, and it appears worthy of investigation to see if this also occurs with surfing paddling ability. As such, research based on an UE strength training intervention in surfers of different abilities is required.

It is notable that based on time motion analysis of surfing, there is a tremendous amount of sprint and endurance paddling that occurs as a natural part of surfing's recreational and competitive activity. Therefore paddle training for surfers is already occurring with large volume. Implications of this literature review suggest that the effects of an actual paddle training intervention (which seems to be the logical first step to investigate paddling ability) may not be worthwhile. This is especially relevant considering the lack of formalised strength training in surfing and a threshold level of strength required for success in most activities. Again this appears to give a sound rationale to examine the performance benefits of researching the effects of strength training as a priority as this is absent from the current strength and conditioning practices of surfers.

CHAPTER 3: METHODS

3.1 Subjects

Thirty-six male surfers (age 29.7 ± 7.7 years, height 177.4 ± 7.4cm, weight 76.7 ± 9.9kg) participated in this series of studies. Subjects were classified as either adult male competitive surfers (COMP) or adult male recreational surfers (REC). COMP consisted of adult male surfers who had competed in Australian open boardriders club competitions, World Qualifying Series (WQS) or World Championship Tour (WCT) events. REC consisted of adult male surfers who had a minimum of 4 years surfing experience. As an appropriate level of surfing expertise (e.g. elite level) was required for this study combined with the distinct lack of strength training in current surfing training practices, a defined level of strength training background was not a criterion for subject selection.

To investigate the amount of subject numbers needed to make the study viable, a comparison was made of the December 2011 Surfing Australia World Games selection camp athletes' paddle testing results. To complete this comparison, overall group 15m sprint and 400m paddle performance (average and standard deviations) were compared against the average of the 2nd, 3rd and 4th fastest times in the 15m from that same selection camp. Because of the large difference between the sample averages in the 400m paddle performance and the surprisingly high statistical power with absolute

400m paddle time, a comparison was also made with the selection camp's overall 400m average speed samples average/SD with a "predicted" 0.1m/s improvement in 400m average speed.

The 15m sprint statistical power calculations contained a sample average of 10.14s with a test value of 9.34s (SD +/- 0.94s). This meant that the subjects would be expected to improve their time by an expected 0.8s over the course of the study. At an acceptable alpha level of 5% and acceptable beta error level of 80%, a sample size of 10 would achieve a statistical power of 85.2%.

The 400m time trial statistical power calculations contained a sample average of 343.29s with a test value of 315s (SD +/- 24.06s). This meant that the subjects would improve their time by an expected 28.3s over the course of the study. At an acceptable alpha level of 5% and acceptable beta error level of 80%, a sample size of 10 would achieve a statistical power of 98.1%. As mentioned previously, because of the large expected improvement contained in the 400m statistical power calculations, 400m average speed was also used in a separate statistical power calculation with an expected 0.1s improvement. The 400m average speed calculations contained a sample average of 1.17m/s with a test value of 1.27m/s (SD +/- 0.08m/s). From this calculation, there would be a required sample size of 2, which would deliver a

statistical power of 99%. From these calculations a sample size of 10 per group was seen as more than sufficient.

From these calculations, a sample size of 10 was identified as being more than adequate to demonstrate significant relationships (e.g. statistical power greater than 80% at an alpha level of 0.05) between variables throughout the study (Version 3.1.1; G*Power, Kiel, Germany) (Faul, Erdfelder, Buchner, & Lang, 2009).

3.1.1 Conduct, Treatment and Testing of the Subjects

All the subjects received a clear explanation of the study. This included risks and benefits of participation. If after the explanation, the individual decided not to be included in the analysis it would not negatively affect any current or future competitive opportunities or team selection. All subjects, and their parent or guardian where necessary, provided written informed consent. The study procedures were approved by the Human Ethics Committee at Edith Cowan University, and procedures conformed to the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Subjects were put through a specific protocol on each day of testing. This protocol was identical on every assessment day in respect to exercise selection, test order, intensity and time. The three categories of tests were assessed in the following identical order: anthropometry, sprint paddle, UE

strength and endurance paddle. Randomisation of test order (e.g. endurance paddle before sprint paddle or UE strength assessments) may have potentially negatively influenced the subject's test results and as such was avoided. To avoid having lengthy waits for subjects on testing days, they were tested in groups of 3-4 staggered across the day. The subjects were tested at pre-determined times with the entire testing session lasting no longer than 90 minutes. Subjects were put through a familiarisation session prior to the initial testing session and testing was conducted at the same time of day on all test days. All testing was performed in the same facility (Surfing Australia High Performance Centre, Casuarina, Australia). Subjects were asked to follow their usual diet and hydration practices throughout the entire study or studies they were involved in. This included consuming the same meals and fluids at the same times before testing and not beginning any new sports supplement intake during the course of the study.

3.1.2 Anthropometry

All subjects were assessed for height, mass, relative arm span (arm span / height), relative seated height (seated height / height), relative biacromial width (biacromial width / height) and the sum of 7 skinfolds. The sum of 7 skinfolds was determined as the total of the measurement of triceps, sub scapulae, biceps, supraspinale, abdominal, quadriceps, and calf skinfold using a Harpenden skinfold calliper (British Indicator, United Kingdom). A composite ratio of body mass divided by the sum of 7 skinfolds was then

determined to reflect the amount of mass that is made up of lean tissue, termed the lean mass index (LMI) (J. M. Sheppard, Chapman, Gough, McGuigan, & Newton, 2009), modified from original methods (Slater et al., 2006) . All the tests were conducted by a practitioner certified by the International Society for the Advancement of Kinanthropometry whose Typical Error of Measurement (%TEM) was 2.4% for skinfold measurements and 0.3% for all other measures.

3.1.3 Sprint and Endurance Paddling

Paddle testing was performed in an outdoor 25m swimming pool. This allowed for simple outline of distances for the subjects, and control for the potential effect of ocean conditions such as tides and currents. Each subject performed the test on their own surfboard and wore surfing boardshorts.

Subjects performed a paddling warm-up consisting of 200 m of low-intensity paddling, followed by a specific sprint paddling warm-up of 4 x 15 m sprint paddling efforts at 60, 70, 80, and 90% volitional effort on approximately two minute intervals. After two minutes rest, the subjects completed two maximal effort sprint-paddling time-trials (i.e. 2 x 15 m) to determine maximum sprint paddling performance with the best of the two trials being their final result. The sprint paddle efforts were commenced from a stationary, prone lying, floating position.

Using a purpose-built horizontal position transducer (I-REX, Southport, Australia) attached to the back of each subject's boardshorts, kinematic data was gathered and kept for analysis on a personal computer (see Figure 1). The position transducer recorded a time-stamp for each 0.02 m of displacement, thereby allowing determination of sprint times from the start to 5 m, 10m, and 15m, a procedure that has been validated with surfboarding paddling in a pool (Coyne, 2011; J. M. Sheppard et al., 2013).

Figure 1. Horizontal position transducer (attached to boardshorts) and computer set up for data collection.

The timed endurance paddle test was performed over a 20m up and back

course in the same pool, using 2 pool lane widths, so that non-stop paddling of 400m could be accomplished. The paddling test was conducted with small buoy markers at both ends of the 20m distance. This meant subjects paddled 20m and completed a 180 degree turn at each end around the buoy, until 400m was completed, 10 laps up and back. (see Figure 2).

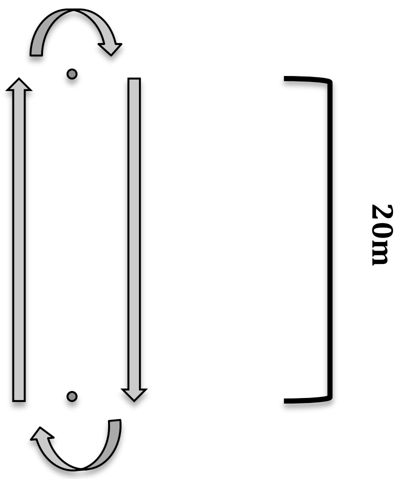

Figure 2. Outline of 400m timed endurance paddle test.

3.1.4 UE Strength

Subjects performed a generalized warm up consisting of callisthenic and dynamic stretching exercises, lasting 10 minutes. After the warm up, athletes commenced the Pull Up testing procedure first. This involved 5 repetitions with bodyweight followed by 4, 3, 2 and 1 repetitions with an increasingly greater external load. The external load was increased by suspending certified plate weights from a standard lifting belt worn around the waist for every decrease in repetitions. After these repetitions, the athletes performed only single repetitions with additional external load attached to their waists with 2–3 minutes of rest provided between repetitions. Once a failed lift occurred as defined by defined movement and tempo standards (outlined below), the successful weight lifted in the previous lift was recorded as the subject's 1RM. External load was increased by 1.25 to 10kg between sets depending on the strength level of the subject, speed of concentric

movement and relative body mass. This testing procedure was then repeated in the exact same manner for the 1RM Dip test.

Distinct anatomical markers and movement standards were identified to assist with evaluation of the subject's performance. For the pull up, the testing protocol entailed the subject holding a fully flexed shoulder with extended arms for 2s to eliminate any slight jumping off the floor, a lack of shoulder flexion or stretch shortening cycle activity e.g. kipping (a gymnastic maneuverer that produces SSC activity in the shoulder) before beginning their pulling action (see Fig. 3. pull up start position). To ensure a successful repetition, the subject's proximal inferior aspect of the mandible (see Fig 4. proximal inferior aspect of mandible) must have passed the horizontal plane of the pull up bar (e.g. the technique cue used was to "beach the jaw on the bar") (see Fig 5. end position of pull up). Subjects were then required to return to the initial position taking 4s to complete the repetition. Subjects were not allowed to swing, 'kip' or bounce out of the bottom ROM to generate elastic energy during the pull up. However they were allowed to flex their hip (e.g. raise their knees) to complete a successful repetition as long as the repetition met the range of motion and tempo standards.

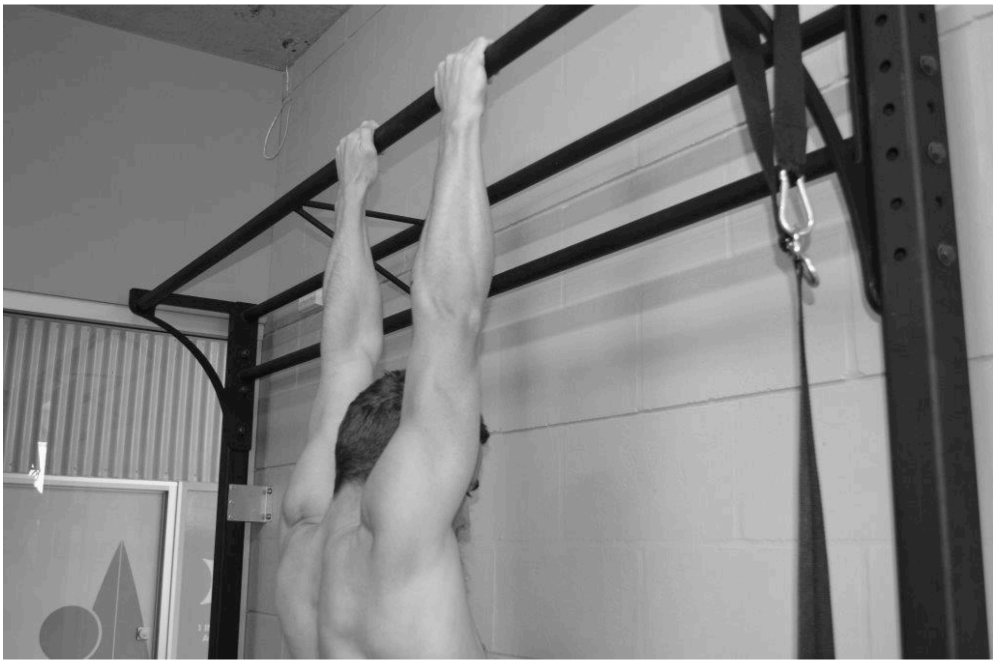

Figure 3. Pull up start position.

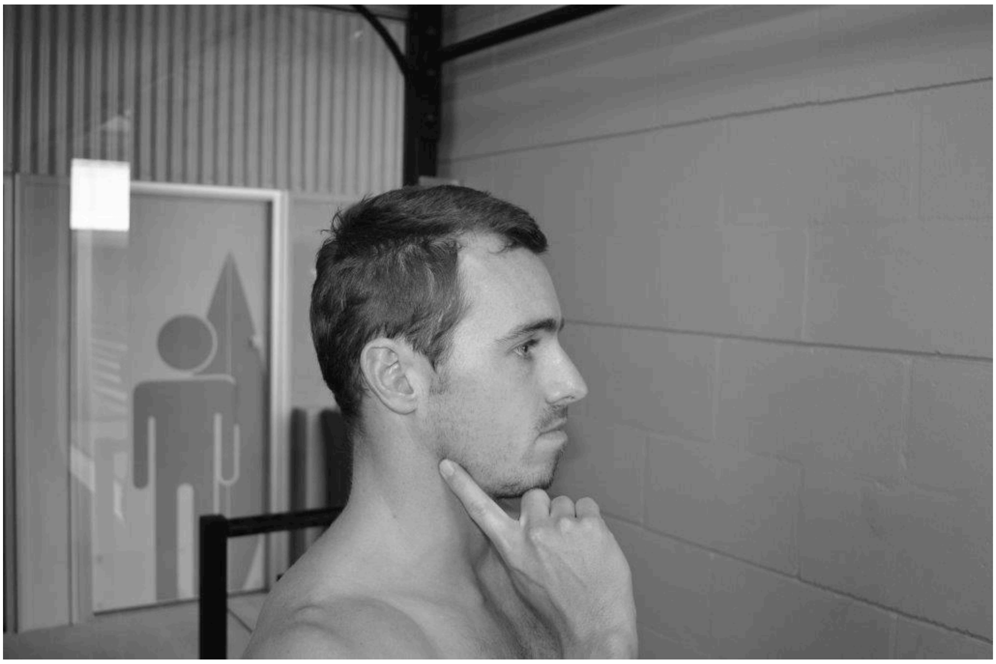

Figure 4. Proximal inferior aspect of mandible.

Figure 5. End position of pull up

For the dip, the testing protocol required the subjects to begin supported on the parallel bars in a fully extended elbow position (see Fig 6. dip start position). The parallel bars were adjustable so that subjects could choose their strongest preferred width of the bars. From this position, subjects lowered themselves over 4 seconds to a “depth” point where the bicep made contact with the forearm greater than the subject’s combined 2^{nd} and 3^{rd} digit width from distal biceps tendon (see Figure 7. depth marking on forearm and Figure 8. bottom dip position). This “depth” point was marked on each subject’s forearm. To complete the successful repetition, subjects were then required to return to the initial support position. As with the Pull Up, subjects were not allowed to swing, kip or repeatedly bounce out of the bottom ROM to generate elastic energy during the repetition. Again, they

were allowed to flex their hip (e.g. raise their knees) to complete a successful repetition as long as the repetition met the range of motion and tempo standards.

Figure 6. Dip start position

Figure 7. Depth marking on forearm

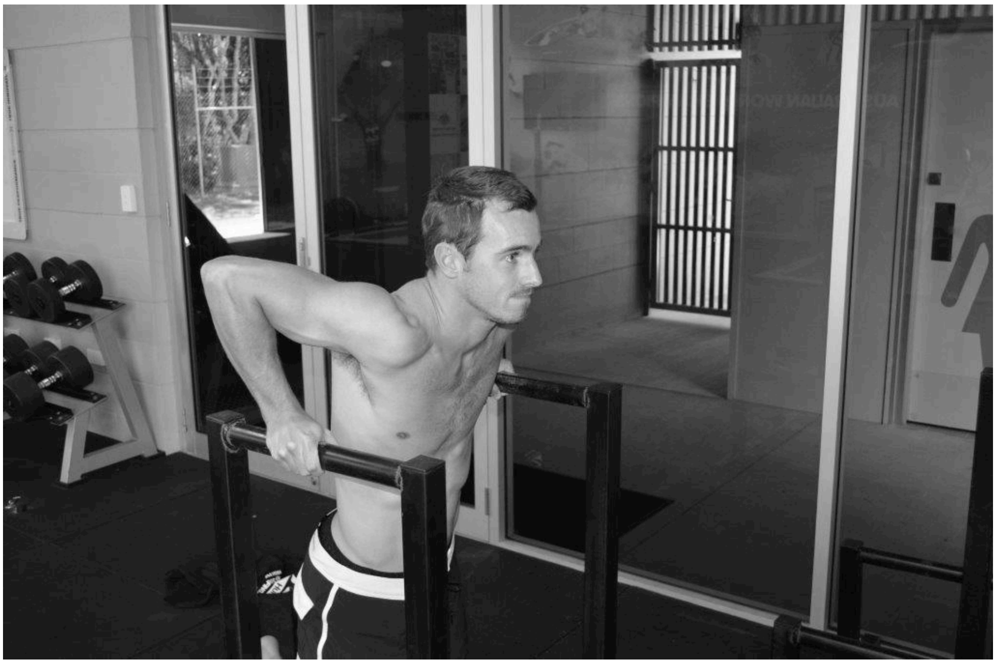

Figure 8. Bottom dip position

3.2 Study 1 - Reliability of Pull Up, Dip and 400m Paddle

Fifteen male surfers (age 27.8 ± 6.5 years, height 174.2 ± 10.1cm, weight 73.9 ± 9.8kg) participated in this study. Subjects were familiar with pull up and dip exercises, were surfers of varied ability levels (recreational to international competitors) and mixed resistance training experience (novice to greater than 10 years experience). Subjects were excluded if they had a recent history of UE orthopaedic disorders or were unable to complete the tests as prescribed.

Subjects were asked to refrain from resistance training 48 hours prior to both tests. To begin testing, subjects were weighed and then performed a generalized warm up consisting of callisthenic and dynamic stretching exercises, lasting 10 minutes. After the warm up, athletes commenced the UE strength testing procedure outlined in Section 3.1.4. The subject's results were determined by adding the subject's body weight to the external load lifted (absolute load 1RM) and then dividing that total load by bodyweight (relative 1RM).

Subjects then returned 7 days after the initial testing session to repeat this testing sequence of 1RM pull up followed by 1RM dip. The distinct anatomical markers and movement standards identified in 3.1.4 were used to assist with the evaluation of the subjects' performance and reliability of test-retest performance.

Reliability data was calculated by determining the Intra-Class Correlation co-efficient (ICC), Typical Error of Measurement, and Percentage Typical Error of Measurement (as co-variance, %CV) using Hopkin's methods(W. G. Hopkins, 2000b). Smallest Worthwhile Change (SWC) data was also calculated from the trial data as follows: 0.2 x Between Subjects Standard Deviation. A ratio between pull up and dip to assess symmetry of pushing and pulling musculature was also generated from the mean values of pull up and dip performance across trials.

3.3 Study 2 – Correlational and Discriminate Analysis

COMP and REC surfers were assessed to highlight differences in anthropometric, UE maximal strength and paddling between groups of surfers of different ability and to assess if correlations that were found across the cohort were also relevant to both COMP and REC surfers. Twenty nine male surfers (29.7 ± 7.7 years, 177.6 ± 7.0cm, 76.8 ± 10.3kg) participated in this study. Subjects were divided into COMP (n=13) or REC (n=16) groups based on level of surfing competitive history. As in Study #1, subjects were excluded if they had a recent history of UE orthopaedic disorders or were unable to complete the tests as prescribed. Subjects were guided through the anthropometric tests as described in 3.1.2. After this, they then performed the Sprint and Endurance Paddling and UE Maximal Strength Tests (and associated warm ups) as described in 3.1.3 and 3.1.4.

From the anthropometric measures, 1RM UE strength tests and paddling tests, a correlation analysis was performed on both COMP and REC groups and on the cohort as a whole. Comparisons of the difference between COMP and REC were determined using an independent paired t-test, with Cohen's effect size (d) applied to determine magnitude of any differences observed. For all means-based testing, minimum significance was considered to be achieved when $p \leq 0.05$, with a 90% confidence interval (CI).

3.4 Study 3 – UE Maximal Strength Training Intervention

After the correlation analysis was performed, a repeated measures study was designed to assess the impact of a 5-week maximal strength training intervention on the subjects' anthropometry and paddling ability. Nineteen subjects (age 29.7 ± 7.7 years, height 177 ± 7.9cm, weight 77.4 ± 10.9kg) were matched and then placed in a control (CONT) or training group (TRAIN) and to the greatest extent possible, also matched for age, strength, arm span, competitive surfing ability and paddling performance. As previously described in Study #1, subjects were excluded if they had a recent history of UE orthopaedic disorders or were unable to complete the tests as prescribed.

As with the previous investigations, subjects were guided through the anthropometric tests as described in 3.1.2. After this, they then performed the Sprint and Endurance Paddling and UE Maximal Strength Tests (and

associated warm ups) as described in 3.1.3 and 3.1.4. Subjects allocated to the TRAIN group then underwent a 5 week period of 3 upper body strength training sessions per week which were conducted with at least one days rest in between each session (i.e. non-consecutive days). In these sessions, subjects performed a general warm-up consisting of 5 minutes light skipping and a dynamic flexibility warm up (which is similar to warm up procedures before competitive surfing heats). Following 2-3 minutes rest, two sub-maximal preparatory warm-up sets (2-4 reps) were performed for pull ups and dips. Subjects then executed the following training protocol alternating between Day 1 and Day 2 for 18 exercise sessions:

Table 1. 5 week UE maximal strength training schedule

Day	Workout	Reps	Tempo	Rest
1	A1: Pull Up	5, 4, 3, 2, 1	4010	180s
	A2: Dips	5, 4, 3, 2, 1	4010	180s
2	A1: Dips	5, 4, 3, 2, 1	4010	180s
	A2: Pull Up	5, 4, 3, 2, 1	4010	180s

For the 5, 4, 3, 2, 1 repetition loading scheme we utilised a training load that was appropriate for each repetition and speed of execution (tempo). The tempo prescription is written in a four digit sequence with the first number representing the eccentric contraction period, the second number the pause before beginning the concentric contraction, the third number the concentric contraction period and the last number the pause before beginning the eccentric contraction. The alternation of the pull up and dip between days was designed to overcome any preferential learning effects between the two

strength exercises. It should be noted that this loading scheme was not an actual repetition maximum (RM) for each set (i.e. not true to failure training). For each repetition, it was a load that could be lifted with excellent technique at the correct tempo and was close to the maximum training weight for the subject at that particular time. The external loading scheme for the pull ups and dips required the subjects to add a small load (choice of 1.25kg or 2.5kg) to each working set's weight from Day 1 to Day 1 sessions and Day 2 to Day 2 sessions. For instance, if the subject completed 15kg, 20kg, 25kg, 30kg, & 35kg external loads for 5, 4, 3, 2, & 1 repetitions respectively on the previous Day 1, they would then attempt 16.25kg, 21.25kg, 26.25kg, 31.25kg & 36.25kg on the following Day 1. If they athlete could not complete all 15 repetitions successful, they stayed at this load until they could. This scheme allowed the subjects to progressively overload the resistance used and become accustomed to near maximal loads. It also conformed to the well-established criterion for improving relative strength with low repetitions (i.e. 1-6 repetitions) and multiple sets (3-10 sets) (Baechle, 1994; Zatsiorsky & Kraemer, 2006). This repetition protocol has been used to improve relative strength previously both anecdotally with elite athletes and by other experienced strength and conditioning coaches (Poliquin, 2005). Three minutes recovery was provided in the alternation between the pull ups and dips.

Aside from the training intervention, TRAIN subjects were also instructed to undertake normal activity levels with this being monitored using activity logbooks. This was so activity levels could be compared with the CONT group. At the onset of the study, subjects were also asked to provide a recall of surf volume leading up to the study for the fortnight prior. Due to the relative inexperience with structured strength training of the subjects, TRAIN subjects were also given an information sheet detailing expectations regarding training attendance/etiquette and also training with injuries (e.g. if the athlete hurt their knee, upper body sessions could still be completed).

Of the Study 3 training cohort (n=32), 9 subjects withdrew from the investigation through UE injury (n=1) or logistical reasons (e.g. travel, competitions) (n=6). The UE injury did not occur as a result of the training intervention. Additionally two subjects' results were excluded due to the particular subjects not meeting subject inclusion criteria. After the 5-week training period, the remaining subjects were retested in the anthropometric, UE strength and paddling tests as outlined previously. Differences between Paddling, Strength, and Anthropometric data between TRAIN and CONT groups of surfers were then assessed.

3.5 Statistical Analyses

In the first study, reliability data was calculated by determining the Intra-Class Correlation co-efficient (ICC), Typical Error of Measurement, and Percentage

Typical Error of Measurement (as co-variance, %CV) (W. G. Hopkins, 2000b). Smallest Worthwhile Change (SWC) data was also calculated from the reliability trial data using the following formula: 0.2 x Between Subjects Standard Deviation(William G. Hopkins, 2006). A ratio between pull up and dip to assess symmetry of pushing and pulling musculature was also generated from the mean values of pull up and dip performance across trials, and assessed for reliability.

In the second study, the anthropometric, 1RM UE strength and paddling measures were used to provide a Pearson correlation analysis on COMP and REC groups and on the cohort as a whole. Correlations were designated as trivial (0-0.1), low (0.1-0.3), moderate (0.3-0.5), high (0.5-0.7), very high (0.7-0.9) and practically perfect (0.9-1) (Batterham & Hopkins, 2006). Comparisons of the difference between COMP and REC groups were performed using an independent paired t-test, with Cohen's effect size (d) applied to determine the magnitude of any differences observed.

In the third study, Cohen's Effect Sizes (*d*) were also calculated to reflect the magnitude of any changes observed between pre and post intervention within and between groups. The Cohen's *d* values were considered with 0.2, 0.5, and 0.8 values demonstrating small, moderate, and large effect sizes, respectively (Cohen, 1988). Due to the number of subjects and the

involvement of high level athletes who perform a tremendous volume of paddling in surfing, reference change of likelihood data using Hopkin's methods (W. G. Hopkins, 2000a, 2002) was also calculated to give meaningful information on the practical effect of the strength training intervention. The precision of change in the measurements were based on the typical error of measurement from the reliability studies and the smallest worthwhile change expressed as likelihoods. These likelihoods were classified as "unlikely", "possibly", and "likely" with the probabilities being <25%, 26-74%, >75% respectively (William G. Hopkins, Marshall, Batterham, & Hanin, 2009). Similar to the first study, the probabilities that the differences in variables tested were substantial and worthwhile were calculated using 0.2 x between subject SD and expressed in absolute units, using practical inferences (William G. Hopkins, 2006).

These statistical procedures were also repeated for further analysis to investigate the effect of subject's initial strength levels on the UE maximal strength intervention group's paddling performance. The UE maximal strength intervention group was separated into stronger (>1.2 relative Pull Up) and weaker (<1.2 relative Pull Up) groups.

For all means-based testing, minimum statistical significance was considered to be achieved when $p \leq 0.05$, with a 95% confidence interval (CI).

CHAPTER 4: RESULTS

4.1 Study 1 - Reliability Study

The descriptive analysis, including means and SDs for the group along with the Intra-Class Correlation Coefficient, Typical Error of Measurement and % Co-Variance, and Smallest Worthwhile Change for the pull up and dip are presented in Table 2.

Table 2. Reliability of measures of Intra-Class Correlation Co-Efficient (ICC), Typical Error Of Measurement (TE), % Co-Variance (%CV) and Smallest Worthwhile Change (SWC) of absolute external load 1RM pull up, absolute external load 1RM dip, relative 1RM pull up and relative 1RM dip test in male athletes. 90% confidence intervals in parentheses.

	Trial 1	Trial 2	ICC	TE	%CV	SWC
Absolute Load 1RM Pull Up (kg)	105.48 ± 17.59	105.92 ± 17.97	0.99 (0.96-0.99)	2.11 (1.55-3.33)	2.22 (1.6-3.6)	3.52
Absolute Load 1RM Dip (kg)	116.75 ± 24.05	116.93 ± 22.85	0.99 (0.96-0.99)	2.72 (1.99-4.29)	2.41 (1.8-3.9)	4.81
Relative 1RM Pull Up	1.43 ± 0.15	1.43 ± 0.15	0.96 (0.89-0.99)	0.03 (0.02-0.05)	2.22 (1.6-3.6)	0.030
Relative 1RM Dip	1.58 ± 0.22	1.59 ± 0.23	0.97 (0.90-0.99)	0.04 (0.03-0.07)	2.41 (1.8-3.9)	0.045

The mean absolute and relative pull up to dip ratio for the cohort was 0.91 ± 0.10.

The descriptive analysis, including means and SDs for the group along with the Intra-Class Correlation Coefficient, Typical Error of Measurement and %

Co-Variance, and Smallest Worthwhile Change for the 400m Timed Endurance Paddle Test are presented in Table 3.

Table 3. Reliability of measures of Intra-Class Correlation Co-Efficient (ICC), Typical Error Of Measurement (TE), % Co-Variance (%CV) and Smallest Worthwhile Change (SWC) of 400m timed endurance paddle test. 90% confidence intervals in parentheses.

	Trial 1	Trial 2	ICC	TE	%CV	SWC
400m Timed Endurance Paddle Test (s)	446 ± 84.6	437 ± 80.5	0.99 (0.96-1.00)	9.21 (6.53-15.64)	2.01 (1.4-3.5)	16.92

4.2 Study 2 – Correlational and Discriminate Analysis

Significant correlations between anthropometric, UE maximal strength and paddling variables in the cohort and COMP group are presented in Table 4. Correlations between anthropometric, UE maximal strength and paddling variables for REC surfers are not displayed due to a lack of relevance to the study's aims.

Table 4. Significant correlations ($p<0.05$) between paddling, upper body strength and anthropometric variables in competitive and recreational surfers.

	5m	10m	15m	Pvel	400m
			POOLED		
REL Arm Span	-0.46	-0.45	-0.45	0.46	-0.57**
Sum7 Skinfolds	0.41	0.40	0.39	-0.42	0.48**
Rel 1RM Pull Up	-0.43	-0.42	-0.41	0.42	-0.33†
			COMP		
Sum 7 Skinfolds	0.71**	0.70**	0.68	-0.65	0.87**
Weight	0.70**	0.71**	0.70**	-0.67	0.75**
Rel 1RM Dip	-0.76**	-0.74**	-0.71**	0.66	-0.48†

** Denotes significance at $p<0.01$
† Denotes significance at $p>0.05$

Competitive surfers were significantly faster in all aspects of paddling variables (Table 2 and Figures 9, 10, 11). Competitive surfers also had a significantly longer relative arm span than recreational counterparts. Comparisons of the differences along with effect size between COMP and REC groups are presented in Table 5.

Table 5. Comparison of paddling, upper body strength and anthropometric variables between competitive (n=13) and recreational (n=16) surfers.

	COMP	REC	p value	d
5m (s)	3.88*	4.35	0.04	-0.82
10m (s)	6.86*	7.64	0.03	-0.87
15m (s)	9.86*	11.03	0.03	-0.91
400m (s)	364.93**	452.66	0.00	-1.36
REL Pull	1.24	1.29	0.32	-0.35
REL Dip	1.33	1.48*	0.03	-0.74
REL dip:pull	1.08	1.14	0.10	-0.59
Weight (kg)	76.18	76.98	0.81	-0.08
Sum7 (mm)	88.56	91.77	0.82	0.09
LMI	1.00	0.95	0.74	0.13
Height (cm)	176.89	177.72	0.72	-0.12
REL Sheight	0.51	0.51	0.46	0.29
REL Arm Span	1.04**	1.02	0.00	-1.16
REL BiWidth	0.24	0.22	0.11	-0.67

* Denotes significance at $p<0.05$
** Denotes significance at $p<0.01$

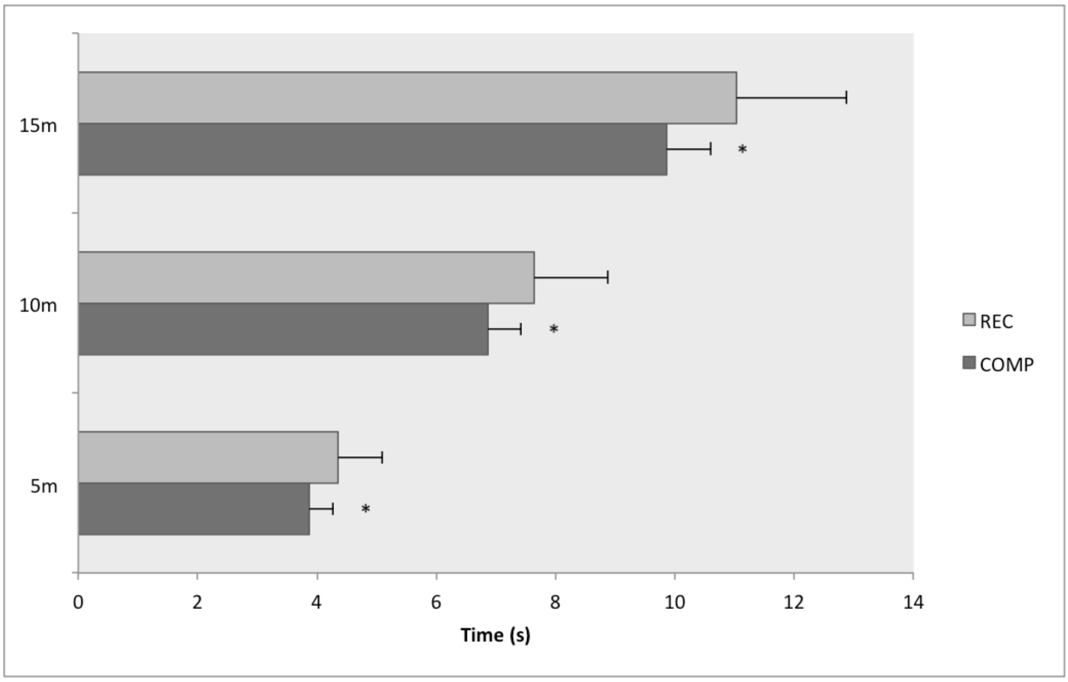

Figure 9. Sprint paddle kinematics in competitive (n=13) vs. recreational (n=16) surfers. 5m (p=0.05, d=0.82), 10m (p=0.04, d=0.87), 15m (p=0.04, d=0.91)

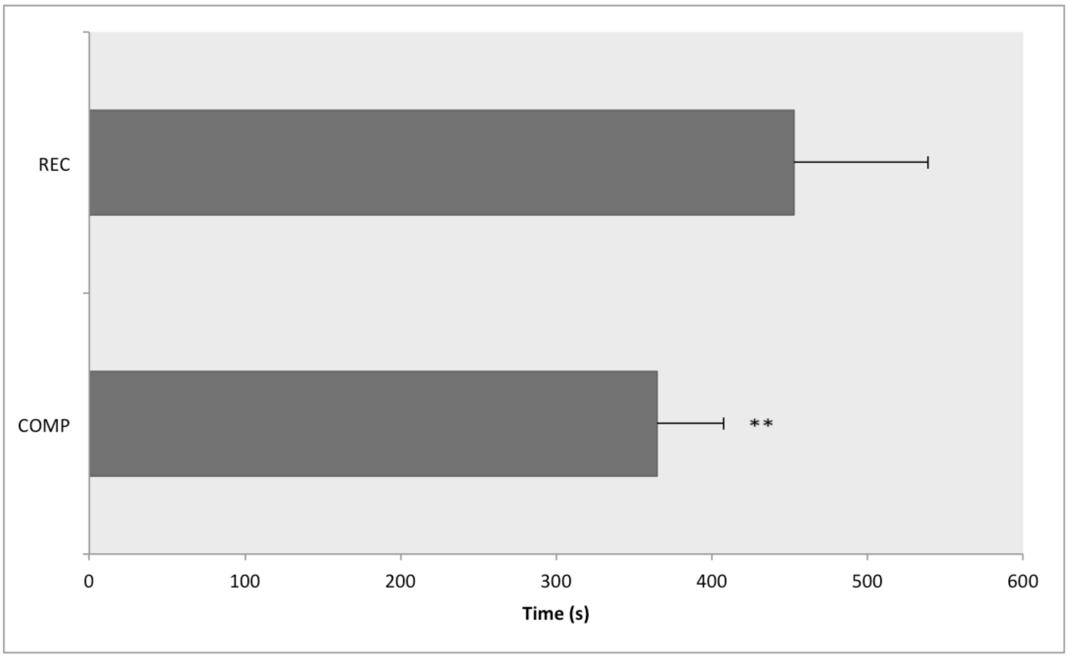

Figure 10. 400m time trial in competitive (n=13) vs. recreational (n=16) surfers. 400m (p=0.01, d=1.36)

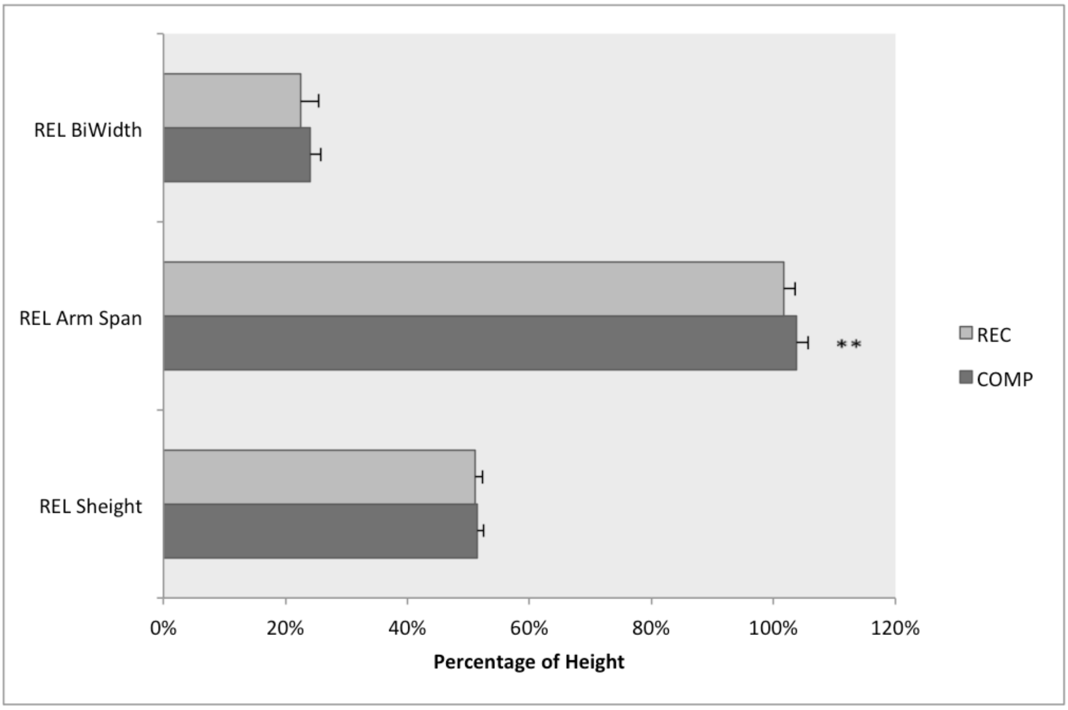

Figure 11. Relative biacromial width (REL BiWidth), relative arm span (REL Arm Span) and relative seated height (REL Sheight) in competitive (n=13) vs. recreational (n=16) surfers. REL BiWidth (p=0.11, d=-0.67), REL Arm Span (p=0.00, d=-1.16), REL Sheight (p=0.46, d=0.29)

4.3 Study 3 – UE Maximal Strength Training Intervention

The results of the UE maximal strength training intervention are displayed below. Between group and within group comparisons for both control and intervention groups have been presented. Stronger & weaker subject's results from the intervention group are also presented.

4.3.1 Maximal Strength and Control Groups Within and Between Group Comparisons

This section presents the results of the within and between group comparisons of both the Maximal Strength group and the control group.

Table 6. Within-group comparisons of the UE Maximal Strength Training Group from pre to post 5-week training period. Data are mean ± SD

	UE Maximal Strength Group (n=11)			Within Group Differences		
					Chances that the true differences are substantial	
	Pre	Post	Change	Effect Size	%	Qualitative
Body Mass (kg)	75.79 ± 13.0	76.55± 12.9	0.75 ± 1.33	0.06	0%	Unlikely
Sum7 (mm)	108.99 ± 39.67	98.46 ± 34.73	-10.53 ± 8.74	37.28	87%	Likely
5m (s)	4.32 ± 0.97	4.19 ± 0.53	-0.13 ± 0.49	-0.17	56%	Possibly
10m (s)	7.61 ± 1.57	7.5 ± 0.86	-0.11 ± 0.75	-0.09	49%	Possibly
15m (s)	11 ± 2.34	10.89 ± 1.25	-0.1 ± 1.17	-0.06	20%	Unlikely
400m (s)	455.05 ± 121.63	428.82 ± 84.92	-26.24 ± 43.79	-0.25	75%	Likely
Rel 1RM Pull Up	1.17 ± 0.15	1.24 ± 0.16	0.07 ± 0.06	0.45	89%	Likely
Rel 1RM Dip	1.33 ± 0.18	1.44 ± 0.19	0.11 ± 0.05	0.59	94%	Likely

Sum7 = sum of 7 skinfolds; 5m = time taken to sprint paddle 5m; 10m = time taken to sprint paddle 10m; 15m = time taken to sprint paddle 15m; 400m = time taken to paddle 400m; Rel 1RM Pull Up = relative 1RM Pull Up; Rel 1RM Dip = relative 1RM Dip.

Table 7. Within-group comparisons of the Control Group from pre to post 5-week training period. Data are mean ± SD

	Control Group (n=6)			Within Group Differences		
					Chances that the true differences are substantial	
	Pre	Post	Change	Effect Size	%	Qualitative
Body Mass (kg)	77.5 ± 2.38	77.34 ± 2.36	-0.16 ± 1.56	-0.07	0%	Unlikely
Sum7 (mm)	67.55 ± 25.51	65.87 ± 24.33	-1.68 ± 5.27	-0.07	1%	Unlikely
5m (s)	4.14 ± 0.38	4.26 ± 0.35	0.12 ± 0.10	0.33	10%	Unlikely
10m (s)	7.25 ± 0.56	7.43 ± 0.62	0.18 ± 0.28	0.30	9%	Unlikely
15m (s)	10.40 ± 0.79	10.66 ± 0.89	0.26 ± 0.47	0.31	1%	Unlikely
400m (s)	416.35 ± 39.64	413.5 ± 45.27	-2.85 ± 13.06	-0.07	16%	Unlikely
Rel 1RM Pull Up	1.29 ± 0.13	1.34 ± 0.14	0.05 ± 0.03	0.37	71%	Possibly
Rel 1RM Dip	1.39 ± 0.31	1.42 ± 0.31	0.03 ± 0.07	0.10	43%	Possibly

Sum7 = sum of 7 skinfolds; 5m = time taken to sprint paddle 5m; 10m = time taken to sprint paddle 10m; 15m = time taken to sprint paddle 15m; 400m = time taken to paddle 400m; Rel 1RM Pull Up = relative 1RM Pull Up; Rel 1RM Dip = relative 1RM Dip.

Table 8. Between-group comparisons of the UE Maximal Strength Training Group and the control group over a 5-week training period. Data are mean ± SD

	UE Maximal Strength Group (n=11)			Control Group (n=6)			Between Group Differences		
								Chances that the true differences are substantial	
	Pre	Post	Change	Pre	Post	Change	Effect Size	%	Qualitative
Body Mass (kg)	75.79 ± 13.0	76.55± 12.9	0.75 ± 1.33	77.5 ± 2.38	77.34 ± 2.36	-0.16 ± 1.56	-0.63	100 %	Likely
Sum7 (mm)	108.99 ± 39.67	98.46 ± 34.73	-10.53 ± 8.74	67.55 ± 25.51	65.87 ± 24.33	-1.68 ± 5.27	1.23	100 %	Likely
5m (s)	4.32 ± 0.97	4.19 ± 0.53	-0.13 ± 0.49	4.14 ± 0.39	4.26 ± 0.34	0.12 ± 0.1	0.71	87%	Likely
10m (s)	7.61 ± 1.57	7.5 ± 0.86	-0.11 ± 0.75	7.25 ± 0.56	7.43 ± 0.62	0.18 ± 0.28	0.51	74%	Likely
15m (s)	11 ± 2.34	10.89 ± 1.25	-0.1 ± 1.17	10.4 ± 0.79	10.66 ± 0.89	0.26 ± 0.47	0.4	87%	Likely
400m (s)	455.05 ± 121.63	428.82 ± 84.92	-26.24 ± 43.79	416.35 ± 39.64	413.5 ± 45.27	-2.85 ± 13.06	0.72	89%	Likely
Rel 1RM Pull Up	1.17 ± 0.15	1.24 ± 0.16	0.07 ± 0.06	1.29 ± 0.13	1.35 ± 0.14	0.05 ± 0.03	-0.42	59%	Possibly
Rel 1RM Dip	1.33 ± 0.18	1.44 ± 0.19	0.11 ± 0.05	1.39 ± 0.31	1.42 ± 0.31	0.03 ± 0.07	-1.32	88%	Likely

Sum7 = sum of 7 skinfolds; 5m = time taken to sprint paddle 5m; 10m = time taken to sprint paddle 10m; 15m = time taken to sprint paddle 15m; 400m = time taken to paddle 400m; Rel 1RM Pull Up = relative 1RM Pull Up; Rel 1RM Dip = relative 1RM Dip.

Anthropometry

The UE maximal strength group demonstrated an increase in body mass and reduction in Sum7 with moderate and large effect sizes respectively. There was also a 100% likelihood of changes in both body mass (Figure 12) and Sum7 (Figure 13) representing practically meaningful differences.

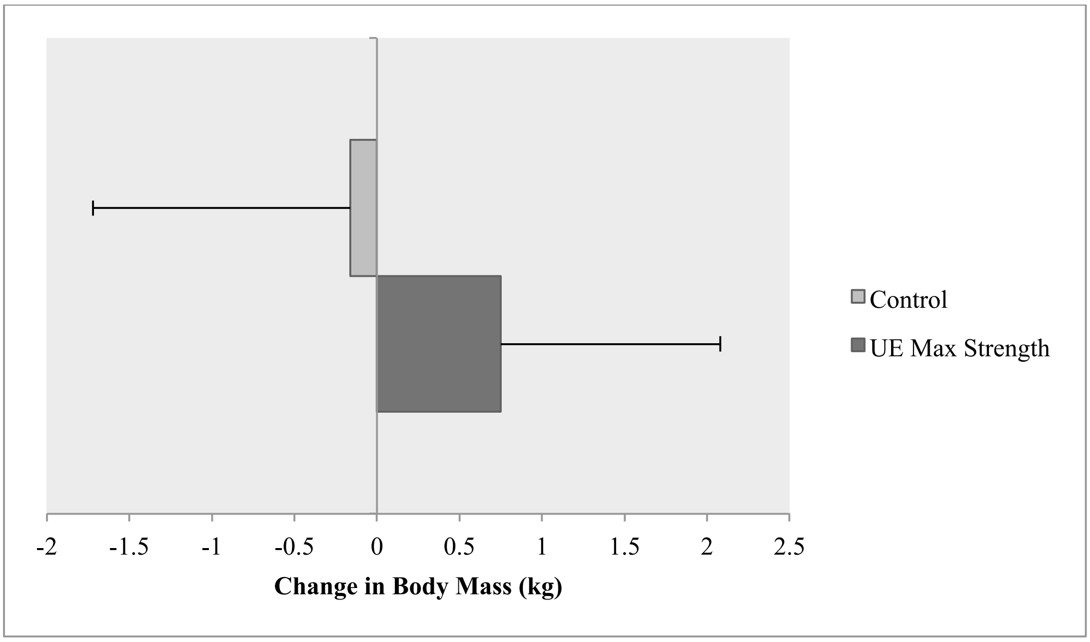

Figure 12. Change in body mass (kg) between an UE maximal strength intervention group and control group over 5 weeks.

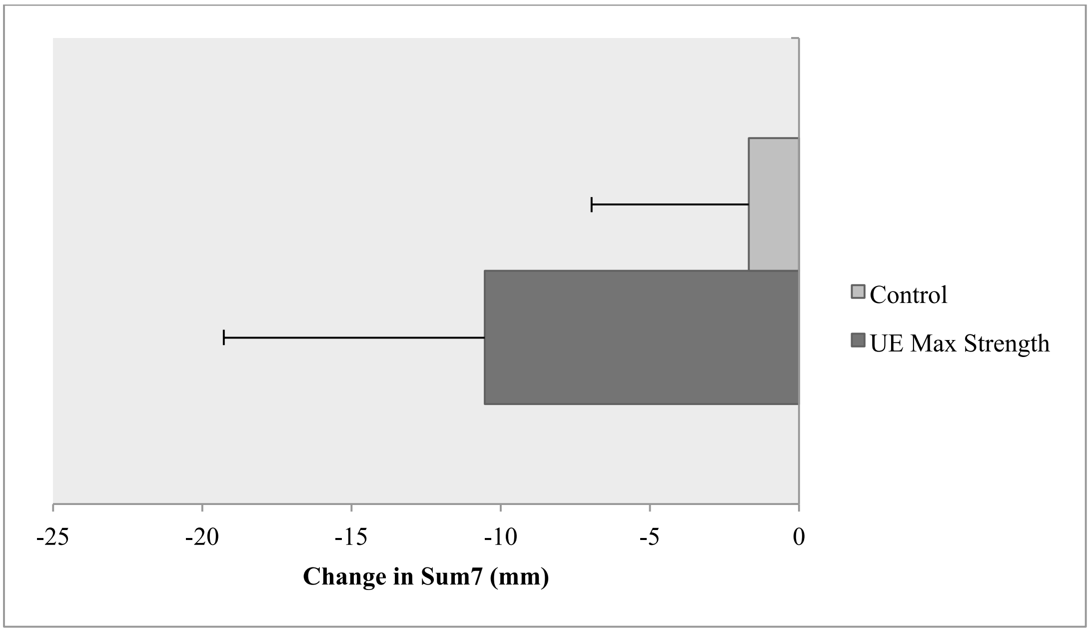

Figure 13. Change in Sum7 (mm) between an UE maximal strength intervention group and control group over 5 weeks.

Paddling Performance

The UE maximal strength group increased their speed over the 5, 10 and 15m while the control group got slower although these changes were not statistically significant. The odds that these were substantial true differences were 87%, 74%, 87% over 5, 10, 15m respectively between groups with a moderate effect size for the 5 and 10m and a small effect size for the 15m sprint paddle (Figure 14).

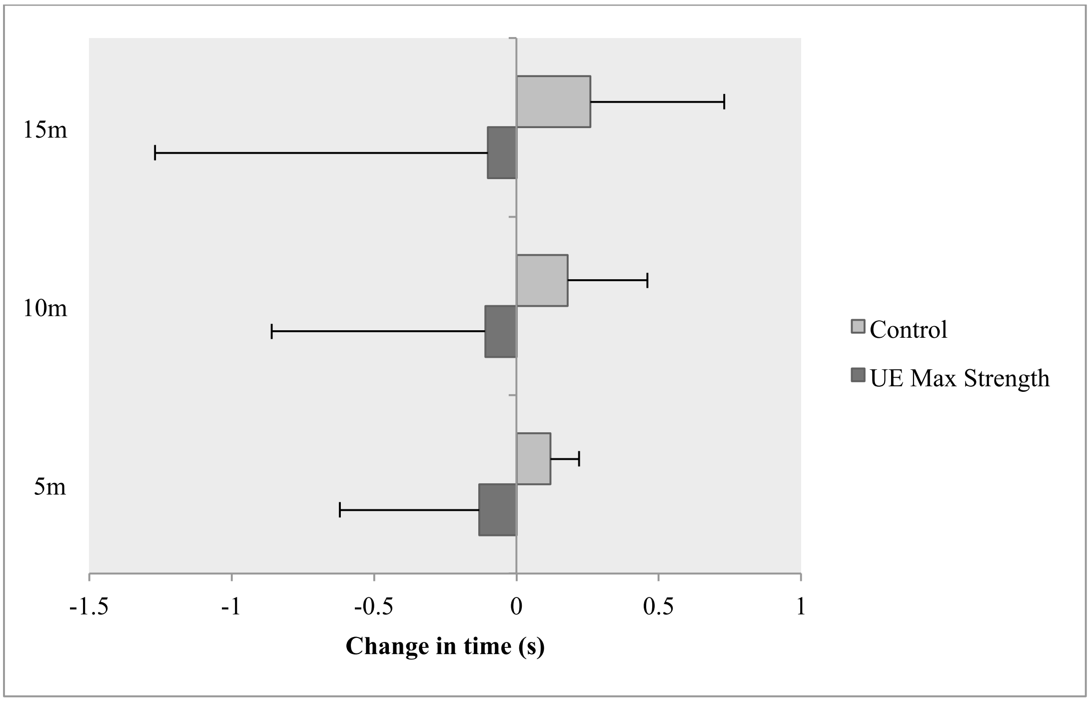

Figure 14. Change in sprint paddling performance between an UE maximal strength intervention group and control group over 5 weeks.

The UE maximal strength group also displayed a faster endurance paddling performance compared to the control group. The 89% likelihood of difference in the 400m Endurance Paddle with a moderate effect size between groups indicates a practically meaningful difference in this instance (Figure 15).

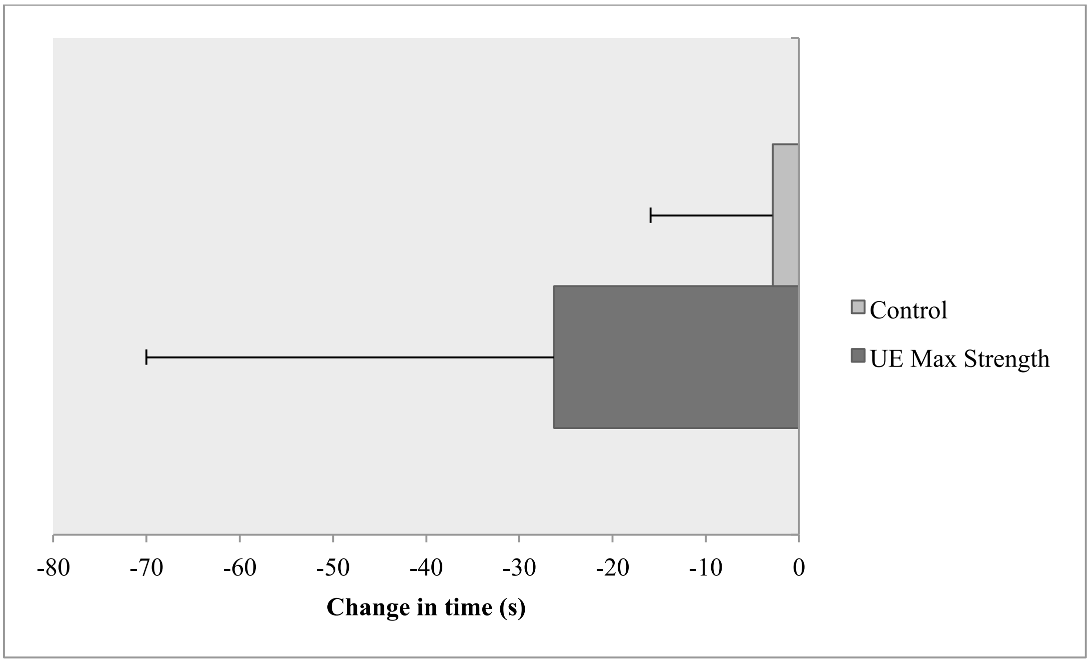

Figure 15. Change in endurance paddling performance between an UE maximal strength intervention group and control group over 5 weeks.

UE Maximal Strength

The greater improvement in relative 1RM Pull Up demonstrated by the UE maximal strength intervention group compared to control (Figure 16) resulted in a 59% chance the true difference was practically meaningful with a small effect size. There was an 88% chance the increase in 1RM Dip strength by the UE Maximal Strength group was a substantial true difference.

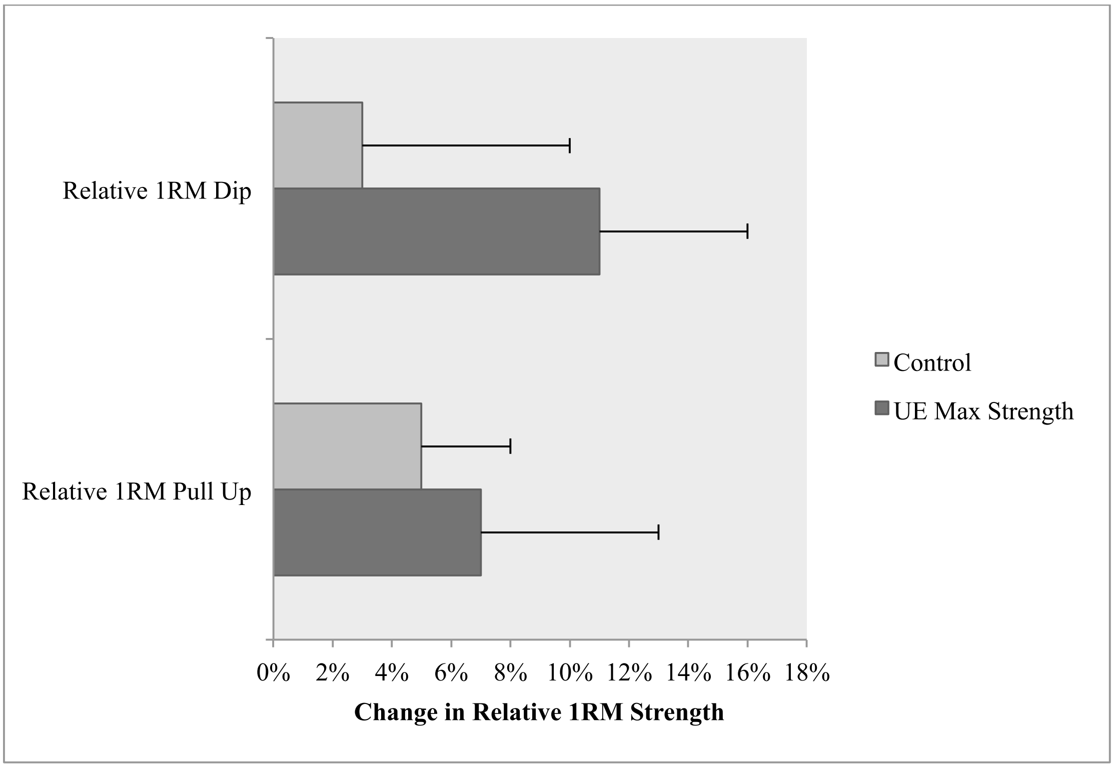

Figure 16. Change in relative pull up and dip 1RM strength between an UE maximal strength intervention group and control group over 5 Weeks.

4.3.2 Maximal Strength Intervention Stronger vs. Weaker Between Group Comparisons

Table 9. Between-group comparisons between the stronger and weaker subjects in the UE Maximal Strength Training Group over a 5-week training period. Stronger subjects are defined as having an initial Relative 1RM Pull Up > 1.2 and weaker subjects are defined as having an initial Relative 1RM Pull Up < 1.2. Data are mean ± SD

	Stronger (Rel 1RM Pull Up > 1.2) Group (n=5)			Weaker (Rel 1RM Pull Up < 1.2) Group (n=6)			Between Group Differences		
								Chances that the true differences are substantial	
	Pre	Post	Change	Pre	Post	Change	Effect Size	%	Qualitative
Body Mass (kg)	73.88 ± 5.39	74.19 ± 4.84	0.31 ± 1.54	77.38 ± 17.56	78.51 ± 17.43	1.13 ± 1.12	0.61	100%	Likely
Sum7 (mm)	94.84 ± 17.57	82.36 ± 10.96	-12.48 ± 9.79	120.78 ± 50.34	111.88 ± 42.91	-8.90 ± 8.32	0.39	100%	Likely
5m (s)	3.76 ± 0.55	3.87 ± 0.33	0.12 ± 0.28	4.79 ± 1.02	4.46 ± 0.54	-0.33 ± 0.54	-1.05	98%	Likely
10m (s)	6.71 ± 0.76	6.94 ± 0.51	0.23 ± 0.30	8.37 ± 1.72	7.97 ± 0.83	-0.40 ± 0.92	-0.92	98%	Likely
15m (s)	9.67 ± 0.95	10.05 ± 0.72	0.38 ± 0.31	12.10 ± 2.64	11.59 ± 1.18	-0.51 ± 1.49	-0.83	100%	Likely
400m (s)	395.82 ± 37.16	383.80 ± 42.25	-12.02 ± 22.18	504.42 ± 148.49	466.33 ± 96.33	-38.08 ± 55.42	-0.62	92%	Likely
Rel 1RM Pull Up	1.32 ± 0.08	1.39 ± 0.08	0.07 ± 0.07	1.05 ± 0.04	1.12 ± 0.10	0.07 ± 0.07	0.00	59%	Possibly
Rel 1RM Dip	1.49 ± 0.09	1.59 ± 0.14	0.10 ± 0.07	1.20 ± 0.12	1.32 ± 0.13	0.12 ± 0.03	0.37	55%	Possibly

Sum7 = sum of 7 skinfolds; 5m = time taken to sprint paddle 5m; 10m = time taken to sprint paddle 10m; 15m = time taken to sprint paddle 15m; 400m = time taken to paddle 400m; Rel 1RM Pull Up = relative 1RM Pull Up; Rel 1RM Dip = relative 1RM Dip

Table 10. Between-group comparisons between the stronger subjects in the UE Maximal Strength Training Group and the control group over a 5-week training period. Stronger subjects are defined as having an initial Relative 1RM Pull Up > 1.2. Data are mean ± SD

	Stronger (Rel 1RM Pull Up > 1.2) Group (n=5)			Control Group (n=6)			Between Group Differences		
								Chances that the true differences are substantial	
	Pre	Post	Change	Pre	Post	Change	Effect Size	%	Qualitative
Body Mass (kg)	73.88 ± 5.39	74.19 ± 4.84	0.31 ± 1.54	77.5 ± 2.38	77.34 ± 2.36	-0.16 ± 1.56	-0.30	100%	Likely
Sum7 (mm)	94.84 ± 17.57	82.36 ± 10.96	-12.48 ± 9.79	67.55 ± 25.51	65.87 ± 24.33	-1.68 ± 5.27	1.37	100%	Likely
5m (s)	3.76 ± 0.55	3.87 ± 0.33	0.12 ± 0.28	4.14 ± 0.39	4.26 ± 0.34	0.12 ± 0.1	0.00	33%	Possibly
10m (s)	6.71 ± 0.76	6.94 ± 0.51	0.23 ± 0.30	7.25 ± 0.56	7.43 ± 0.62	0.18 ± 0.28	-0.17	26%	Possibly
15m (s)	9.67 ± 0.95	10.05 ± 0.72	0.38 ± 0.31	10.4 ± 0.79	10.66 ± 0.89	0.26 ± 0.47	-0.30	36%	Possibly
400m (s)	395.82 ± 37.16	383.80 ± 42.25	-12.02 ± 22.18	416.35 ± 39.64	413.5 ± 45.27	-2.85 ± 13.06	0.50	58%	Possibly
Rel 1RM Pull Up	1.32 ± 0.08	1.39 ± 0.08	0.07 ± 0.07	1.29 ± 0.13	1.35 ± 0.14	0.05 ± 0.03	-0.37	59%	Possibly
Rel 1RM Dip	1.49 ± 0.09	1.59 ± 0.14	0.10 ± 0.07	1.39 ± 0.31	1.42 ± 0.31	0.03 ± 0.07	-1.00	84%	Likely

5m = time taken to sprint paddle 5m; 10m = time taken to sprint paddle 10m; 15m = time taken to sprint paddle 15m; 400m = time taken to paddle 400m; Rel 1RM Pull Up = relative 1RM Pull Up.

Anthropometry

The weaker group demonstrated a greater body mass increase compared to the stronger group. This increase was determined to have a 100% chance the true difference was practically meaningful with a moderate effect size (Figure 17). Conversely, the stronger group had a greater reduction in Sum7 skinfolds that also had a 100% chance the true difference was substantial (Figure 18).

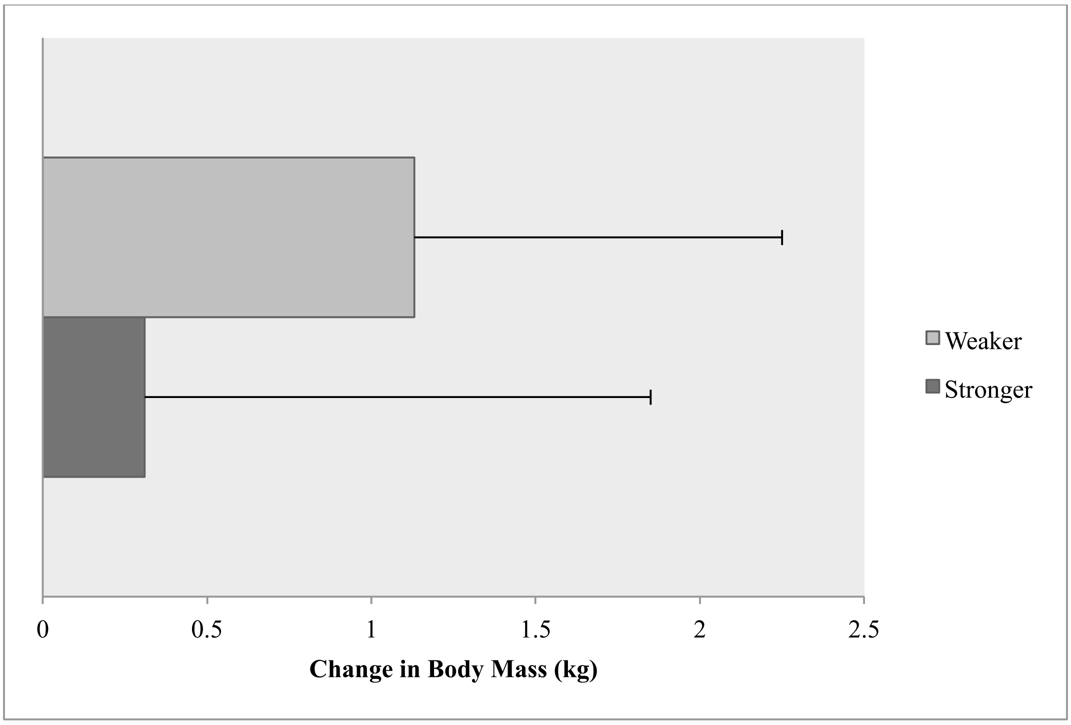

Figure 17. Change in body mass between stronger and weaker groups within an UE maximal strength intervention group over 5 weeks.

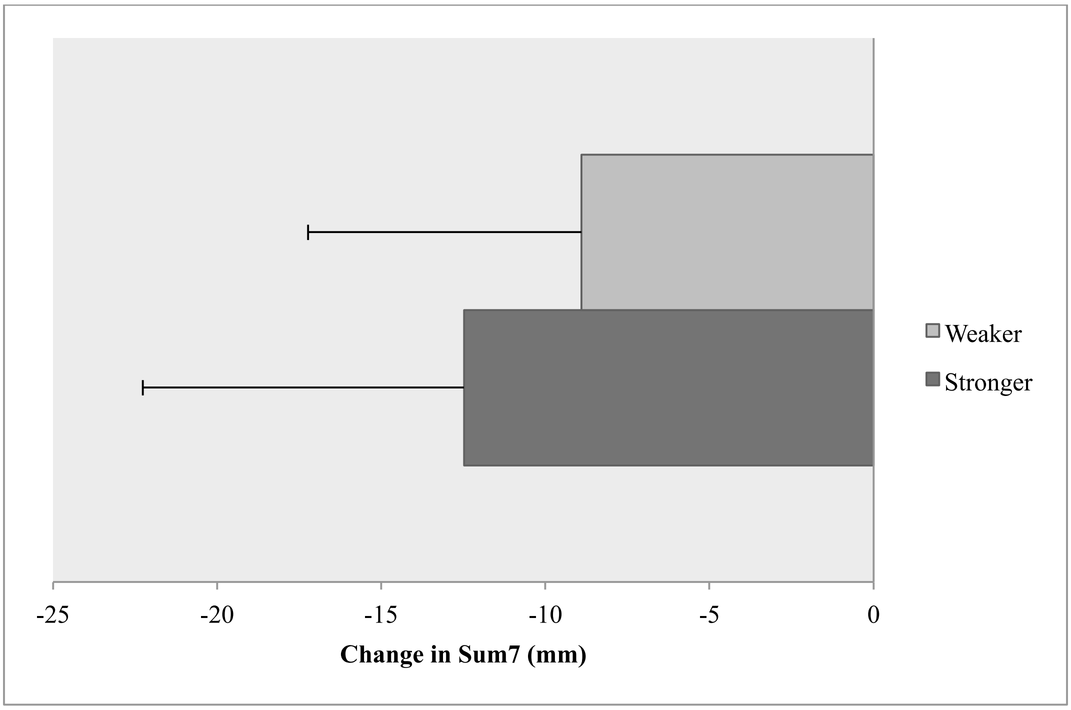

Figure 18. Change in sum 7 between stronger and weaker groups within an UE maximal strength intervention group over 5 weeks.

Paddling Performance

The weaker group increased sprint paddling speed while the stronger group actually exhibited slower performances albeit without reaching statistical significance. The likelihood of meaningful difference was 98%, 98% and 100% over 5, 10 and 15m respectively with a large effect size for all distances (Figure 19).

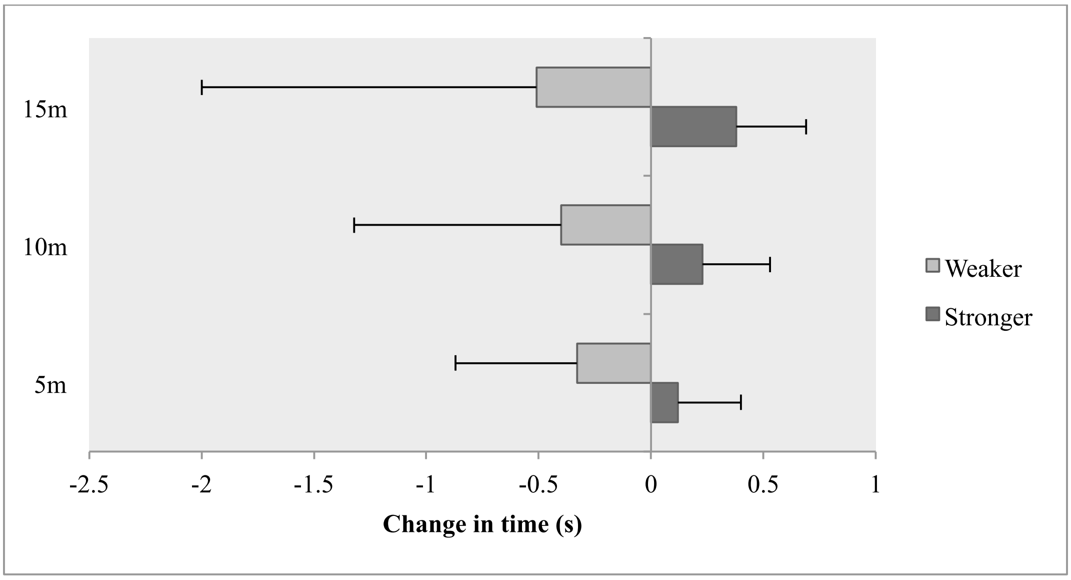

Figure 19. Change in sprint paddle performance between stronger and weaker groups within an UE maximal strength intervention group over 5 weeks.

The weaker group displayed faster endurance paddling performances compared to the stronger group. There was a 92% chance of practically meaningful differences with a moderate effect size between stronger and weaker groups (Figure 20).

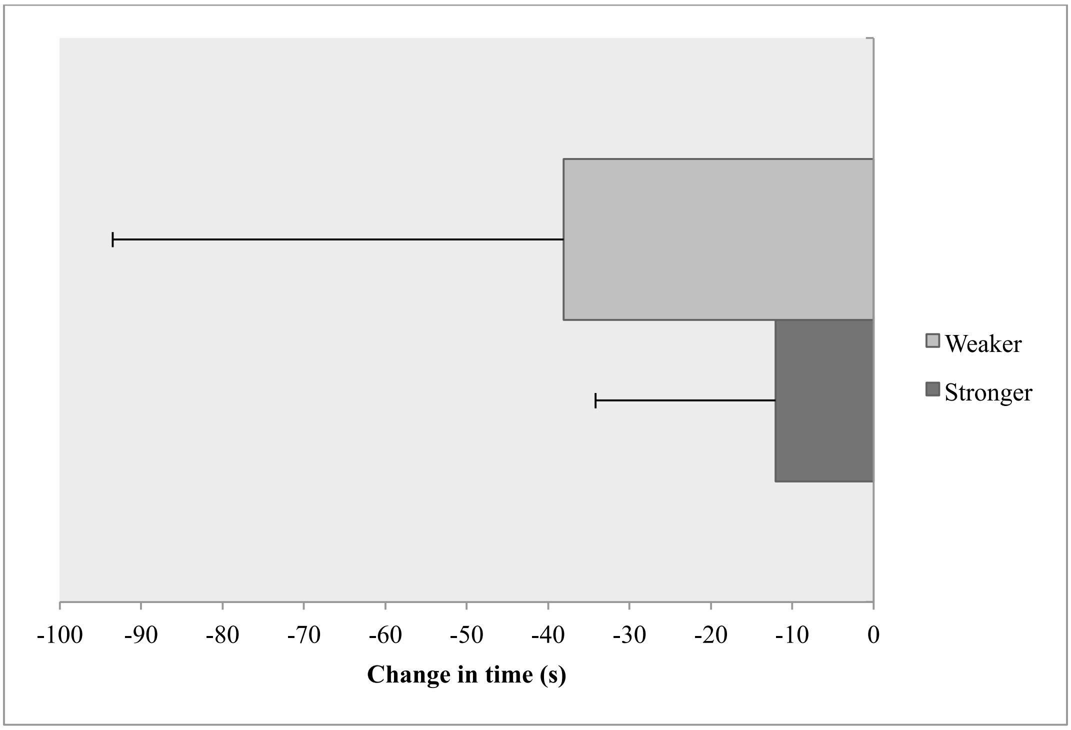

Figure 20. Change in endurance paddle performance between stronger and weaker groups within an UE maximal strength intervention group over 5 weeks.

Maximal Strength

There was no difference between weaker and stronger groups in terms of the change in relative 1RM Pull Up performance over the 5 weeks. There was a slight improvement by the weaker group in relative 1RM Dip performance that was determined to have a 55% chance the difference was meaningful with a small effect size (Figure 21).

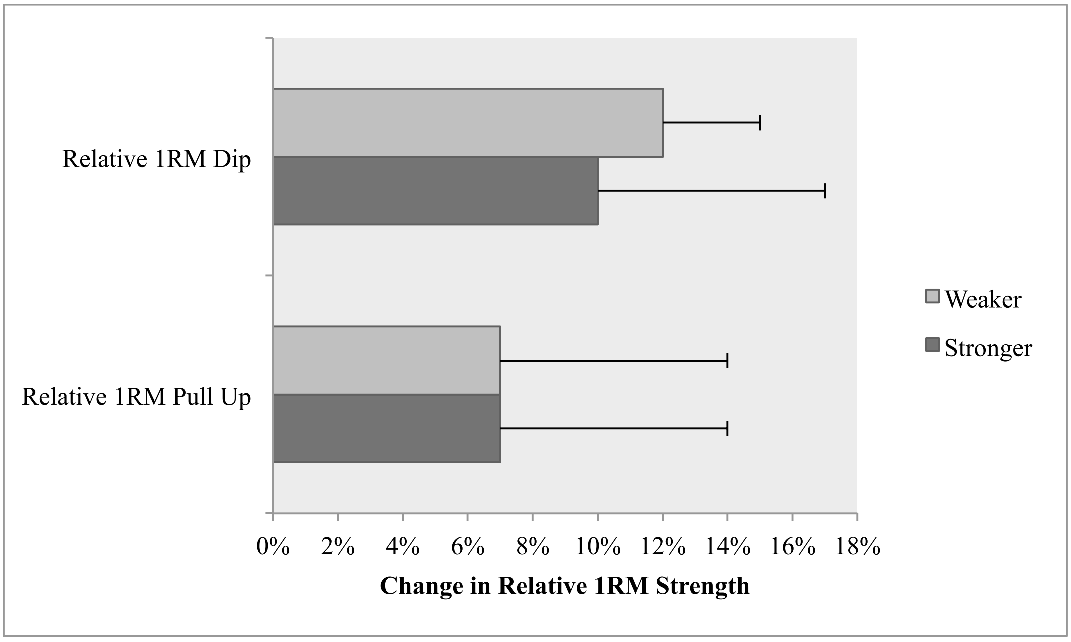

Figure 21. Change in relative 1RM strength in pull up and dip between stronger and weaker groups within an UE maximal strength intervention group over 5 weeks.

CHAPTER 5: DISCUSSION

5.1 Introduction

Surfboard paddling's importance to surfing competition is highlighted by high paddling velocities allowing for positional advantages over competitors and faster entry speeds into waves. This faster entry speed likely enhances the ability to execute a greater number of manoeuvres that increase the judges' score (Loveless & Minahan, 2010; Mendez-Villanueva & Bishop, 2005; Mendez-Villanueva et al., 2005; J. M. Sheppard et al., 2012). To examine the effects of anthropometric and strength variables on surfboard paddling, there were a number of hypotheses that were created and tested to accomplish this research goal. The initial hypothesis of this research was that performance in the pull up and dip (when controlled with tempo and range of motion criteria) along with a 400m surfboard endurance paddle test would be reliable. From the reliability investigations performed for this study, it was determined that this was indeed the case. It was also theorized that 400m surfboard paddling endurance test will have a greater discriminative ability to distinguish between surfers of different abilities than previous surfboard paddling tests (e.g. stationary paddle ergometer) (Loveless & Minahan, 2010; Meir et al., 1991; Mendez-Villanueva et al., 2005). From the analysis in Study #2, this seemed to be so and appears to suggest water based paddling

assessments may be preferable over stationary paddle ergometers for validity purposes.

The next hypothesis of the study was that there would be high correlations between surfboard paddling ability, anthropometric variables and UE strength. It was also theorized that there would be significant differences between competitive and recreational surfers in these anthropometric variables. The current results suggest that some (but not all) anthropometric variables are correlated with greater surfboard paddling ability and are also correlated with surfing ability e.g. competitive vs. recreational. UE strength also seems to be correlated with greater surfboard paddling ability in both sprint and endurance paddling bouts.

The last hypothesis of the study proposed that the use of a short term UE CKC maximal strength training intervention would improve surfboard paddling ability; particularly in sprint paddle performance. The outcome of this study was that short-term exposure to maximal strength training elicits improvements in paddling performance measures. However, the magnitude of performance increases appears dependent on initial strength levels with differential responses between strong and weaker athletes over the course of a short maximal strength training program.

5.2. *Study 1 - Reliability Study*

The purpose of this investigation was to examine the reliability of and interaction between two CKC UE strength tests – the pull up and dip. Both tests, when performed with the movement and tempo standards utilized in this study, demonstrate high reliability in both absolute external load and relative to body mass. This is valuable because the ability to reliably assess strength qualities in these movements can give insight for the strength and conditioning or sports medicine professional for athlete selection, rehabilitation/return to sport and training determination. It also gives athletes and coaches confidence that observed changes are due to training or de-training induced changes, and not due to inconsistent methodology.

The information obtained from this study also allows the strength and conditioning specialist to assess the balance of the agonist and antagonist musculature in two CKC tests that appear to be highly reliable and may have high context validity to a number of different sports. Specificity principles relating to the kinetic chain are especially important when developing an UE exercise program in rehabilitation and athletic training. If an athlete is involved in a predominately CKC sport (e.g. swimming, kayaking, gymnastics), it seems preferable to test the athlete with CKC exercises over OKC exercises (e.g. lat pull down, barbell bench press). It may also be

preferable to emphasize these exercises in the rehabilitation and training of the individual's functional status e.g. activities of daily living and/or sports that require CKC movements (Kibler, 2000; Kibler & Livingston, 2001; Kibler et al., 2001; Sciascia & Cromwell, 2012).

The results of this study determined the relative strength of the upper body musculature used for the dip movement is 1.11 times stronger than the musculature involved in pulling for an injury free surfing cohort. This 1.11 ratio between dip and pull up strength relative to body weight becomes a valuable resource to add to the structural balance figures already proposed in previous work (D. G. Baker & Newton, 2004b; McKean & Burkett, 2010) and to accommodate for when dealing with a surfing population. As the mechanisms of shoulder injuries in surfing and other aquatic sports are more clearly understood, this may aid in prevention and rehabilitation of injuries and identification of potential limiting factors in performance. As noted previously, there are few studies examining ratios between such strength assessments and their utilization to guide training interventions (Young et al., 2014). Adapted from research on developing maximal neuromuscular power (Cormie et al., 2011), it can be suggested that a training program that focuses on the least developed quality will result in the greatest performance improvements. In this case and at present for surfers, it may be suggested if

an individual has a relative 1RM Dip performance > 1.11 relative 1RM Pull Up performance; the individual would be advised to focus their training on developing relative 1RM Pull Up strength. The training emphasis may be the opposite if relative 1RM Dip performance < 1.11 relative 1RM Pull Up performance (Table 11).

Table 11. Theoretical expectation when using a relative 1RM dip : pull up maximal strength ratio to determine exercise focus

Ratio	Diagnosis	Training Intervention
Dip > 1.11 Pull Up	Athlete may possess inadequate levels of maximal Pull Up strength	Maximal strength training is encouraged for the Pull Up
Dip < 1.11 Pull Up	Athlete may possess inadequate levels of maximal Dip strength	Maximal strength training is encouraged for the Dip

Future research endeavours with surfing populations and other specific populations (elite athletes, other sports, injured athletes) are warranted to assess the influence on this ratio. This could be conducted with two goals in mind. To assess the structural balance ratio between the pull up and dip for injury prevention, the ratios of athletes with UE injury history could be compared to the ratios of athletes without UE injury history to see if any significant correlations can be ascertained. To assess the validity of the ratio for sporting performance, this could be accomplished by discriminate analysis of the dip : pull up ratios between higher and lower performers and correlational analysis between this ratio and performance measures within a sport.

Practitioners can use data from the present study to guide when a worthwhile change has been observed in their athlete's performance in these two exercises (e.g. 3% for relative pull up strength or 4% for relative dip strength)

whether in repeat testing or training. However, best practise would be to obtain population-specific data of this type. These calculations can play an important role in goal setting for both the sports medicine and strength and conditioning professional.

By applying these tests, the strength and conditioning or sports medicine professional has a useful tool that can be incorporated into an athletic training or rehabilitation program to assess the efficacy of the training, aid in progression of rehabilitation, and help determine readiness to return to sport. Another advantage of these tests is that they permit reliable assessments of UE strength maximums without need for i) a large amount of staff and/or ii) expensive equipment (e.g. isokinetic devices), providing straightforward and practical assessment that can be conducted with limited resources.

The combination of UE tests seem to be superior to a single test for evaluating upper body strength, to ensure that both pressing and pulling strength is evaluated, and to evaluate the ratio of strength between the two. Practitioners should decide whether these tests have relevance and/or context validity to their sport or populations based on biomechanical factors that include (but are not limited to) speed of contraction, open vs. closed

kinetic chain and angle of force production. Possible limiting factors in performance and potential injury risk may be derived from the comparison of these two tests. Rehabilitation and return to sport from UE injury can also be monitored by performance in the pull up and dip.

5.3 Study 2 – Correlational Analysis

The purpose of this investigation was to assess the potential relationship between anthropometry, upper body strength qualities (pull up and dip) and paddling kinematics in both competitive and recreational surfers.

As previous researchers in competitive surfers have reported a correlation between arm span and sprint paddle performance (J. M. Sheppard et al., 2012), this study seemed valuable to further explore possible interactions between anthropometry and surfboard paddling. The relative arm span correlations with paddling performance reconfirm some of the previous anthropometric research from swimming (in particular the freestyle stroke (Carter J.E.L. and Ackland, 1994; Carter, 1982)) and will also assist talent identification programs in competitive surfing.

The high positive correlation found between sum of 7 skinfolds with paddling kinematics in both competition surfers and the whole cohort suggests that surfers (and especially competitive surfers) require low levels of fat mass to

optimize their surfing performance. The high correlation between body mass and paddling kinematics in competitive surfers also indicates that there is a "threshold" weight for fat free mass above which performance enhancements may be hampered. Even if the athlete is very lean, the increased weight appears likely to decrease their performance. It stands to reason that the strongest association between sum of 7 skinfolds and weight with paddling performance was with 400m time trial ($r = 0.87$ and $r = 0.75$ respectively). As with any repeated cyclical movement, efficiency is paramount to increased performance and excess fat mass or weight may impede levels of surfing ability.

As found in previous research (J. M. Sheppard, McNamara, P., Osborne, M., Andrews, M., Oliveira Borges, T., Walshe, P., & Chapman, D.W., 2012) there was a significant correlation between relative 1RM pull up strength and sprint paddling ability (5m, 10m, 15m). However, there does not seem to be a significant correlation with 1RM pull up strength and endurance paddling (400m) ability ($r = -0.33$, $p = 0.08$). As with the initiation of any movement (R. Enoka, 2000), the surfer must overcome a higher resistance to begin with to accelerate their body and surfboard on the water. Therefore it is logical that correlations between upper body strength and paddling speed decrease as distance increases (J. M. Sheppard et al., 2012).

However when the COMP cohort was examined, the significant correlation between relative 1RM pull up strength and sprint paddling ability did not exist. This is dissimilar to previous research, although it should be noted that Sheppard et. al. (J. M. Sheppard, McNamara, P., Osborne, M., Andrews, M., Oliveira Borges, T., Walshe, P., & Chapman, D.W., 2012) found differences in competitive surfers between faster and slower paddlers with an average relative 1RM Pull Up strength of 1.27 and 1.15 respectively. As the current average relative 1RM Pull Up strength for competitive surfers was 1.24, this may indicate that once a certain level of Relative Pull Up strength is reached (e.g. above 1.2), improvements in paddling speed are not necessarily associated with Pull Up strength. Further improvements in paddling speed above this point may be associated with other exercises (e.g. dip strength as outlined below), CKC pulling exercises that focus on faster contraction speeds and higher stretch shortening cycle activity and/or actual paddling speed interventions. Furthermore, specific paddling based interventions may be utilized to promote a positive effect. For example, sprint-interval paddle training methods, resisted paddling, or over-speed paddling (paddling with a current) are all worthy of evaluation.

Another noteworthy observation was that relative 1RM dip strength in competitive surfers was very highly correlated with sprint paddling ability ($p<0.01$). Similar to relative 1RM pull up strength, this wasn't correlated with

endurance paddling ability. More research is needed on pull up and dip strength in relation to paddling ability.

There were no significant correlations with the relative dip : pull up ratio and paddling performance measures in competitive surfers or in the cohort as a whole. Further there did not appear to be any significant difference in the relative dip : pull up ratio between higher (1.08 ± 0.09) and lower (1.14 ± 0.13) performers. This may suggest that the dip : pull up ratio of 1.11 garnered from Study #1 does not need to be modified with performance measures in mind when selecting exercises. It also suggests that the ratio between dip and pull up strength may not be as important as simply increasing relative UE strength levels in both movements for improvements in sprint paddling.

As found in previous research (Loveless & Minahan, 2010; J. M. Sheppard et al., 2012; J. M. Sheppard et al., 2013), sprint paddling velocity (5m, 10m, 15m) is a valid discriminator between surfers of differing competitive levels. This investigation also found a large and significant difference (p=0.00) in endurance paddling ability between surfers of different aptitude. This supports the aforementioned concept that paddling endurance in surfers may be better assessed with a water based paddling time trial rather than a

laboratory based setting (J. M. Sheppard et al., 2013) due to contextual validity and the nature of the kinetic chain (e.g. open vs. closed) assessed in the test. Our results could also be interpreted to indicate recreational surfers may improve surfing ability with a training focus towards improving paddling endurance over 400m (rather than improving sprint paddle scores) as this is the largest difference between groups. Unlike paddling, it does not seem that upper body strength is a valid measure to distinguish between surfers of different ability.

The outcomes and performance data from this study can be applied to assist in the talent identification of surfers and in anthropometric monitoring of elite surfers during their competitive career. The information will also help strength and conditioning coaches, dieticians and sport scientists tailor individual surfer's training and nutrition programs to ensure high levels of relative strength in pull up and dip are achieved, low levels of skinfolds are maintained and that any extra mass developed through training will not be detrimental to surfing performance.

5.4 Study 3 – UE Maximal Strength Training Intervention

The purpose of this study was to assess the impact of a short-term 5-week maximal strength training intervention on UE maximal strength levels, anthropometric variables and surfboard paddling ability. Due to the high

volume of surfboard paddling that occurs naturally within surfing activity and an apparent lack of formalised maximal strength training by surfers, an UE maximal strength training intervention appeared to offer the greatest opportunity to improve surfboard-paddling ability.

UE maximal strength training seemed to significantly decrease body fat as measured by Sum7 and to a much lesser extent, increase body mass. Bearing in mind the high negative correlation with Sum7 and paddling speed (especially endurance bouts) from Study #2, these anthropometric changes are of noteworthy potential for surfing athletes. To analyse where surfing performance may be improved in an athlete's profile, it may be worthwhile to compare a surfing athlete's body mass and Sum7 to norms for elite surfers (e.g. WCT). This may be especially important if the athlete's Sum7 is above those norms, UE maximal strength training (alongside a nutritional intervention) may be an effective way reducing body fat levels to optimal levels for performance.

On the other hand, considering the high negative correlation between mass and paddling speed in both sprint and endurance efforts in competitive surfers from Study #2, there may need to be monitoring of athletes' mass (especially if the athlete is already very lean) when undertaking UE maximal strength training. This is to make sure they do not broach a "threshold" weight for fat free mass above which performance may be hampered. It

should be mentioned that this would be more of a concern to athletes with little to no experience with maximal strength training. These individuals are much more likely to accumulate fat free mass in the initial stages of maximal strength training as it is a novel stimulus. This may be less of a concern in situations where strength training isn't a novel stimulus for athletes. e.g. experienced trainees or the athlete is undertaking high levels of endurance training concurrently (Bell, Syrotuik, Martin, Burnham, & Quinney, 2000; Garcia-Pallares & Izquierdo, 2011; J. M. Wilson et al., 2012).

Relative UE maximal strength performance measures in the pull up and dip appear to have increased following the 5-week training period. There seemed to be a greater improvement in relative dip strength (d = -1.32, 88% likelihood of substantial true difference between training and control groups) compared to relative Pull Up strength (d = -0.42, 59% likelihood of substantial true difference between training and control groups) in the training group. One possible explanation for this may be the dip is an "easier" exercise relative to bodyweight (determined by the dip : pull up (1.11:1) ratio revealed in Study #1) and strength improvements in this exercise are more accessible over a short training period of 5 weeks. Another possible explanation may be that as the control group were instructed to continue with normal weekly activity during the study period, for many subjects, this might have meant performing Pull Ups on a regular basis.

This may have impacted the differences in improvements between training and control cohorts.

Regardless of these differences, these improvements in strength seem to be valuable for surfing athletes. Considering the previous research correlating greater relative pull up strength to sprint paddling speed (J. M. Sheppard et al., 2012), the improvements in pull up strength garnered from the intervention can be seen as desirable. Further, the improvements in relative dip strength from the training may be even more valuable for competitive surfers considering the high significant correlations with relative dip strength and sprint paddling ability over 5, 10 and 15m ($p<0.01$) found with competitive surfers in Study #2.

It should be noted the a 5 week strength training period is a very short intervention in terms of a strength stimulus compared with the majority of the research on strength training. This brief length of study time will significantly decrease the probability of finding worthwhile change in any type of maximal strength results. However due to nature of competitive surfing and the travelling demands placed on surfing athletes, it is very rare that a competitive surfer will have greater than a 5 week period at any one time at any one place to concentrate on improving a physical quality. It is encouraging for the surfing population that there seems to be positive

adaptations in maximal relative strength in a period of time that will fit into a competitive surfers schedule.

The last hypothesis of the study proposed that the training group would improve surfboard paddling ability to a greater extent than the control group; particularly in sprint paddle performance. The paddling kinematics assessed demonstrated likely substantial true differences between the training and control groups following the investigation period. When discussing these results, it must be remembered that the control group were still exposed to regular bouts of paddling during the study period as part of their normal week-to-week surfing activity.

Interestingly, although the training group seemed to improve in all aspects of paddling ability, it was the endurance paddle performance measure (400m) that seemed to improve the most with the strength-training stimulus compared to the control condition. Considering the hypothesis of strength training improving sprint paddle performance more so than endurance paddle performance due to the many referenced effects of strength on acceleration, power and speed qualities (Cormie et al., 2010a, 2010b, 2011; Nuzzo et al., 2008), this was not expected. However it does align with previous research on the effects of strength training on endurance activity

that shows a beneficial effect for performance (Hoff et al., 2002; Hoff et al., 1999; Ronnestad et al., 2010; Storen et al., 2008; Sunde et al., 2010b; Yamamoto et al., 2008). This is especially interesting considering the results of Study #2, which did not find a strong correlation between endurance paddling and UE strength.

One reason for the greater improvement in the endurance paddle measure may be the development of improved neuromuscular function and coordination of the UE derived from the maximal strength training. These types of effects are similar to research that demonstrates a predominately neurological response to short term bouts of resistance training (Baechle, 1994). This may have increased the subject's paddling stroke economy, which theoretically would enable them to operate at lower levels of cardiorespiratory function at the same paddling speed e.g. enhanced economy(Hoff et al., 2002; Hoff et al., 1999; Storen et al., 2008; Sunde et al., 2010b). Another possible reason for the greater development in endurance paddling ability may the effect that maximal strength training had on the fat mass of the subjects. The most significant effect of the strength training intervention when comparing training and control groups seemed to be a reduction in the training groups' fat mass (d = 1.23, 100% likelihood of substantial true difference between groups). As a lower fat mass was

significantly correlated ($p<0.01$) with 400m endurance paddle performance in both competitive surfers and the whole cohort from Study #2, this reduction in fat mass (Sum7) may be an unexpected cause of improvement in the endurance paddling performance measures.

When splitting the training group's results into stronger (>1.2 relative 1RM pull up strength) and weaker (<1.2 relative 1RM pull up strength) groups, there were many interesting observations. The first was that from pre to post intervention the weaker group seemed to gain more body mass but had a lower reduction in fat mass (e.g. Sum7) than the stronger group. The stronger group did not seem to gain any body mass but had a greater reduction in fat mass than the weaker group. This may indicate maximal strength training had a more hypertrophic effect on the weaker subjects. Again this corresponds with the notion that weaker or inexperienced athletes are much more likely to accumulate fat free mass in the initial stages of maximal strength training as it is a novel stimulus.

There was no difference in strength gains in the pull up between stronger and weaker groups. There was a small 2% greater improvement in the weaker group with the Dip exercise which possessed a small effect size (0.37) and 55% chance the difference between the two group's improvements were

true. Again relative to bodyweight, the subjects seemed to have gained more strength in the Dip compared to the Pull Up. This may suggest the Dip is an "easier" exercise relative to bodyweight and strength improvements in this exercise may be more readily acquired over a short training period. Another possible explanation for this result may be that the dip exercise was a more novel stimulus compared to the pull up for the cohort and as such experienced a greater improvement. In other words, it may simply be that prior to participation in the study, the subjects were more regularly using pull-ups in their programs, and less experienced/trained in the dip exercise, allowing for a steeper improvement curve in the dip exercise compared to the pull-up.

The effects of maximal strength training on paddling velocity seemed to be profoundly influenced by the initial strength levels of the subjects. When comparing the stronger and weaker groups, the weaker group appeared to have much greater improvements in sprint paddling performance. The weaker group's improvements after the maximal strength training compared to the stronger group had effect sizes of -1.05, -0.92, -0.83 and a 98%, 98%, 100% chance the differences were true and substantial over the 5m, 10m, and 15m respectively. Of note is the stronger group's sprint paddling

measures in the follow up testing were very similar to the control (i.e. non training) group. The stronger group did display possibly greater improvement in the 400m-endurance paddle with moderate effect size compared to the control group. This improvement in the stronger group was not as great as the weaker groups' improvement (12.02 vs. 38.08, d = -0.62) and the difference between the two groups had a 92% probability that it was substantial.

These results support the contention that there may be a certain level of relative maximal strength (e.g. perhaps 1.2 relative 1RM Pull Up) that once achieved, any further gains in relative maximal strength may not produce appreciable performance gains in surfboard paddling performance; especially sprint paddling. If so, it may be warranted for athletes that possess the necessary quantities of relative maximal strength to focus their available training time on more specific methods (e.g. resisted sprint paddling) and in developing other physical or mental qualities that may influence performance. In this particular case, it may be more appropriate to implement surfboard paddling training interventions (sprint or endurance) in athletes' training rather than continuing to devote training units to maximal strength. If athletes do not possess or have momentarily lost this particular level of relative maximal strength, it may be more valuable to their

performance if their training is focused on developing or regaining that level of maximal strength. This is especially pertinent considering the effects gaining and maintaining strength has on performance across a wide range of sports (D. Baker, 2001a, 2001b, 2002b; D. G. Baker & R. U. Newton, 2006; 1994; Peyer et al., 2011b).

Since maximal strength underpins physical performance, it is essential that athletes have appropriate levels of strength to successfully participate in their sport. The appropriate amount of strength differs between sports and individual athletes. As such, it is part of the strength and conditioning coach's role to calculate that appropriate amount. To better illustrate the determination of training methods based on initial strength levels for surfboard paddling performance, a brief outline is presented in Table 12. Table 12 contains recommendations that have been adapted from Cormie and colleagues (Cormie et al., 2011) .

Table 12. Theoretical expectation when using initial strength levels to determine training focus

Initial Strength Levels	Diagnosis	Training Intervention
<1.2 Rel 1RM Pull Up	Athlete possesses inadequate levels of maximal strength	Maximal strength training is recommended
>1.2 Rel 1RM Pull Up	Athlete possesses adequate levels of maximal strength	Maximal strength to be maintained at current levels. Other training foci recommended

It should be noted that this diagnosis and training intervention is solely based on a 5-week maximal strength training intervention and the experiences of the author. More investigation may be warranted to establish if a longer bout of maximal strength training changes the initial strength level used for diagnosis and training intervention. Strength and conditioning coaches should also be aware that as maximal strength improves, the rate at which performance improves decreases and any further improvements may be brought about through other training methods (Daniel G. Baker & Robert U. Newton, 2006). Nonetheless improving maximal strength beyond a "threshold" level may result in performance enhancements that are not a direct result of strength training. For example, maximal strength training may aid in soft tissue resiliency, which may allow an athlete to complete the necessary volume of training that is required for further performance enhancement without injury.

5.5 Conclusion

These findings support the first hypothesis that Pull Up, Dip and 400m Endurance Paddle are valid and reliable means of identifying training induced changes. The use of a dip : pull up ratio may be used to guide more specific exercise choices for a strength and conditioning coach working with surfers. Meanwhile, a water-based surfboard paddling endurance test appears to effectively discriminate between higher and lower performing surfers and at this stage, should be employed for testing over laboratory based stationary paddle ergometers for validity purposes. The second hypothesis is also supported with competitive surfers possessing significantly greater relative arm spans and greater paddling speeds over short and (especially) long distances compared to recreational surfers. In addition, relative 1RM Dip strength and fat mass are highly correlated with paddling performance in competitive surfers. The final hypothesis of this study was partly accepted with paddling performance measures improving as a result of maximal strength training in weaker subjects. However in stronger subjects, maximal strength training may not be needed to improve paddling performance or the bout of maximal strength training may need to be greater than 5 weeks.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 *Conclusions of the Research Project*

The following conclusions were established from the results of this research project:

1. Measures of 1RM Pull Up and 1RM Dip strength are reliable when controlled by range of motion and tempo standards.
2. The measurement of endurance paddling ability (400m) is acceptably reliable.
3. A relative 1RM dip : 1RM pull up ratio may be used to base exercise selection in UE strength training programs.
4. In recreational and competitive surfers, relative arm span and fat mass are significantly correlated with sprint paddling performance ($p=0.02$-0.04 and 0.01 respectively) and endurance ($p=0.01$ and 0.00 respectively) paddle bouts. Relative 1RM Pull Up strength is significantly correlated with sprint (but not endurance) paddling performance.
5. In competitive surfers alone, relative arm span is not significantly correlated to strength, nor is relative 1RM Pull Up strength to paddling performance. Body mass and fat mass are significantly negatively correlated with sprint ($p=0.01$) and endurance ($p<0.00$) paddling

performance. Relative 1RM Dip strength is significantly correlated ($p<=0.00-0.01$) with sprint (but not endurance) paddling performance.

6. The biggest differences between competitive and recreational surfers are endurance paddling performance and relative arm span.
7. Maximal strength training in the Pull Up and Dip appear to produce improvements in paddling performance although weaker subjects may derive greater benefit from this training. Stronger subjects may develop more efficient paddling performance enhancements through other training methods.

6.2 Recommendations for Future Research

This study was the first to quantify both absolute and relative reliabilities for 1RM Pull Up and Dip tests. Furthermore, this is one of the first studies to compare Pull Up to Dip strength and propose a ratio to help aid exercise selection in training programs. It is suggested that further investigations focus on establishing the validity of both the Pull Up and Dip compared to other exercises for athletic performance in other sports. Establishing whether optimal Pull Up to Dip ratios exist for sports that involve UE pushing and pulling through the use of discriminate and correlational analysis would be warranted. It would also be worthwhile to investigate the relationship between the Pull Up and Dip ratio and UE injury across both general and athletic populations and within individual sports. Other exercise forms of UE

pushing and pulling could also be utilised if they replicate the kinetic chain of the sport or were to be proven more valid to performance/injury in a particular sport.

This study appeared to reveal a “threshold” level of maximal strength (1.2 relative 1RM Pull Up) that if possessed, there seem to be little improvements in paddling performance with short-term maximal strength training. As such, thorough investigations into the point, this maximal strength “threshold” is reached for individual sports would be important to determine for strength and conditioning practitioners working in those sports. Although a longer maximal strength training period may have produced more significant paddling improvements, the nature of professional surfing means that strength and conditioning practitioners are unlikely to have any more than 5 weeks in an uninterrupted block to work with a surfing athlete. Therefore for these athletes that have attained “threshold” strength, explorations of the effects other forms of training (e.g. UE ballistic and/or plyometric training) have on paddling performance is needed. Other studies comparing surfboard paddle training and maximal strength training could also be undertaken.

In regard to studying the effect surfboard-paddling training would have on paddling velocity, further diagnostics based on the existing paddling tests could also be developed to aid the strength and conditioning coach. These could include investigating whether average velocity in 15m sprint compared to 400m endurance paddle is a valid discriminator between athletes or is correlated with performance. Research into how this paddling ratio could be used to guide paddling training interventions for athletes e.g. whether they perform sprint or endurance paddling training to enhance performance; would also be warranted.

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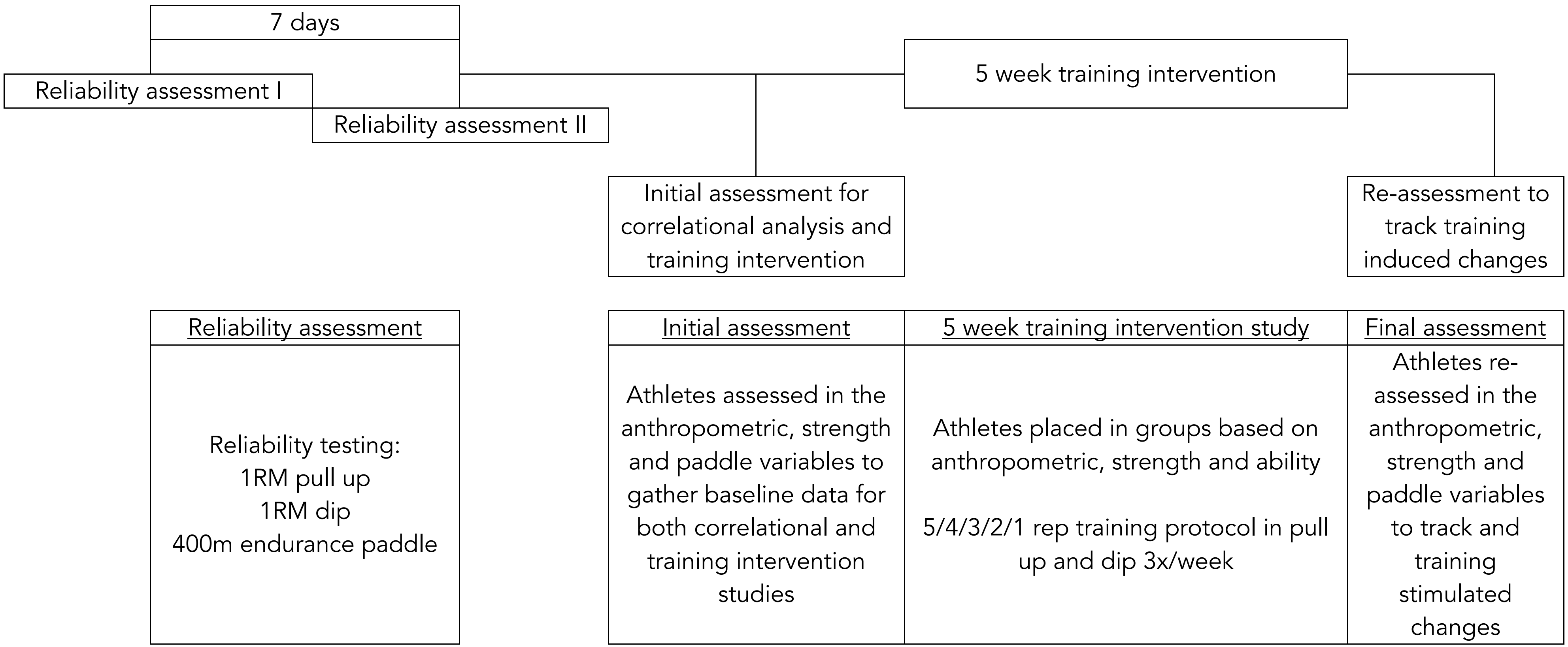
APPENDIX A: SCHEMATIC OF STUDY DESIGN



APPENDIX B: INFORMED CONSENT FORM

INFORMED CONSENT

Chronic Influence of upper-body strength training on paddle kinematics and performance in elite surfers

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

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

I as a participant or as a parent/guardian have been informed of the procedures involved in this study and have been provided with an information letter detailing the nature of the study. I as a participant or as a parent/guardian have been fully informed of the nature of the tests and potential risks involved, of which I assume voluntarily. I as a participant or as a parent/guardian have been informed that I may withdraw my participation or the participation of my child at any time and for any reason without penalty. The primary benefit of participation in this study will be obtaining information about my individual physical fitness capabilities that will assist my or my child's surfing.

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

If you have any questions or require any further information about the research project, please contact: Joseph Coyne at 0411529390, email coach@josephcoyne.com or Dr. Jeremy Sheppard at 0433334849, email jeremy.sheppard@ecu.edu.au. If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer
Human Research Ethics Officer
Edith Cowan University

100 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170 Email: research.ethics@ecu.edu.au

Declaration

I ____ have read all of the information contained on this sheet and have had all questions relating to the study answered to my satisfaction. I agree to participate in this study realising that I am free to withdraw at any time, for any reason without prejudice. I agree that the research data obtained from this study may be published, provided I am not identifiable in any way.

Participant: ___________________________ Date: _________________

Participants under the age of 18:

Parent/Legal Guardian: ________________________________ *Date:* _________________

Investigator: __________________________ *Date:* _________________

APPENDIX C: TRAINING INFORMATION SHEET

Hurley Surfing Australia HPC (7 Barclay Dr, Casuarina NSW) Session Times

Day	Time
Monday	6:30am
Wednesday	6:30am
Friday	6:30am

Coyne Conditioning (25/2 Calabro Way, Burleigh Heads QLD) Session Times

Day	Time
Monday	6:30pm
Wednesday	6:30pm
Thursday	6:30pm

Training Program

- Training will be alternated between Day 1 and Day 2
- You will complete three sessions per week

Day 1

Exercise	Reps	Rest	Tempo
A1: Pull Up	5, 4, 3, 2, 1	180s	4010
A2: Dips	5, 4, 3, 2, 1	180s	4010

Day 2

Exercise	Reps	Rest	Tempo
A1: Dips	5, 4, 3, 2, 1	180s	4010
A2: Pull Up	5, 4, 3, 2, 1	180s	4010

Notes

- To be part of the training study, we need you to be able to complete 90% of sessions (at least 13 out of 15 sessions)
- You cannot weight train any other major upper body lifts (e.g. bench press, barbell row) during the 5 week training period.
- All other forms of activity should be kept as normal
- If you have a lower body injury (e.g. rolled ankle, knee pain) that occurs during the course of the study, we expect you to have it diagnosed by a medical professional but you will still be able to train during the study.
- If you have an upper body injury (e.g. dislocated elbow, shoulder injury) that occurs during the course of the study, we expect you to have it diagnosed by a medical professional and depending on their advice will determine if you are able to continue training.
- Try to arrive to the training sessions at least 15 minutes before they are due to begin.