

CHARLES UNIVERSITY

Faculty of Physical Education and Sport

**Posterior chain muscle endurance and arm paddling peak power
in amateur female surfers**

Diploma thesis

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I declare that this thesis has been composed by myself and that this thesis has not been submitted for any other degree or professional qualification. I confirm that the work submitted is my own. I confirm that appropriate credit has been given within this thesis where reference has been made to the work of others.

Prague, 2.4.2019

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ABSTRACT

Title: Posterior chain muscle endurance and arm paddling peak power in amateur female surfers

Objectives: Thesis is dedicated to female surfing, particularly paddling, as this is an undiscovered area of research. Very few studies have been carried out, which would focus on muscle activity in surfing. None of the studies focused on posterior chain or muscle activity of female surfers while paddling. Not only that the level of competitive surfing is increasing rapidly, as it will be part of Olympic Games in Tokyo in 2020, but the recreational surfers are also becoming more literate about surf science and willing to improve their surfing performance by dry land surf specific trainings. Surfing industry represents a worldwide business, where big companies offer sponsorship, which is reasonable motivation for young athletes (M. Mendez-Villanueva & Bishop, 2005). As the number of recreational and competitive female surfers is raising as well, the level of competitive female surfing is increasing (Booth, 2001) and professional female surfers are becoming equal in regards to getting the same amount of prize money in competitions, more research should be dedicated to female surfing. The aim of this thesis was to study association between posterior chain endurance and other variables such as frequency of surfing sessions, surfing load and arm paddling peak power in

recreational female surfers. This thesis also deals with chronic surfing injuries that may be caused prolonged isometric back extension in long period of arm paddling.

Methods:

Fourteen recreational female surfers were assessed for weight, posterior chain endurance and paddling peak power. Pearson correlation analysis was used for determination the significant correlations between variables. Posterior chain endurance was correlated with basal peak power, peak power after posterior-chain-fatiguing exercise, procentual difference between basal and post-fatiguing-exercise peak power, relative basal peak power, surfing experience in years, frequency of surfing in summer and winter and frequency of surfing and upper body strength training in summer and winter.

Results:

Very weak correlation was found between posterior chain endurance and paddling peak power. However, strong correlation was found between frequency of surfing and posterior chain endurance. There was association between frequency and load of surfing between paddling peak power.

Practical applications:

This study can be used by sport coaches to design training program for surfers. It can be also used as foundation for further research in surfing injuries and EMG activity of the muscles of posterior chain in arm paddling.

Keywords:

surfing, arm paddling, posterior chain, muscle endurance, peak power, injury prevention, back pain, surf specific training

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LIST OF ABBREVIATIONS

CKC	Closed kinetic chain
CONT	Control group
EMG	Electromyography
MF	Muscle fiction
PAP	Peak activation at phase
RM	Repetition maximum
SD	Standard Deviation
TMA	Time-motion analysis
TRAIN	Training group
WSL	World Surf League

INTRODUCTION

1. THEORETICAL PART

1.1. The urgency of research

In the past, surfing was mainly male sport. As the popularity of surfing is increasing, there are more and more professional and amateur female surfers. It is not only professional surfers but also surfers on the amateur level, who are searching for information and means of improving their level of surfing. Thus, there is need for more research in the field of amateur female surfing. There are not so many amateur female surfers who would perform radical manoeuvres on a surfboard. Majority of them spend most of their time in water paddling against the waves to get to the line up, against the current or sprint paddling to catch waves. Again, no research on this topic has been done but based on my experience and talking to other amateur female surfers, fatigue when paddling and catching the waves is one of the main problems. This thesis reveals association between posterior muscle chain endurance and arm paddling peak power. Further research could be done to investigate association between posterior muscle chain endurance, paddling peak power and trunk mobility. That could be used as background evidence for implementing some basic exercise program for amateur female surfers, who want to accelerate their progress in surfing.

Actually, the history of female surfing dates back at least 1000 years in Hawaii. In those days, women have been seen as equals, with an emphasis on athletic abilities, and deep understanding of the ocean. Women have long played a central role in surfing. However, this changed with popularization of surfing. And gender tradition in surfing became stereotyped, which served marketing interests. It is standard practice that the companies who sponsor top

competitive female surfers to promote their products do not put these athletes in their ads. Instead, models replace surfers. The exception to this rule is when a female competitive surfer happens to be indistinguishable from a model, and then she appears in the ad for the product. The message women receive from these ads is that the actual female surfer is not good enough to represent the company's product in print ads. The greatest discrimination of female surfing is in big wave surfing (the waves are higher than 20 feet). Female surfers were underestimated in the past and were not seen as brave or competent enough for these waves. Thus they did not receive any mentoring or training. Anyway, there are a few women who surf those waves and fight for their equality in this area of surfing (Brennan, 2016).

1.2. Surfing population

There have been few attempts to estimate the number of surfers. However, the information on this topic is sparse and not up to date. The numbers in literature range from 10 million (Buckley, 2002) to 17 million (Atkins, 1997). Data from 1997 show, that people from 70 countries participated in surfing. Surfing population consisted of 2.6 million participants from the USA, 2.2 million from Japan, 1.4 million from Australia, 1.1 million from Europe and 1.8 million from South America (Atkins, 1997). Buckley (2002) predicted that the number of surfers will be increasing at 12 – 16% per year. Moreover, the industry of surfing is growing rapidly and tourism on coastal location profits from surfers undoubtedly. Currently, it was estimated that 20 million people worldwide participate in surfing (J. Nessler et al., 2019). Lazarow (2008) argues that more complex recreation choices might result in turning people away from the recreation and becoming less healthy and more of a long-term cost to society.

The meaning and function of surfing are quite complex: it might be a sport, a profession, a pastime, a religion, a spiritual connection to nature and a way of life (Lazarow,

Miller, & Blackwell, 2008). Even though surfing has some organized elements, it is mostly understood as a recreational lifestyle activity. This activity provides participants with identity that is different compared to those in many traditional organized sports. Recreational surfers report intense feelings of “being in the moment”, being “stoked” and being “connected to the nature”. Surfing, being a lifestyle and adventure sport, provides participants with endless opportunities of personal and possibly professional growth (Wheaton, 2017).

The term “serious leisure” pictures the commitment that many surfers have to this activity (Lazarow et al., 2008). “Serious leisure can be defined as the systematic pursuit of an amateur, hobbyist, or volunteer activity that is sufficiently substantial and interesting for the participant to find a career there in the acquisition and expression of its special skills and knowledge” (Stebbins, 1992). Serious leisure involves high level of personal involvement, technical competence and commitment which may actually be equal to professionalism (Lazarow et al., 2008).

According to a study focused on forecasting participation in marine recreation in 2010 in the U.S., rates in surfing should have increased first in 2005 and then decline in 2010. That means that the number of participants should have raised from 3.37 million in 2000 to 3.63 million (7% increase) in 2005 and 3.81 million in 2010 (13.1% increase from 2000) (Bowker, Hospital, & Stone, 2005). The authors of this study claim that these numbers may be understated, since the level of educational attainment, which is positively related to participation rates, was held constant over the forecast period because forecasts of the future level of educational attainment were not available. Compared to some other activities, which were predicted to decline in participation rates (swimming, visiting beaches) and those predicted to increase in participation rates (scuba diving, visiting watersides besides beaches), surfing was forecasted to have constant participation rates (Bowker et al., 2005). Another source shows that the number of participants in surfing in the United States raised from 2.17 million

in 2006 to 2.68 in 2017. However the number is not raising constantly, but fluctuating ('Participants in surfing U.S. 2006-2017 | Statistic', n.d.). Surfing is not only expanding in intensity in traditional locations, but also reaching into new environments, often in third world countries. It is major recreational and economic activity involving intimate human interaction with coastal environments. Over the past three decades, the value of surfing to the global economy has grown significantly. Thus, the importance of the economic and social value of surfing should be taken into consideration (Lazarow et al., 2008).

In spite of the global growth of surfing and ever-increasing rise in professionalism, there is currently a paucity of research to assist coaches and practitioners on assessment and conditioning of athletes. Various methods of performance analysis have long been used within a wide range of sports, few studies have implemented such analysis in surfing (O. R. L. Farley, Abbiss, & Sheppard, 2017).

Until recently, surfing was a sport dominated by men. In the United States, women made up just five percent of the surfing population in the mid-1990s but by the end of that decade the participation climbed to 15% (Nourbakhsh, 2008). Since professional female surfers are drawing greater media attention than ever before, they are also seen by a surf companies as the perfect mean to develop this global industry further. Sponsorship experience of fifteen sponsored female surfers was studied in order to examine lifestyle marketing practices of major surfing companies as lifestyle branding has been developed as a modern marketing strategy (Franklin, 2012).

1.3. Physical and physiological characteristics of surfing

Surfing requires whole body physical skills, technique, mental aptitude and physical fitness(M. Mendez-Villanueva & Bishop, 2005). Surfing is characterized as an intermittent activity (Coyne et al., 2016). It consists of exercise bouts, which vary in duration, intensity

and involve different parts of the body, and numerous recovery periods (Mendez-Villanueva & Bishop, 2005). Regarding the ratio of activities which comprise surfing, paddling dominates the activity characteristics (J. O. Coyne et al., 2016; Sheppard, Osborne, Chapman, Andrews, & McNamara, 2013). Based on time-motion analysis of one hour recreational surfing session in the study of Mendez-Villanueva and Bishop (2005), arm paddling accounts for 44% (Meir, Lowdon, & Davie, 1991), remaining stationary represents 35%, actual wave riding constitutes only 5% and miscellaneous (activities such as duck diving, recovering the board after falling) 16% of the total time. However, there are many environmental factors such as swell size, inconsistent surf, currents, wave length, wave frequency, type of break (beach break or point break), wind and line-up situation influencing the ratio of these constituents (J. O. Coyne et al., 2016; Meir et al., 1991; M. Mendez-Villanueva & Bishop, 2005; J. M. Sheppard, Osborne, Chapman, Andrews, & McNamara, 2013). In competitive surfing, paddling represents 35–54%, waiting 28–42%, miscellaneous activities such as ‘duck diving’, wading and ‘wipe-outs’ 2.5–5% of total time. Actual wave riding is the only element judged during competition but it accounts only for 3.8–8.12% of total time (Matthew J. Barlow, Gresty, Findlay, Cooke, & Davidson, 2014; Matthew John Barlow, Rowe, Ruffle, Davidson, & O’hara, 2016a; O. R. L. Farley, Harris, & Kilding, 2012; A. Mendez-Villanueva, Bishop, & Hamer, 2006).

Previous study showed that female surfers spent $62.58 \pm 10.18\%$ of the time sitting, $30.7 \pm 9.44\%$ of the time paddling, and $6.37 \pm 2.91\%$ of the total time actually riding. When comparing these values with those of male surfers during competition, it is apparent that the female surfers spend a greater proportion of their time waiting/sitting than males. Female surfers also appear to spend less time paddling compared with male surfers (Matthew John Barlow et al., 2016a). The time spent riding was comparable with the 3.8–8% range presented

in the literature by Mendez-Villanueva et al. (2006) and Farley et al. (2012) for male participants during competition.

The fact that there are multiple different activities in surfing leads to variety of physiological responses of surfers to specific activities that surfing involves – paddling, wave riding, duck diving, recovering surfboard, sprint paddling. The duration of one surf session varies extensively, depending on the conditions, from 20 minutes in competitive surfing to 4-5 hours practice sessions during good wave conditions (Meir et al., 1991; M. Mendez-Villanueva & Bishop, 2005). Thus, endurance paddling ability is also very likely to be a highly relevant physical activity when assessing paddling ability (J. O. C. Coyne et al., 2017). Heart rate in recreational surfing ranges from 75% to 85% of maximum (Mendez-Villanueva & Bishop, 2005). Average oxygen consumption while surfing is $1.68L \cdot min^{-1}$. Surfing poses large demands on aerobic and anaerobic system. Whilst only aerobic metabolism is utilized during the periods of moderate- and low-intensity activity, bouts of high intensity exercise challenge both: aerobic and anaerobic metabolism (Mendez-Villanueva & Bishop, 2005).

When looking at the nature of a surfing session, surfer paddles first in a prone position to the take off area. At times it is necessary to duck-dive under the breaking waves and to continue paddling. Second, the surfer waits for a suitable wave to approach. Third, the surfer paddles at an effective speed to gain enough momentum to be taken by the wave. Fourth, the surfer must stand up quickly and perform movements on the board in order to continue riding the wave. After the completion of wave riding, the surfer paddles back out to the take off area (Schroeter, 2008).

Although technical and skill abilities play a big role in surfing performance, importance of physical fitness should not be omitted. Surfing requires high level of aerobic fitness. That is supported by the fact that the peak oxygen uptake values of surfers are

comparable with other upper-body endurance-based athletes and higher compared to untrained subjects (Mendez-Villanueva & Bishop, 2005). Cardiovascular fitness in surfers competing at international level was examined in 1980 using a submaximal cycle ergometer test. The mean values reported were 70.2 ± 10.7 for males and $62.2 \pm 8.2 \text{ ml.kg}^{-1}.\text{min}^{-1}$. That suggests that elite surfers are ranked high compared with endurance athletes. Other study used surf specific tests – handcranking, tethered board paddling, paddling on a swimbench – to determine the specificity of aerobic fitness testing for surfers. Mean VO_{2max} scores were 41.6 ± 4.0 and 40 ± 2.9 , $54.2 \pm 10.2 \text{ ml.kg}^{-1}.\text{min}^{-1}$ respectively. Arm/leg ratio reaches to 85% if subjects are highly trained in activities using primarily arms (Meir et al., 1991).

In regards to anaerobic fitness, surfing requires upper body strength in a pop-up phase, similar to a standard push up, to stand on their feet when attempting to catch a wave. Surfers also need to sprint paddle at high intensities for a few seconds to catch a wave. Lower body strength is used while riding a wave in a standing position. To maintain position on the wave, surfers need to pump their legs. Additionally, performing manoeuvres requires squatting and pushing their feet into the surfboard (Schroeter, 2008). General fitness index to assess surfers is peak aerobic power (W), tested by incremental arm paddling exercise test to exhaustion. Higher level surfers achieve greater values than lower level surfers (Mendez-Villanueva & Bishop, 2005). The results in arm paddling peak power ranged from 300 to 450 W in recreational male surfers. The results varied according to subjects' body weight and resistant settings of the swim bench ergometer. The bigger body weight and resistance setting, the bigger the peak power output (Loveless & Minahan, 2010).

In contrast, Shroeter (2008) measured peak power of recreational surfers in vertical jump. Males scored average and females scored above average in this test, which suggests that recreational surfers may not require high scores in lower-extremity muscular power if they are not attempting powerful manoeuvres. The scores for peak power of less experienced

surfers were lower than the scores of more experienced surfers. Muscular strength was assessed by 1RM tests on bench press and leg press, in which recreational male surfers scored in the 90th percentile for bench press as well as the leg press. Female surfers scored in the upper 80th percentile for the bench press and 90th percentile for the leg press.

It was suggested that the predominant energy source during a 1 to 2 hour surfing session is provided mainly by aerobic metabolism. The energy for sprint paddling and explosive movements during wave riding is provided by the Anaerobic glycolysis provides the energy for extended periods of rapid arm paddling used to reach the “take-off” area (Meir et al., 1991). The estimated mean energy expenditure of 60 min recreational surfing session was $33.7 \text{ kJ} \cdot \text{min}^{-1}$ ($8.03 \text{ kcal} \cdot \text{min}^{-1}$). That is comparable with sporting activities such as canoeing at $6.4 \text{ km} \cdot \text{h}^{-1}$, cycling at $20.8 \text{ km} \cdot \text{h}^{-1}$, tennis and swimming freestyle (Meir et al., 1991).

1.4. The importance of the research

Surfing is a specific sport, therefore the greater understanding of physical demands and technical aspects of surfing is vital for enhancing performance and improvement in training prescription of athletes is required. Performance analysis is the systematic collection and analysis of data to provide a valid record of athletic performance. Although performance analysis methods are subjective to some degree, as they rely on human observation, nowadays, they incorporate modern technologies and analytical techniques. Furthermore, coaches and researchers have precise procedures when entering and examining data correctly to reduce error in interpretation of the data (O. R. L. Farley et al., 2017).

1.5. Past research

There have been few studies analysing internal loads of male surfers' heart rate and external loads of surfing activities through time-motion analysis using video recordings and GPS data during competition, training, and recreational surfing, which provides valuable information about physiological demands, energy systems involved and intensities and durations of activity (Matthew John Barlow, Gresty, Findlay, & Cooke, 2015; Matthew John Barlow et al., 2016a; A. Mendez-Villanueva & Bishop, 2005). Other studies focused on injuries (Burgess, Swain, & Lystad, 2019; Dimmick, Brazier, Wilson, & Anderson, 2013; Falconi, Flick, Ferguson, & Glorioso, 2016; Furness et al., 2014; Hammer & Loubert, 2010; Hay, Barton, & Sulkin, 2009; Hohn, Robinson, Merriman, Parrish, & Kramer, 2018; Inada et al., 2018; Klick, Jones, & Adler, 2016; Lina E. Lundgren et al., 2016; Lina Elizabeth Lundgren, 2015; Minghelli, Nunes, & Oliveira, 2018; Mitchell, Brighton, & Sherker, 2013; Nathanson, Haynes, & Galanis, 2002; Pikora, Braham, & Mills, 2012; Sano & Yotsumoto, 2015; Takakura, Yokoyama, Sakuma, Itoh, & Romero, 2013; Woodacre, Waydia, & Wienand-Barnett, 2015; Zoltan & Taylor, 2005), anthropometric profiles of surfers (Matthew John Barlow et al., 2016a; J. Coyne, 2015; J. O. Coyne et al., 2016; J. Sheppard, Osborne, Chapman, & Andrews, 2012), the testing for selection purposes (Matthew John Barlow et al., 2016a; J. O. Coyne et al., 2016; Loveless & Minahan, 2010b; J. M. Sheppard et al., 2012) scoring in competition (O. Farley et al., 2013; L. Lundgren, Nimphius, & Sheppard, n.d.; Lina E. Lundgren et al., 2015; A. Mendez-Villanueva, Mujika, & Bishop, 2010; Tran et al., 2015). Some of the researchers in surfing focused on athletes' work-rate profile monitoring, while using manual video-based time-motion analysis (TMA) (O. R. L. Farley et al., 2017). The majority of this work has been performed with male participants and there have been only a few surfing related studies involving female participants within the nutritional, biomechanical and physiological fields (Anthony & Brown, 2016; Matthew John Barlow et al., 2016a;

Eurich et al., 2010; Felder, Burke, Lowdon, Cameron-Smith, & Collier, 1998; Secomb et al., 2013).

It was found out that female surfers are not as active in their approach to catching waves and positioning as their male counterparts. However, past research indicates that females had similar wave counts during their 20-minute heats (7 ± 3 waves) to the surfers observed during competition by Farley et al. (2012) (7 ± 2 waves). It is likely that the reduced time spent paddling will account for some of the difference in total distance during the heat that was observed in the same study (1267.43 ± 579.49 m) in comparison with that of the Farley et al. (2012) (1.605 ± 313 m). Given the similar wave counts and difference in the activity profile between male and female surfers, we could suggest that female surfers do not actively compete for waves in the same way as their male counterparts (Matthew John Barlow, Rowe, Ruffle, Davidson, & O'hara, 2016b)

1.5.1. Paddling

Paddling is an important component of surfing. Paddling represents 54% of the actual time spent in water when surfing (J. O. Coyne et al., 2016). Physical training can impact performance. Paddling ability is associated with skill level (J. Nessler et al., 2019).

Paddling is a functional and complex movement, since it requires coordination of multiple segments and bi-articular muscles (J. A. Nessler, Silvas, Carpenter, & Newcomer, 2015). Paddling comprises of “pulling” and “pushing” the body over and through the water surface (J. O. Coyne et al., 2016). Paddling appears to be the main source of aerobic muscular activity in recreational surfing (Meir et al., 1991). Paddling is the only means of locomotion to access the surf break and move into position to catch waves, as well as to create enough momentum to paddle into the wave itself. It is done by alternating left and right strokes, while

maintaining position on the board (J. M. Sheppard, Osborne, et al., 2013). Surfers spend the greatest part of paddling time by paddling back out through breaking waves to the take-off area. Although the average time for paddling for the researched group was 25.9 s, all subjects had intervals which exceeded one minute and some of them recorded periods exceeding two minutes (Meir et al., 1991). Both, endurance and explosiveness are important for surfing performance. Surfers who lack stamina are unable to maneuver and position themselves in the proper place to catch waves. On the other hand, surfers, who lack explosive power and are unable to paddle at maximal velocities, usually enter waves later and thus, have to perform a quick pop-up (stand up on the board) when the waves are more vertical. Consequently, the phase of actual wave ride is more challenging as well (J. Nessler et al., 2019).

1.5.2. Surfboard paddling and swimming

Past research showed that there are considerable biomechanical similarities between surfboard paddling and freestyle swimming (J. M. Sheppard, Nimphius, et al., 2013). High correlations were found also between upper body strength and power and freestyle swimming performance (Hawley, Williams, Vickovic, & Handcock, 1992; Toussaint & Beek, 1992).

1.5.3. Upper body strength, anthropometric features and paddling

Paddling a surfboard requires strength, stability, and practice. For the avid surfer, paddling becomes a relatively effortless skill. For the novice, paddling can be frustrating and painful. Being relatively fit and accustomed to strenuous exercise helps in paddling. It can be definitely a workout until one becomes efficient (Guisado, 2011).

As mentioned above, paddling movement is comprised of pushing and pulling movement. Paddling is actually a closed kinetic chain (CKC) activity, because the distant segment is fixed and the body moves around it. Or at least it can be called as quasi-CKC

activity when accounting for the fluid movement around the hand. Thus, the study of Coyne et al. (2016) examines the utilization of pull up and dip exercises as CKC measure of upper extremity strength in surfers. Strong association was found between relative upper-body pulling strength and sprint paddling ability (J. M. Sheppard et al., 2012). However, this correlation did not exist when only the competitive cohort was tested (J. O. Coyne et al., 2016). In spite of this fact, researchers found differences in competitive surfers between faster and slower paddlers, which indicates that once a certain level of relative pull-up strength is reached, improvements in paddling speed may not be necessarily associated with pull-up strength (J. O. Coyne et al., 2016). Strong correlation was found between relative 1RM dip strength and sprint paddling ability (J. M. Sheppard et al., 2012). On the contrary, there was no significant correlation found between endurance paddling (400 m trial) and relative 1RM pull-up or dip strength. The reason for that may be that with the initiation of every movement, surfers must overcome a higher resistance to begin with to accelerate their body and a surfboard on the water. It means that with increasing distance, correlations between upper-body strength and paddling speed decreases (J. Coyne et al., 2017; J. M. Sheppard et al., 2012).

1.5.4. Effect of strength training on surfers

Strong correlation between strength and sprint paddling performance does not indicate cause and effect. Thus, there was a research conducted on examining the effect of 5 week upper body maximal strength training on endurance and sprint paddling in competitive and recreational surfers. Six competitive and eleven recreational male surfers were recruited for this research. Training group (TRAIN) consisted of eleven subject (four of them were competitive surfers). In the control group (CONT) there were six subjects (2 of them were competitive). Before the training intervention and after 5 weeks of training, fat mass, upper

body relative strength – 1 repetition maximum (RM) pull-up and 1RM dip strength, sprint (5, 10,15m) and endurance (400m) paddling performance were tested (J. Coyne et al., 2017).

1.5.5. Anthropometry and paddling performance

Sheppard et al. (2012) investigated the relationship between anthropometry and upper-body strength with sprint paddling performance. Significant correlation between arm span and sprint paddling was ascertained (Sheppard et al., 2012), however, there are no studies examining the correlation between arm span and endurance paddling performance. Strong correlation between fat mass and weight with paddling performance in competitive surfers was found, especially in 400 m paddling trial. That shows the negative effect of excess weight and fat mass on prolonged surfboard paddling performance (Coyne et al., 2016).

In regards to relationship between strength training and body composition, researchers found difference between weak and strong participants. In weak surfers, there was higher increase in body mass compared to strong, whereas strong subjects experienced greater reduction in fat mass than the weak. Surfers who are weak or have no experience with strength training are much more likely to accumulate fat-free mass in the initial stages of maximal strength training due to the fact that it is novel stimulus (J. Coyne et al., 2017). This evidence is important because previous study discovered that decrease in fat mass improved performance in 400-m endurance paddle in both groups – competitive and recreational (J. Coyne, 2015). It follows, that coaches should compare athlete's body mass and fat mass with norms for elite surfers (which is of a great significance when athlete's fat mass is above norms) and use this information for upper body strength- and nutritional intervention to enhance athlete's level of performance. However, performance may be also hindered when the athlete exceeds the threshold for weight, especially when being very lean before the training intervention (J. O. Coyne et al., 2016). This problem is not relevant when strength

training is not novelty for the athlete or when the athlete has high levels of endurance training (J. O. C. Coyne et al., 2017).

1.5.6. Paddling performance and strength training

Research shows that in TRAIN group sprint paddling speed (5, 10, 15m) increased. However, initial strength level of a surfer actually plays the main role in the effect of maximal strength training on paddling velocity. In weak surfers, there was greater increase in both: endurance and sprint paddling performance. However, in control group both: endurance and sprint performance worsened. It was hypothesised that upper-body strength training will have the greatest effect on sprint paddling performance. Interestingly, even though TRAIN group improved in all the aspects, the greatest improvement was in endurance paddling trial (400 m). Data indicate that increase in upper body strength results in enhanced paddling economy and theoretically enables to paddle at lower levels of cardiorespiratory function at the same paddling speed. It was found out that the greatest difference between paddling speed of recreational and competitive surfers was in 400-m trial (J. Coyne, 2015; J. O. Coyne et al., 2016; J. M. Sheppard, Nimphius, et al., 2013). The biggest difference between competitive and recreational surfers was in endurance paddling performance. It indicates that improving endurance paddling performance may result in improving the surfing ability of recreational surfers (Coyne et al., 2016).

However, it also should not be forgotten that the most significant effect of the strength training intervention of the TRAIN group was a reduction in fat mass in comparison with the CONT (J. Coyne et al., 2017). As lower fat mass was correlated with better endurance paddling ability (J. Coyne, 2015), it may actually be that this decrease in fat mass might be the cause of better performance in endurance paddling trial (J. Coyne et al., 2017).

In the study of Coyne et al. (2017), greater improvement in relative dip strength compared to relative pull-up strength after 5-week strength training was found. This finding is valuable with respect to previous study showing significant correlations between relative dip strength and sprint paddling ability over 5, 10 and 15 m (J. Coyne, 2015).

As mentioned above, Coyne et al. (2016) did not find a significant correlation with 1RM relative pull-up or relative dip strength and endurance paddling (400 m) ability. The average relative 1RM pull-up strength for competitive surfers in this study was 1.24, However in the later study, Coyne et al. (2017), found out that in the group of strong surfers, the greatest difference between TRAIN and CONT group was in 400-m paddling trial. On the other hand, the results of the sprint paddling trials of CONT and TRAIN group of strong surfers were quite similar. Sheppard et al. (2012) found differences in competitive surfers between faster and slower paddlers with relative 1RM pull up strength of 1.27 and 1.15, respectively.

That indicates that once certain level of maximal relative strength is reached, further gains in maximal relative strength may not improve performance in surfboard paddling, especially sprint paddling ability. Thus, strong surfers should engage in more specific training methods such as resisted sprint paddling or developing other mental and physical qualities (J. Coyne et al., 2017).

In general, in surfing, there is high volume of sprint and endurance paddling, which appears naturally within surfing activity (J. Coyne et al., 2017). All the evidence suggests that sprint and endurance paddling performance are both important for competitive outcome (J. O. Coyne et al., 2016). On the other hand, there is a lack of formalized maximal strength training. An upper body maximal strength training might be a great opportunity to improve surfboard paddling ability. Surprisingly, World Surf League (WSL) surfers (the best competitive surfers) demonstrate low training age (<1-2 years) in strength conditioning. It is

also recommended to establish adequate levels of strength before power and speed, which implies that strength training is meaningful for surfing performance (J. Coyne et al., 2017).

More research should be conducted on endurance paddling performance, including examining the correlation between endurance paddling performance and maximum repetition at body weight pull ups and dips should be done (J. O. Coyne et al., 2016).

1.5.7. Paddling technique with arched back

There are multiple surfing manuals dealing with surfing and paddling technique. Paddling technique is complex, however, this thesis focuses on relationship between arm paddling performance and posterior chain. Thus, this section will only refer to only one feature of arm paddling – back posture when paddling.

According to surfing methodical manuals, back should be extended when paddling (Babič, 2008; Bryant, 2014; Guisado, 2011; Wisewell, 2013). Wisewell (2013) argues that one should keep their chest high when paddling. They should not lie flat on the board, because this will severely hamper their paddling technique. Strong paddling helps surfers to better position themselves for waves and catch them once they are in the lineup (place where the waves are breaking). Body posture is important key for paddling. Chest should be kept high off the board at all times. One should not lie flat with chest on the board, even though it may feel natural. Paddling with the chest high allows surfers to pull more water, thus maximizing the power of the arm strokes (Wisewell, 2013). Most beginners have problems with keeping their chest up when paddling. It requires a great deal of back extensor strength and endurance. However, it is the key to powerful paddling. When the chest is up, surfers are able to pull water more easily because their shoulders are in stronger position. In other words, they have a greater biomechanical advantage when paddling with their chest off the board.

Keeping their head up will help them keep their shoulders relaxed and their stroke fluid (Guisado, 2011).

Rob Case, global surfing paddling technique expert, creator of XSWIM and the Surfing Paddling Academy, explains the difference between paddling technique with and without arching the back on two athletes. The first was a young surfer with more than 6 years of experience in surfing, who took one on one paddle stroke analysis and training to increase his paddling efficiency to catch more waves while saving the energy. This athlete was told to keep his back arched to increase the leverage of his arm in the stroke. The data shows that this athlete took 22 fewer strokes per minute (1320 strokes per hour saved) when decreasing the arch in his back, which resulted in 25% increase in efficiency of arm paddling. The adult surfer who took the one on one paddling training experienced 24% improvement in stroke efficiency by lowering the arch in his back (Rob Case, 2017).

1.5.8. Sprint paddling technique adjustments

Recent study focused on the sprint paddling adjustments. Participants paddled 5, 10 and 15 m distance with different conditions: short and long paddle strokes, chest down, chest up, low arm recovery and high arm recovery. It was found out that chest low to the board, without considerable extension through the back and low arm recovery resulted in superior performance in sprint paddling (J. M. Sheppard, Osborne, et al., 2013).

There is lack of studies examining paddling from a qualitative point of view. There was only one study dealing with paddling technique. Authors of this study used video analysis and knowledge of elite surf coaches to identify differences in paddling technique among surfing population and allocated them to 3 main categories: 1) Paddle stroke length; 2) Chest position 3) Arm recovery. This study was conducted on 20 competitive male surfers. 9 subjects were competing on national level and 11 subjects were competing at World Tour

events. It was found out that the surfers' normal paddling technique was superior, compared to all technique variations. There are two reasons for that. The first is that the surfers were the most habituated to their normal paddling technique. The second reason is that there was singular coaching cue, and therefore was representative of what could be an extreme manifestation of each cue for comparison purposes (J. M. Sheppard, Osborne, et al., 2013).

It was also found out that a moderate stroke length was most optimal. There was actually no difference found between long and short paddle stroke. The aim of the long paddle stroke is to reach as far forward as possible and pull through as far back as possible. On the other hand, short paddle stroke results in higher cadence. It was anticipated that the shorter and higher cadence stroke would be superior for initial acceleration and the longer paddle stroke would be beneficial for top speed components of the sprint paddle time trial. Researchers assumed that long paddling stroke would result in the ability to apply force over longer period of time and thus the impulse from each stroke would be larger. However this hypothesis was not confirmed by this study. The reason for that might be that the most effective position of arm is when the hand and arm are in a vertical position, however, in the longer stroke the hand and arm are in a poor position to apply appropriate force at the start and finish of the stroke.



Figure 1. Surfer performing a long arm paddling stroke. The lines represent the arm entry for a moderate and short paddle stroke (J. M. Sheppard, Osborne, et al., 2013)

In sprint paddling, low chest position was beneficial in comparison to the high chest position. Researchers explained this phenomenon by hypothesizing that high chest position might place the shoulder and arm in a poor position for propulsion. High chest position is, however, the most common technique in surfers (J. M. Sheppard, Osborne, et al., 2013).



Figure 2. Low chest position in sprint paddling. Action is characterised by a relatively neutral spine with the chest and sternum in contact with the surfboard (J. M. Sheppard, Osborne, et al., 2013)

Experiment shows that low arm recovery led to faster paddling. Reason may be that unlike swimming, surfer is not able to roll on a surfboard when paddling and thus it is not efficient way to recover arm in paddling or beneficial for the stroke impulse.



Figure 3. High elbow recovery during sprint paddling. Bent elbow is higher than the torso. Straight line represents low arm recovery position (J. M. Sheppard, Osborne, et al., 2013)

It was found out that kicking when paddling is faster than only paddling. Surfers kick their legs when paddling in following occasions: 1) when catching a wave 2) when moving away from the impact zone of the wave (place where the waves are crashing) 3) when wanting to receive priority for the next wave in competition. Surfer competing for the best take-off position will gain the distance needed to get priority for catching a wave, which is really important for surfing performance (Loveless & Minahan, 2010b). It is not known however, whether kicking legs when paddling actually helps with propulsion or whether it changes the position of centre of mass and decreases drag (Rob Case, 2017).

There was a study examining the effect of wetsuit on paddling. Researchers did not try to find only the average magnitude of variability of the paddling movement. Their study focused also on structure and organization of movement variability in paddling cycles. Successive movement cycles are interdependent and variability between cycles is a rich source of information about the nature of movement coordination. Thus they used nonlinear analysis techniques to examine patterns of motion that occur over time and to evaluate neuromuscular control of repetitive paddling movement (J. A. Nessler et al., 2015).

1.5.9. Swimbench

There was a study using biokinetic swimbench ergometer to examine the correlation between sprint freestyle swimming and arm power in competitive swimmers. Researchers found strong relationship ($r = 0.90$) between arm power and sprint performance. Highest power values were recorded at arm velocities between 2.05 and 2.66 m.s^{-1} and the mean velocity producing peak power was $2.4 \pm 0.11 \text{ m.s}^{-1}$. It was also observed that correlation between arm power and swimming performance decreased with increased swimming distance (Sharp, Troup, & Costill, 1982).

Since the freestyle arm pull is a complex set of varying joint motions and multiple upper body muscle groups are used, the power measurements must be made while duplicating the actual movement as a whole to gain a full understanding of the role played by power in swimming. Although the swim bench pull does not exactly mimic the swimming pull as executed during free swimming, the pull taken on the bench is similar in the sense that the joint angles and muscle groups vary in the same way as in actual swimming (Sharp et al., 1982). Currently, researchers observed similarity between the EMG-stroke profiles in endurance surfboard paddling and land-based paddling (J. Nessler et al., 2019).

Swim-bench has been used by many swimmers for the purpose of improving muscle strength, power and endurance of specific muscle groups related to arm stroke. That has been based on the concept of specificity of strength training, which means that the maximal benefit may be obtained from an exercise motion which most closely simulates that in actual performance (Ogita & Taniguchi, 1995).

One study examined changes in performance parameters of the propulsive muscles (triceps longum, triceps lateralis and latissimus dorsi) during swim bench exercise in swimmers. Surface electromyography (EMG) was used to assess the intramuscular coordination in terms of fatigue and motor unit recruitment to determine the intra-individual effects of different periods in the normal training process. There was difference between junior and elite swimmers. In elite swimmers, the variation in performance was in relationship with variation in training loads whereas in junior swimmers there was a trend to improve performance with no relationship to training load. The main reason for that was body growth and enhanced physical abilities which accounted for a steady improvement in swimming performances throughout the training year in junior swimmers. The elite athletes, however, had already reached a stable performance level, and thus the long term-changes are small. In

that case, performance is predominantly affected by the present and previous training load (Ganter et al., 2007).



Figure 4. Initial position on the isokinetic swim bench for the exhausting 30-s test using the butterfly arm stroke (Ganter et al., 2007)

Fatigue occurred in propulsive muscles even during the 30-s test on the swim bench. Decreasing EMG frequencies throughout the test indicated progression of localized muscle fatigue. This phenomenon appeared almost in the all test for the triceps brachii caput longum and laterale. Contrarily, the decrease in latissimus dorsi was not consistent. The reason for that may be that triceps brachii caput longum and laterale is important for propulsion in freestyle swimming and has long activity time (as well as latissimus dorsi), but is smaller in size than latissimus dorsi muscle (Ganter et al., 2007).

In the past, researchers used tethered boards (Lowdon, Bedi, & Horvath, 1989), arm crankers (Lowdon et al., 1989), swim-bench ergometers (Meir et al., 1991), and modified kayak ergometers (Mendez-Villanueva et al., 2005) to investigate peak aerobic power during surfboard paddling. Swimbench ergometer was used to measure external power output in swimmers (Swaine, 2000) and kneeboard paddlers (Morton & Gustin, 1997).

A study examining reliability of maximal-paddling performance in surfers was conducted. Peak power output was measured in 11 male surfers during six 10-s maximal-intensity paddling trials. These tests were executed in laboratory as well as on field. For the laboratory test, swim bench was used and the field tests were accomplished in the pool. Two tests were done in a pool: with and without kicking. Authors of this study found no differences among the laboratory or field tests. Thus, they conclude that both swim bench and swimming pool tests are reliable in measuring maximal-paddling performance (Loveless & Minahan, 2010b). As mentioned above, Loveless and Minahan (2010) used swim bench to assess maximal-paddling performance in surfboard riders. Although it is not known if swim-bench ergometry can be used to assess maximal-paddling performance due to uniqueness of upper-body paddling position – hyperextension of the trunk and lack of hip drive, Loveless and Minahan (2010) argue that swim bench ergometers are currently the most sport-specific devices available for surfboard paddling.

1.5.10. Front Crawl

As the pattern of front crawl stroke varies between individuals, it is more important that swimmers develop the “feel” for the water rather than copying the best front crawl swimmers. Also the velocity of swimming correlates with maximal distance per stroke at a low frequency. Swimmers with long maximal stroking distance at low frequency achieve high swimming velocity. For swimming performance improvement, it was suggested to practise with slow stroke frequencies and longer distance per stroke (Toussaint & Beek, 1992).

1.5.11. Muscles used in paddling

Arm paddling cycle can be divided into two phases: propulsion of the body (pull-through) and the return phase of the hand (recovery). The greatest anterior position was established as the beginning of the stroke (0%). Table 1 shows the beginning and the end of each phase in percents of the stroke duration (J. A. Nessler et al., 2015).

Table 1. Phases of arm paddling stroke. (ii) (J. A. Nessler et al., 2015)

Phase	From (% of the stroke)	To (%of the stroke)
Hand entry (ii)	0 (ii)	20 (ii)
Propulsive phase (ii)	20 (ii)	70 (ii)
Return phase (ii)	70 (ii)	20 (ii)

Although, there is currently a paucity of information available for muscle activation in water-based activities (Jeff A. Nessler, Hastings, Greer, & Newcomer, 2017), a study focused on EMG activity in muscles in arm paddling was executed. The study focused on both endurance paddling as well as sprint paddling. The endurance paddling condition was determined by the speed of 1.0 m.s^{-1} and the speed of sprint paddling was 1.6 m.s^{-1} . 3 muscles were examined in this study: latissimus dorsi, deltoid (middle and posterior) and trapezius (upper and middle). The EMG test showed that in sprint paddling the activation of all tested muscles increased. Moreover, there appeared a more extreme rate of muscle recruitment in latissimus dorsi in the greater velocities (J. Nessler et al., 2019).

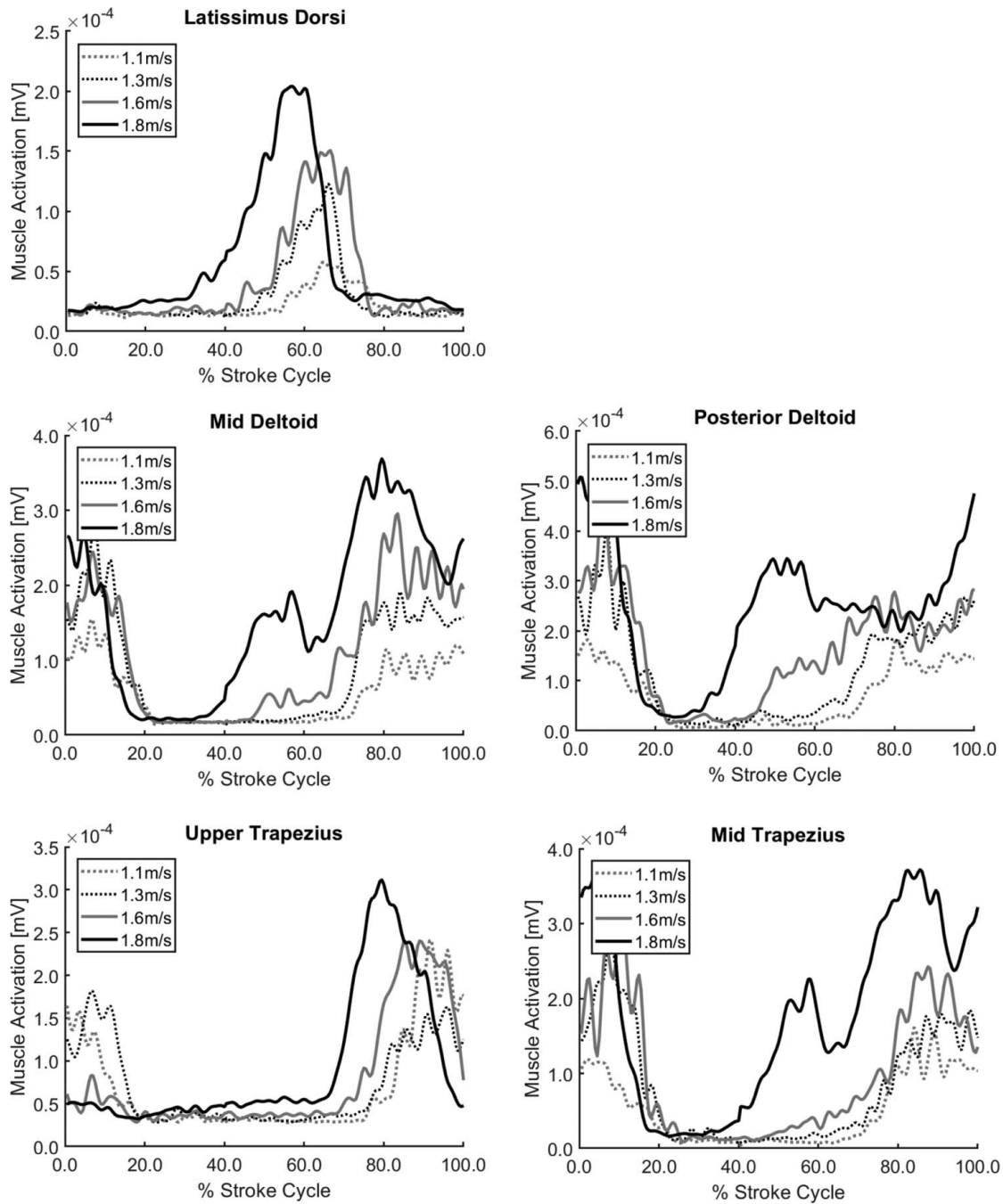


Figure 5. Muscle activation patterns (for the right side) at 4 different paddling velocities. Muscle activation is expressed with respects to the stroke cycle (0% hand at the most anterior position) (J. Nessler et al., 2019)

Thus, the region from 20 to 70% of the stroke corresponds to propulsive phase and the part of the stroke from 70 to 20% corresponds to the return phase. Hand entry occurs at 0-20% of the stroke duration. The table above shows that latissimus dorsi and triceps brachii contribute

primarily to propulsion because their peak activation was around 40 and 50% of the stroke cycle respectively (mid-propulsive phase). Erector spinae was the most activated during the mid-propulsive phase as well, which suggest that this muscle mainly provides stability for forceful shoulder and elbow extension on the ipsilateral side. The remaining muscles were most active during the middle of the return phase (80-100% of the stroke duration). Upper trapezius and infraspinatus were active longer than mid trapezius, which indicates that it may contribute mainly to the return on the hand. Middle deltoid had two peaks of activity. The main appeared at late return phase. The smaller peak appeared at 60% of the paddling stroke duration, which means that it might be auxiliary muscle in propulsion (J. A. Nessler et al., 2015).

*Table 2. Muscles used in paddling, their function and peak activation of these muscles at the percentage of paddling stroke. *Peak activation at phase (% of a stroke cycle); **Role/function of the muscle; ***Active mainly during middle of the return phase; (i)(J. A. Nessler et al., 2015; J. Nessler et al., 2019)*

Muscle	PAP*	MF**	comments
Latissimus dorsi	50	propulsion	
Triceps brachii	40	propulsion	
Erector spinae	60	Providing stability for forceful shoulder and elbow extension on the ipsilateral side	
Infraspinatus	80-100		Remained active longer than mid trapezius
Upper trapezius	80-100		Remained active longer than mid trapezius
Mid trapezius	80-100***		
Mid deltoid	80-100	also play a role in augmenting the propulsive activity of latissimus dorsi and triceps brachii	Smaller peak at 60% of the paddling stroke

To sum up, muscle activation in arm paddling stroke on a surfboard was similar to free-style swimming, especially the unique pattern of activation of the middle deltoid (J. A. Nessler et al., 2015). There was difference between the activation curve of latissimus dorsi when paddling with and without wetsuit. In the attempt with wetsuit, latissimus dorsi was most active at 30-60% of the paddling stroke cycle and the activity of this muscle remained constant in this part of the stroke. However, when paddling without wetsuit, the activation of latissimus dorsi reached the highest point at 55% of the stroke and was really obvious compared to the rest of the cycle. However, there is a need to examine the role of the other muscles including supraspinatus, subscapularis, serratus anterior, and pectoralis major to understand the activation pattern in greater detail (J. A. Nessler et al., 2015).

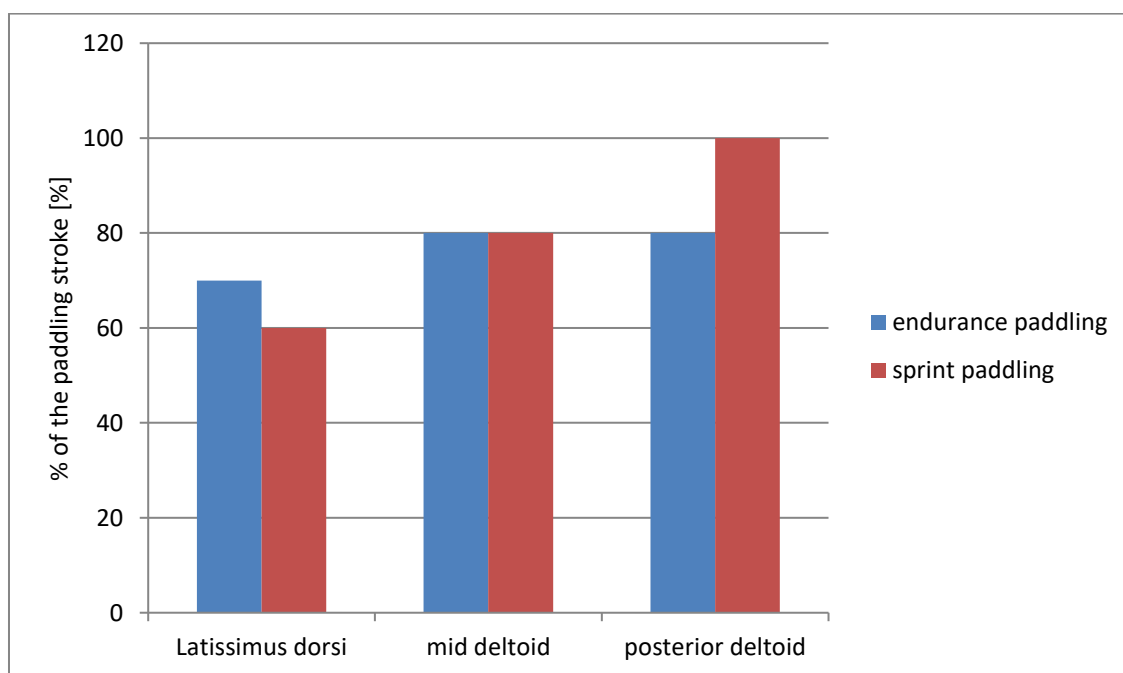


Figure 6. The greatest activity of 3 muscles (latissimus dorsi, mid deltoid and posterior deltoid) in the procentula part of the paddling stroke cycle in endurance and sprint paddling.

Nessler et al. (2015) recorded activity of the lumbar region of erector spinae muscle, middle deltoid, upper and middle trapezius, infraspinatus, pectoralis major, medial head of triceps brachii and latissimus dorsi using surface EMG. Participants were tested under two

conditions: paddling with wetsuit and paddling without wetsuit. After the measurement, the peak level of activation and burst duration for each muscle were calculated.

The data for pectoralis major had to be excluded because they were corrupted in some subject due to periodic contact with the surfboard.

There was a case study on the activity of biceps and triceps brachii during 200 m crawl swimming trial. This study showed that the activity of both muscles decreased with increasing distance. One reason for that might be limitations in production capacity of the swimmer. However characteristics of the art of swimming which are changing with fatigue increase may be another cause. These findings are important for trainers who should apply them when creating training program for strength and / or resistance (Conceicao et al., 2010).

Table 3. Comparison of muscle activity in swimming and surfing. *not mentioned in the studies; **maximal voluntary contraction; (i)(J. A. Nessler et al., 2015; J. Nessler et al., 2019; Jeff A. Nessler et al., 2017); (ii) (Martens, Figueiredo, & Daly, 2015; J. A. Nessler et al., 2015; Pink, Perry, Browne, Scovazzo, & Kerrigan, 1991)

Muscle	Stroke phase or function in swimming	Stroke phase or function in surfboard arm paddling
Upper trapezius	Return phase (scapular rotation) most active during the entry and exit phase (ii)	Return phase (i)
Mid trapezius	*	Middle of return phase (i)
Rhomboids	Return phase (ii)	*
Supraspinatus	Return phase (ii)	*
Infraspinatus	*	Return phase (i)
Anterior deltoid	Return phase (ii)	*
Middle deltoid	Return phase (ii)	Return phase (i)
Posterior deltoid	Return phase; contributes to propulsion (ii)	Return phase (i)
Pectoralis major	Propulsion (71% of MVC**) active mainly during the “pull” interval (ii)	Propulsion (i)
Latissimus dorsi	Propulsion (75 % of MVC**) active mainly during the “push” interval (ii)	Propulsion (i)
Teres minor	Humerus stabilization (followed closely the activation pattern of pectoralis major) (ii)	*
Biceps brachii	Prime mover in early propulsion (ii)	*
Brachioradialis	Prime mover of early propulsion (ii)	*
Triceps brachii	Early propulsion (Strong triceps and biceps coactivation in two phases: first in early pull-through (stability of elbow joint to overcome water drag); second was found before the hand enters the water to brake the end of the recovery movement and control the hand velocity just before its entry into the water) (ii)	Propulsion (i)
Flexor carpi ulnaris	Early propulsion (ii)	*
Erector spinae	*	Mid-propulsion (providing stability for forceful shoulder and elbow extension on the ipsilateral side) (i)

1.5.12. Injuries

Surfing does not contribute to balanced muscular development. Due to the prolonged maintenance of posture when lying prone on the surfboard and repetitive paddling activity, surfers have more powerful shoulder flexors and extensors than other athletes, and less abdominal strength than other athletes. Surfers have also limited flexibility in shoulders, back and hamstrings. The repetitive arm stroke and body posture during adopted board paddling combined with muscular imbalances, such as weak core and rotator cuff imbalance, result in the overuse injuries of spine and shoulders (Mendez-Villanueva & Bishop, 2005). More research in prone paddling posture and muscles of the posterior chain might be helpful in designing compensatory exercise programme for surfers and preventing overuse injuries.

1.5.12.1. Back

A high chest position when paddling on a surfboard may place additional stress on the lower back of a surfer, in order to maintain the additional and potentially extreme extension required (J. M. Sheppard, Osborne, et al., 2013).

There was a study which examined the effect of wearing a wetsuit on the mechanics of surfboard paddling, the control of the movement and the energy use. Participants were paddling at the rate of 25 strokes/min and intensity of 20 Watts. No correlation was found between wearing a wetsuit and increase in metabolic cost, however there was a relationship found between wearing a wetsuit and changes in muscle activity and paddling motion. The results supported the hypothesis that wetsuit stimulates mechanoreceptors, which enhances proprioception and leads to improved control and stability of a joint. These findings could be used in injury prevention in surf paddling (J. A. Nessler et al., 2015). Research focused on the

effect of a neoprene sleeve on knee joint position showed that neoprene sleeve provides additional proprioceptive input (Herrington, Simmonds, & Hatcher, 2005).

More predictable, rigid and inflexible system unable to adapt to changing conditions and lacking variability in repetitive movement can raise risk of overuse injury (J. A. Nessler et al., 2015).

It was found out that greater skill or proficiency in human movement is linked to higher level of complexity of a movement. Opposed to that, lower level of complexity is often associated with increased age, disease and injury (J. A. Nessler et al., 2015).

Nessler et al. (2017) conducted study on the effect of inflatable vest on muscle activation. In this research Ergo Vest™ was used. The trunk was supported with an inflatable bladder located on the anterior aspect of the mid torso, directly under the surfer's sternum. It was found out that inflated vest decreases activity of trunk extensor muscles when paddling. Although, the EMG activity in back extensors decreased while wearing inflated vest, the exact mechanism is unclear. It also might be that the bladder provides increased sensory feedback for these muscles, which has been studied in previous research (J. A. Nessler et al., 2015). Another possibility is that the inflated bladder decreases back extensor muscles activation and results in increased passive back extension, which alters compressive forces and moments in the lumbar spine area.

Low back pain is a common problem in amateur surfers. Lying prone on surfboard and paddling requires shoulder, back and neck extension which can lead to overuse injuries. Little attention to injury prevention and rehabilitation has been paid. Only few products that would improve comfort and reduce injury in surfers have been developed (Jeff A. Nessler et al., 2017). Many researchers focused on mechanism of lower back pain in the general population (Balagué, Mannion, Pellisé, & Cedraschi, 2012; Ehrlich, 2003; Hoy, Brooks, Blyth, &

Buchbinder, 2010; Nguyen, Lefèvre-Colau, Kennedy, Schneider, & Rannou, 2018; Paraskevas, 2018). Some authors suggests that building back muscles helps prevent injury while surfing (Almond, 2009). However, little research focused on subacute low back pain that can occur immediately following bouts of prone activities like surfboard paddling. Although the primary function of back extensor muscles is extending the spine, they may also generate intervertebral compression, which may be reason for low back pain in surfers. Moreover, the activity of erector spinae muscle and isometric trunk extension, which lead to increased activation of erector spinae, are related to low back pain in surfers, even though the aetiology of low back pain is more complex. In contrast with locomotion, standing, lifting and bridging, where relationship between EMG activity in back extensor muscles and low back pain was found, prolonged prone paddling on a surfboard is not weight bearing activity, but generates compression on intervertebral discs and that may be reason for low back pain reported by surfers.

1.5.12.2. Shoulder

Lifting the arm and elbow while keeping the hand clear of dragging on the water surface, as can be seen in paddling technique with high arm recovery would put the glenohumeral joint to increased internal rotation. This position may increase the likelihood of shoulder impingement (J. M. Sheppard, Osborne, et al., 2013).

1.5.13. Posterior chain tests

In the review of literature on isometric back extension tests, Biering-Sorensen test is considered as most clinically useful, since it is easy to perform, it requires no special equipment, and enjoys the most support from the literature. During the test, the legs of the subject are fixed to the table by 3 wide canvas straps and the arms are folded across the chest. The subject is asked to maintain the horizontal position until he or she can no longer control

the posture or has no more tolerance for the procedure or until symptoms of fatigue are reached (Moreau, Green, Johnson, & Moreau, 2001). Evans, Refshauge & Adams (2007) claim that the role of isometric muscle endurance testing and training is unclear from both: performance and injury prevention perspective. The authors examined endurance of trunk extensor muscles in athletes, using the Biering-Sorensen test, which is reliable and receives the most attention of the isometric trunk endurance tests. The mean score in this test was 164 seconds in athletes. No significant difference between the performance of male and female athletes has been found. However, a few studies of non-athletic population report that females scored better than males in this test. The results of the holding time may be influenced by the type of sport and training preferences of the athletes, level of motivation, self-efficacy, body mass index, and training preferences (Evans, Refshauge, & Adams, 2007).

A study from Adegoke and Babatunde (2007) examined the effect of 6 weeks exercise program to increase endurance of trunk extensor muscles. The authors of this study used modified Sorensen test to measure the endurance time. Participants were in prone position with the arms along the body and were asked to keep their body in one line (Figure 7).



Figure 7. Modified Sorensen test. Adapted from “Effect of an Exercise Protocol on the Endurance of Trunk Extensor Muscles – Randomized Control Trial (Adegoke & Babatunde, 2007)

A significant difference has been found between the experimental and control groups after the end of the experiment, as the posterior chain muscle endurance increased in the experimental group (Adegoke & Babatunde, 2007).

McIntosh, Wilson, Affleck and Hall (1998) used isometric prone chest raise test in their study. The subject was in prone position with the legs extended and the hands positioned at the temples perpendicular to the body. The subject was asked to raise the head, arms, and chest from the floor and to hold the position as long as possible while breathing normally. The results of the test varied between gender and age. Mean score of healthy females in the age range 19-29 was 99 seconds and in females in the age range 30-39 was 106 seconds (McIntosh, Wilson, Affleck, & Hall, 1998).

The isometric prone chest raise position is more similar to paddling posture in surfing than Biering-Sorensen-test posture. However in version of isometric prone chest raise, the subjects use the muscles of their arms. Thus, for the use of the study of posterior chain endurance in surfers, modified prone chest raise with arms along the body was used. By holding the arms along the body, the use of arm muscles will be eliminated and thus peak power paddling test will be less affected.

According to the study of Ito et al. (1996) a mean performance time in Biering-Sorensen test was 128.4 seconds in healthy female subjects ($n = 53$). Only 10 males were able to achieve 5 minutes and no one was able to continue the test more than 5 minutes ($n = 37$).

The studies of Evans, Refshauge & Adams (2007) and Adegoke and Babatunde (2007) indicated association between poor performance in Biering-Sorensen test and lower back pain. Thus, it could be useful to search for correlation between posterior chain endurance and experience in surfing.

2. PRACTICAL PART

2.1. Materials and Methods

2.1.1. Participants

Fourteen amateur female surfers (age 30.86 ± 2.95 years, body mass 60.66 ± 3.58 kg, height 1.66 ± 0.06 m, subject characteristics measured mean \pm SD) were recruited from the local surfing population. Their mean surfing experience was 4.36 years SD \pm 4.08. Mean time spent surfing in summer was 387.86 min (6.46 h) per week SD \pm 231.68 min (3.86 h). Mean time spent surfing in winter was 272.14 min (4.54 h) SD \pm 173.62 (2.89 h). Eleven of them participated in upper body strength training 1-7 times a week, mean time spent upper body strength training was 66.07 min SD \pm 50.36 per week. The testing group was quite heterogeneous, as their surfing level reached from beginner to advanced surfers.

2.1.2. Equipment

Commercially available VASA swim bench ergometer was used to test paddling peak power in participants. Hands were strapped to small paddles that were attached to a cable and pulley mechanism that provided resistance by spinning a small wind turbine that simulated water loads. Power generated by the subject was output in real time to a small digital screen.

2.1.3. Method

All subjects received a clear explanation of the study, including the risks and benefits of participation. Griffith University reference number 2018/412 was fully approved by the Griffith University Human Research Ethics Committee.

All subjects indicated that they were of any cardiovascular, musculoskeletal, or neurological condition that might have affected performance. Participants also completed a health history questionnaire and provided written informed consent for testing and data analysis. Approval for this investigation was granted from the Australian Institute of Sport Research Ethics Committee.

The laboratory testing was completed during one day. The laboratory test consisted of prone chest hold to exhaustion, followed by 20 min break, 5 min paddling warm up on swim bench, followed by 2 min break, 10 s of maximal-intensity paddling performed on a Vasa swim-bench ergometer, repeated prone chest hold (10x30s), and 10 s of maximal-intensity paddling performed on a Vasa swim-bench ergometer. The testing day schedule is demonstrated in the table below.

Table 4. Testing protocol.

	<i>Activity</i>	<i>Duration</i>
1	Explanation of the study	5 min
2	Health screening	8 min
3	Informed consent for testing and data analysis	5 min
4	Prone chest hold to exhaustion	Max
5	Break	20 min
6	Paddling warm-up on a swimbench	5 min

7	Break	2 min
8	Maximal intensity paddling	10 s
9	Repeated prone chest hold	10 x 30 s
10	Maximal intensity paddling	10 s

Table 5. Warm-up protocol.

	<u>Activity</u>	<u>Duration</u>
1	Light-intensity continuous paddling	3 min
2	Rest	30 s
3	Maximal intensity paddling effort	5 s
4	Rest	30 s
5	Maximal intensity paddling effort	5 s
6	Rest	30 s
7	Maximal intensity paddling effort	5 s

Prone chest hold to exhaustion was used to measure posterior muscle chain endurance. Participants were asked to hold the *sternum* off the floor while being in prone position. The subjects were asked to maintain maximal flexion of the cervical spine, pelvic stability being maintained through gluteal muscle contraction. Subjects were asked to keep the arms along their body, palms facing their thighs from the sides and not to touch the ground or body with their hands. Participants were barefoot, with feet on the ground and close together. Subjects were asked to maintain this position for as long as possible. Prior to the back extension endurance test, participants were asked to lift their chest from the floor as high as possible. A string was attached to suprasternal notch and Blu Tack was used to tag the maximum distance

from the ground. 75% of the distance was calculated and tagged on the string by Blu Tack as well. Participants were asked to hold their chest as high as possible for as long as possible and maintain >75% of maximum back extension. If the 75% mark touched the ground, participants were warned. When it touched the floor for second time or participants could not hold the chest up any more, the attempt was finished. Isometric prone chest hold endurance test was followed by 20 min break. Peak paddling power was tested on commercially available VASA swim bench ergometer. Hands were strapped to small paddles that were attached to a cable and pulley mechanism. Arm movement was relatively unrestricted, though subjects were instructed to paddle in a manner that was similar to their normal motion while in water. This included lifting their hand above the level of notional surfboard with each stroke to simulate bringing the hand out of the water. Firstly, subject completed 5 min warm upon Vasa swim bench ergometer. Warm up consisted of 3 min light-intensity continuous paddling, 30-s rest and three 5-s maximal-intensity paddling efforts replicating the test start. Each 5-s effort was separated by a 30-s rest. The warm-up was followed by a 2-min rest and 10-s maximal-intensity paddling trial on a swim bench ergometer. Each participant had similar resistance setting (5). Peak power output (W) was recorded from the digital display unit on the ergometer and used as the key performance indicator.

The first maximal-intensity-paddling trial was followed by repeated (10 times) 30-s prone chest hold >75% of maximal back extension with 10-s resting periods and second 10-s maximal-intensity paddling trial on a swim-bench ergometer. Instructions were used for each trial with the surfers verbally encouraged to paddle as hard as they could for the whole trial.

2.2. Results

A mean performance in isometric prone chest hold endurance test was 178.6 seconds in female surfers ($n = 14$). 5 subjects were able to achieve 200 seconds and the best result was 427 seconds. A mean basal paddling peak power performance in female surfers was 202W, the worst performance was 170W and the best 230W. A mean paddling peak power performance after the repeated prone chest raise exercise was 205W. The worst result was 170W and the best 230W.

No correlation was found between the performance in posterior chain endurance test and basal paddling peak power ($r = 0.08$) (Figure 8).

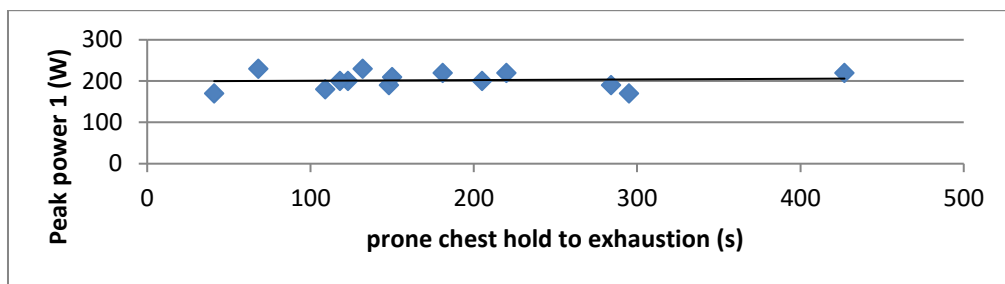


Figure 8. Correlation between isometric prone chest hold to exhaustion (s) and basal paddling peak power (W)

Very low positive correlation was found between the performance in posterior chain endurance test and the paddling peak power after repeated chest raise fatiguing exercise ($r = 0.30$) (Figure 9) and no correlation was found between the surfing experience in years and the performance in posterior chain endurance test ($r = -0.05$) (Figure 10).

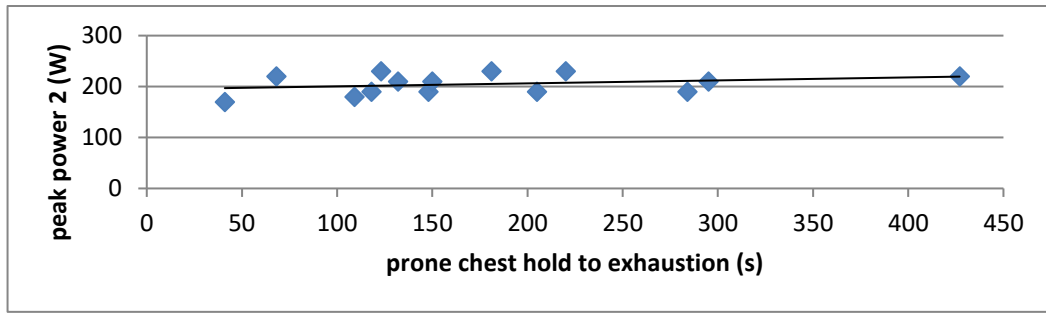


Figure 9. Correlation between isometric prone chest hold to exhaustion (s) with post-fatiguing-exercise peak power (W)

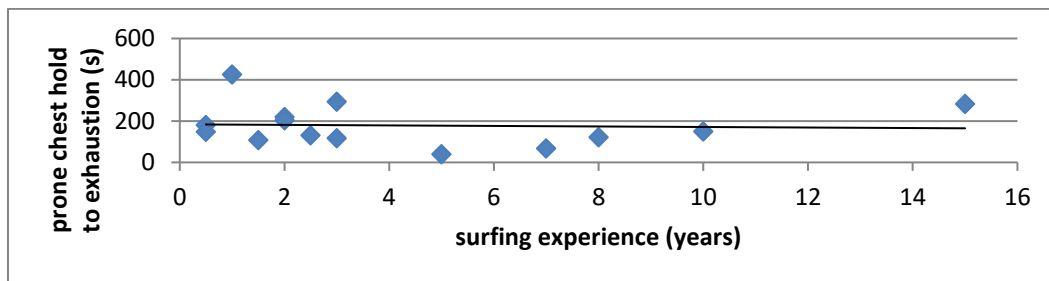


Figure 10. Correlation between surfing experience in years and isometric prone chest hold to exhaustion (s)

Strong positive correlation was found between the posterior chain endurance test and the surfing load in both: summer ($r = 0.68$) (Figure 11) and winter ($r = 0.61$) (Figure 12). The correlation between the posterior chain endurance test and load of surfing and upper body strength training was even stronger in both: summer ($r = 0.73$) (Figure 13) and winter ($r = 0.73$) (Figure 14).

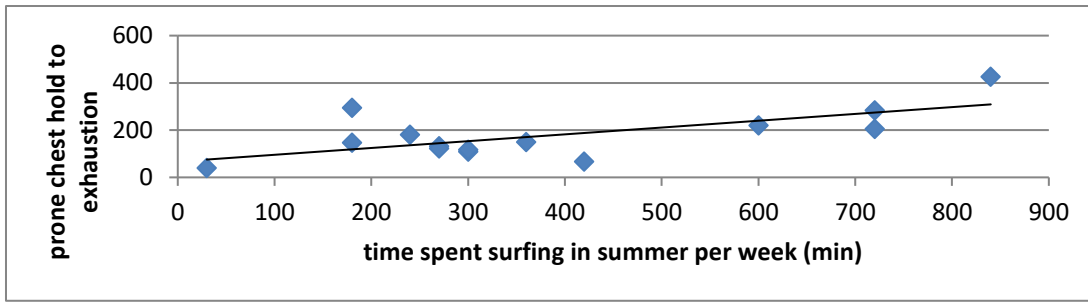


Figure 11. Correlation between the time spent surfing in summer per week (min) and isometric prone chest hold to exhaustion (s)

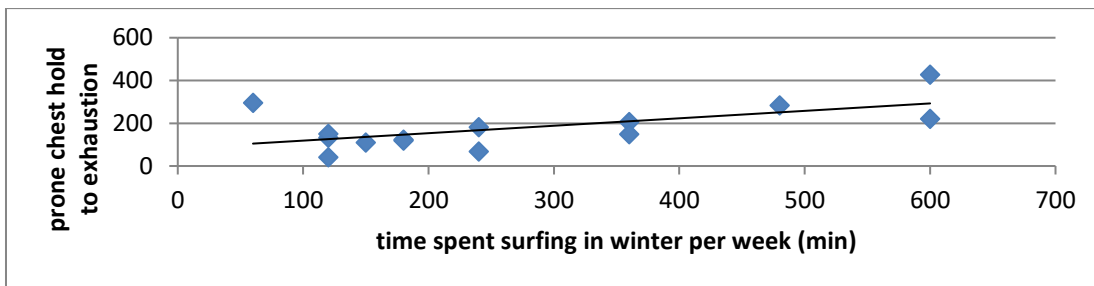


Figure 12. Correlation between the time spent surfing in winter per week (min) and prone chest hold to exhaustion (s).

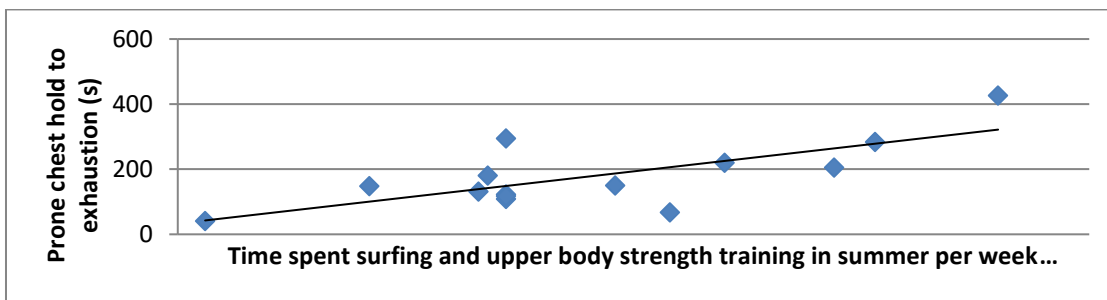


Figure 13. Correlation between the time spent surfing and upper body strength training in summer per week (min) and isometric prone chest hold to exhaustion (s)

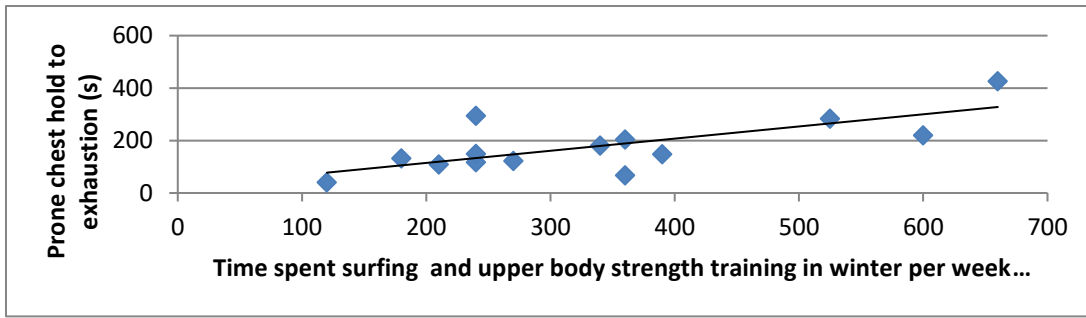


Figure 14. Correlation between the time spent surfing and upper body strength training in winter per week (min) and isometric prone chest hold to exhaustion (s)

Low positive correlation was found between the basal paddling peak power and the load of surfing in both: summer ($r = 0.39$) (Figure 15) and winter ($r = 0.33$) (Figure 16).

Low positive correlation was found between the basal paddling peak power and the load of surfing and upper body strength conditioning in both: summer ($r = 0.41$) (Figure 17) and winter ($r = 0.38$) (Figure 18).

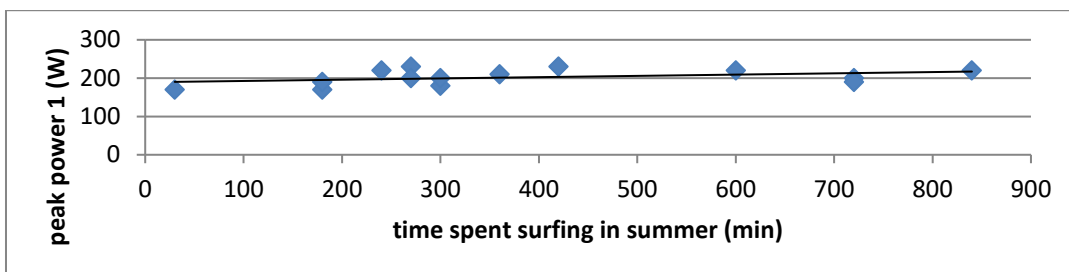


Figure 15. Correlation between the time spent surfing in summer per week (min) and basal peak power (W)

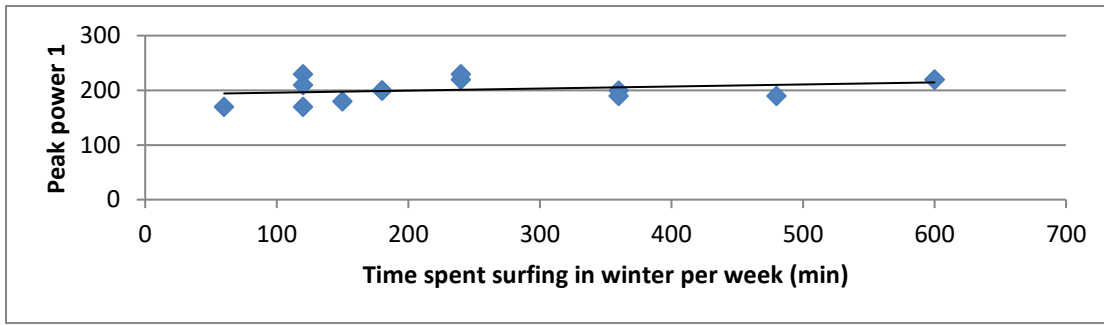


Figure 16. Correlation between the load, frequency of surfing in winter per week (min) and basal peak power (W)

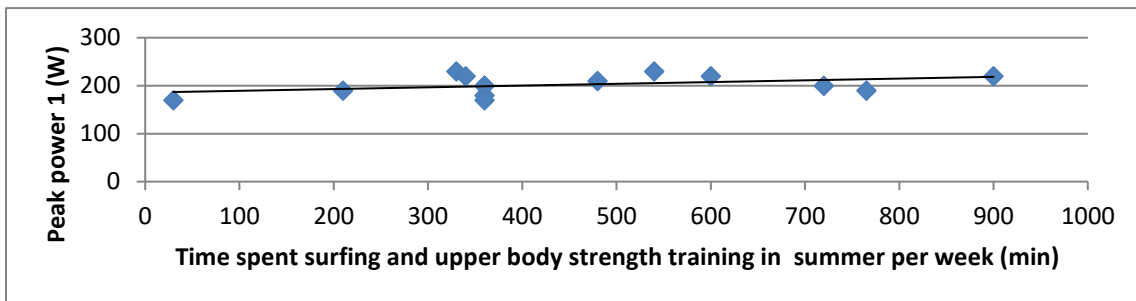


Figure 17. Correlation between the load, frequency of surfing and upper body strength training in summer per week (min) with basal peak power (W)

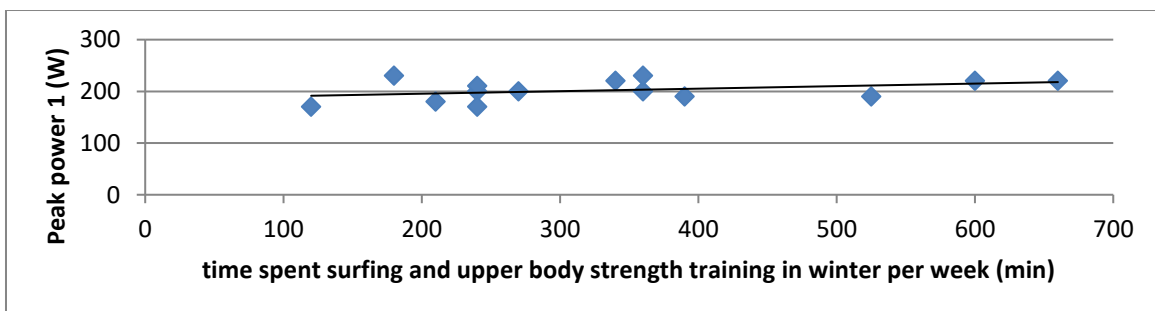


Figure 18. Correlation between load, frequency of surfing and upper body strength training in winter per week (min) with basal peak power (W)

Weak positive correlation ($r = 0.28$) was found between the results in isometric prone chest hold to exhaustion and percentual difference between basal peak power and post-fatiguing-exercise peak power (Figure 19).

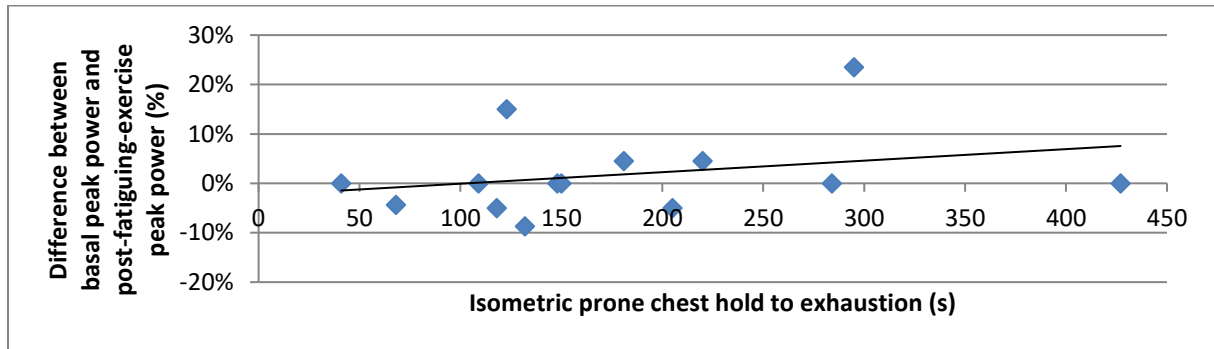


Figure 19. Correlation between the change in peak power after post-fatiguing-exercise (%) with isometric prone chest hold to exhaustion (s)

None or weak negative correlation was found between the percentual change in basal and post-fatiguing-exercise peak power with the time spent surfing in summer ($r = -0.26$) (Figure 20), winter ($r = -0.26$) (Figure 22), time spent surfing and upper body strength training in summer ($r = -0.14$) (Figure 21) and winter ($r = -0.03$) (Figure 23).

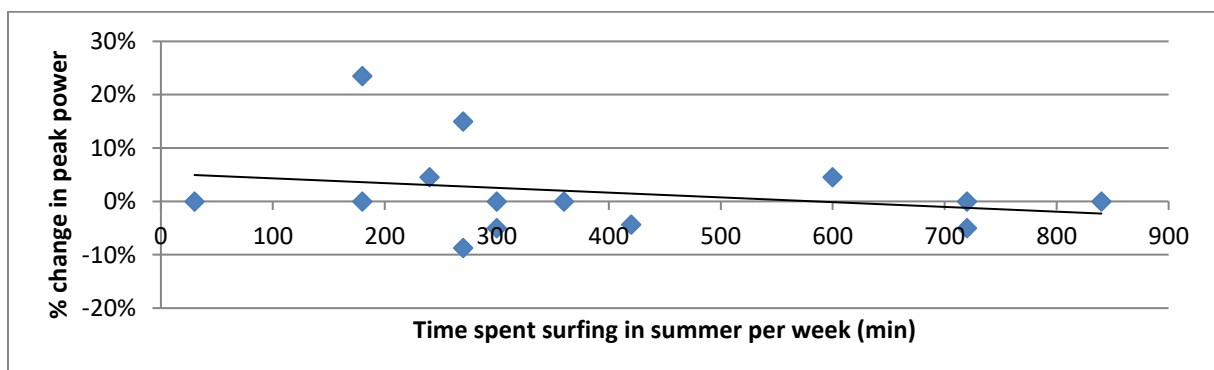


Figure 20. Correlation between the time spent surfing in summer per week (min) with percentual difference between basal and post-fatiguing-exercise peak power (%)

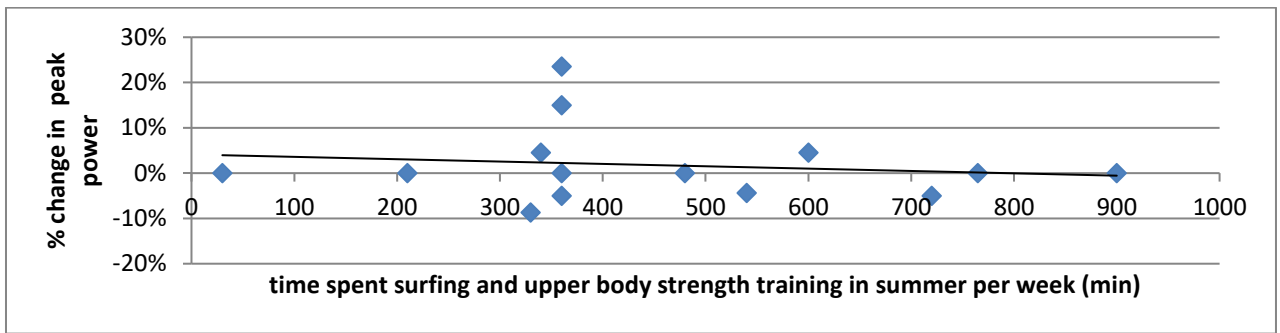


Figure 21. Correlation between the load and frequency of surfing and upper body strength training in summer per week (min) with the percentual difference between basal and post-fatiguing-exercise peak power (%)

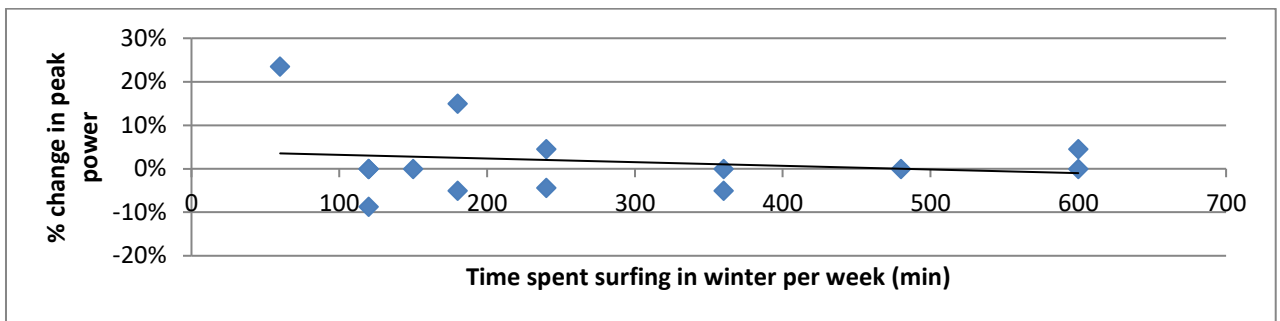


Figure 22. Correlation between the load and frequency of surfing in winter per week (min) with percentual difference between basal and post-fatiguing-exercise peak power (%)

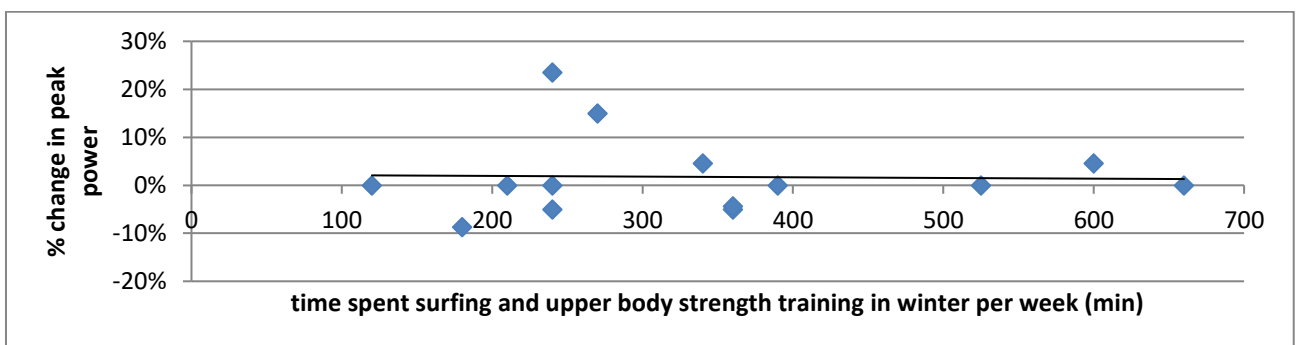


Figure 23. Correlation between the load, frequency of surfing and upper body strength training in winter per week (min) with percentual difference between basal and post-fatiguing-exercise peak power (%)

Weak positive correlation was found between the result in isometric prone chest hold to exhaustion and relative basal peak power ($r = 0.1$) (Figure 24).

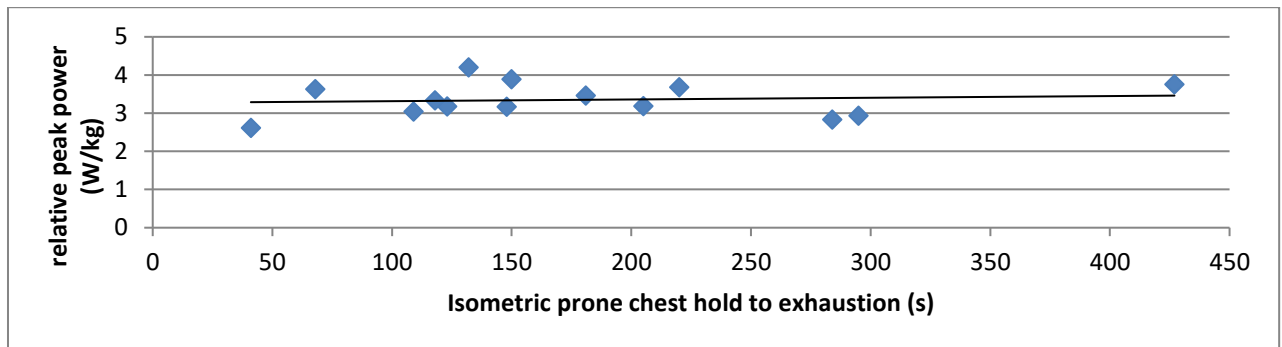


Figure 24. Correlation between the result in isometric prone chest hold to exhaustion (s) and the relative peak power (W/kg)

3. DISCUSSION

No previous research has been found that would examine the correlation between posterior muscle chain and surfing. There has been several studies focusing on anthropometry and paddling performance (Matthew John Barlow et al., 2016a; J. Coyne, 2015; J. O. Coyne et al., 2016; J. M. Sheppard et al., 2012), surfing injuries (Burgess et al., 2019; Dimmick et al., 2013; Falconi et al., 2016; Freeman, Bird, & Sheppard, 2013; Furness et al., 2014; Hammer & Loubert, 2010; Hay et al., 2009; Hohn et al., 2018; Inada et al., 2018; Klick et al., 2016; Minghelli et al., 2018; Mitchell et al., 2013; Nathanson et al., 2002; Pikora et al., 2012; Steinfeld, Keren, & Haddad, 2018; Takakura et al., 2013; Taylor, Bennett, Carter, Garewal, & Finch, 2004; Thompson, Pearce, Chang, & Madamba, 2004; Woodacre et al., 2015; Zoltan & Taylor, 2005), postural control (Chapman, Needham, Allison, Lay, & Edwards, 2008; J. A. Nessler et al., 2015; Jeff A. Nessler et al., 2017; Tran, 2015), peak power of upper and lower extremity (J. Coyne et al., 2017; Keiner, Yaghobi, Sander, Wirth, & Hartmann, 2015; Loveless & Minahan, 2010a; Secomb, 2016), physiological demands (O. R. L. Farley et al., 2012; A. Mendez-Villanueva & Bishop, 2005) of surfing and landing performance (Forsyth, Riddiford-Harland, Whitting, Sheppard, & Steele, 2018; Lina E. Lundgren et al., 2016; Lina Elizabeth Lundgren, 2015). Moreover, the research has been mostly done on competitive cohorts.

3.1. Relevance of swim bench ergometry

In the past, researchers focused on measuring peak oxygen uptake in surfers. They used tethered boards (Lowdon, Bedi, & Horvath, 1989), arm crankers (Lowdon et al., 1989), swim-bench ergometers (Meir et al., 1991), and modified kayak ergometers (Mendez-Villanueva et al., 2005). Swimbench ergometer was used to measure external power output in swimmers (Swaine, 2000) and kneeboard paddlers (Morton & Gustin, 1997).

On the other hand, there are only few studies dealing with peak power in surfing. Loveless and Minahan (2010) measured peak power in male surfers while using swim-bench ergometer. They suggested that it is not known whether swim-bench ergometry can be used to assess maximal paddling performance because of the hyperextension of the trunk and lack of hip drive in paddling technique of surfers. They also state that swim bench ergometer is currently the most surf-specific device available to measure surfboard paddling performance. Relationship was found between arm power and sprint performance in swimmers, when measured on swim bench ergometer. Authors of this study argue that the swim bench does not exactly mimic the swim pull, however, the joint angles and muscle groups vary in the same way in swimming as well as on swim bench (Swaine, 2000). It would be beneficial to examine the similarities and differences in biomechanics of front crawl stroke and surfboard paddle stroke, since it would provide more data and evidence for the use of swim bench in measuring surfboard paddling performance. Even though previous literature stresses the importance of high arch in the back (Babič, 2008; Bryant, 2014; Guisado, 2011; Wisewell, 2013), evidence shows, that lower arch in the back is actually more efficient and energy saving technique of surfboard paddling (Rob Case, 2017), which may make surfboard paddling technique a bit closer to swimming. Based on all this evidence, swim bench ergometer was used in this diploma thesis to measure peak power in female surfers.

3.2. Correlation between paddling peak power and posterior chain endurance in sprint paddling

However, no correlation ($r = 0.1$) between relative arm paddling peak power (W/kg) and posterior chain endurance has been found. Negative association was presumed between isometric prone chest hold and the difference between basal peak power and post-fatiguing-exercise peak power, as it was expected that better isometric prone chest hold results might be

associated with less decrease in peak power test following the posterior chain fatiguing exercise. It was assumed that there will be relationship between the frequency and load of surfing and upper body strength conditioning with peak power. All these assumptions, however, were not supported. It should be considered that posterior chain endurance was measured in the range of 100-75% of maximal back extension. That actually confirms the idea that in sprint paddling, surfers use mainly technique with chest low on the board (J. M. Sheppard, Osborne, et al., 2013) . This implies that posterior chain endurance does not affect sprint paddling. As mentioned earlier (Loveless & Minahan, 2010b), it is also possible that different technique is paddling on a surfboard and paddling on a swim bench might influence results. That was actually observed in front crawl stroke when swimming and on a swimbench ergometer. Even though, difference between swim pull and pull on the swimbench ergometer has been observed, the joint angles and muscle groups vary in the same way in swimming as well as on swim bench (Swaine, 2000). Moreover, surfers were instructed to maintain their paddling technique from surfing for the testing trial.

Loveless and Minahan (2010b) found out that leg kicking while paddling increases speed of paddling in surfers. This information can be used in improving sprint paddling performance in surfers and assist them to catch more waves or catch the waves earlier, which gives surfers more time for actual surfing the wave and gives them more time to stand up on the board (Loveless & Minahan, 2010b). However, the exact principle of how leg kicking increases paddling speed is not known. Interestingly, some experts argue that kicking does not aid propulsion but that its benefit comes from different weight distribution on the board, which results in decreased drag of a surfboard (Rob Case, 2017). Studová and Coxová (2014) argue that contralateral movement pattern, which is characteristic for human gait, where legs and arms move contralaterally, is the most effective, compared to the others: homololateral and homologous movement patterns. Contralaterality integrates left and right, lower and

upper part of the body simultaneously. In other words, contralaterality links all parts of body in one unit. From the evolutionary point of view, contralateral movement pattern is the most developed and complex. It also uses and links both hemispheres of the brain (Studdová & Coxová, 2014). That might suggest that this contralateral connection between arms and legs when paddling results in increased speed and efficiency of paddling performance.

These findings are vital for sprint paddling performance, as they show that it is not only upper body that is important for catching the waves. It may also save energy for catching more waves and aid in injury prevention of surfers.

3.3. Correlation between paddling peak power and posterior chain endurance in endurance paddling

However, no research has been done examining the role of back extension in endurance paddling or sub-maximal paddling performance. That would be actually beneficial for surfing, as surfers spend the greatest amount of paddling time by endurance or sub-maximal paddling, when they have to paddle back out to the place where the wave breaks or while paddling against the current to keep the right position for catching the waves (Meir et al., 1991).

The fact that surfers spend the most of the time by endurance paddling has also health implications. As there was no research dealing with chest position and biomechanics of endurance paddling, no conclusions can be drawn, to whether low chest or high chest position is efficient for endurance paddling performance. However, generally, it is believed that the high chest position is efficient for paddling (Babič, 2008; Bryant, 2014; Guisado, 2011;

Wisewell, 2013). Thus, it can be implied that surfers may spend the most of their time paddling with high-arched back. This leads to low back pain in surfers.

3.3.1. Low back pain in surfers

As surfing does not contribute to balanced muscular development, it happens that due to the prolonged maintenance of posture when lying prone on the surfboard and paddling, surfers have less abdominal strength than other athletes, limited flexibility in shoulders, back and hamstrings (A. Mendez-Villanueva & Bishop, 2005). A high chest position when paddling on a surfboard may place additional stress on the lower back of a surfer, in order to maintain the additional and potentially extreme extension required (J. M. Sheppard, Osborne, et al., 2013). Low back pain is a common problem in surfing population (M. Mendez-Villanueva & Bishop, 2005). However, the aetiology of low back pain is complex (Jeff A. Nessler et al., 2017). Thus, more research in prone paddling posture and muscles of the posterior chain might be helpful in designing compensatory exercise programme for surfers and preventing overuse injuries.

There was a study examining the effect of wearing a wetsuit on the mechanics of surfboard paddling. Researchers argue, that wetsuit stimulates mechanoreceptors and enhances proprioception. (J. A. Nessler et al., 2015). These findings could be used in injury prevention in paddling on a surfboard.

Another study (Jeff A. Nessler et al., 2017) examined the effect of inflatable vest on muscle activation. Data shows that the EMG activity in back extensors decreased while wearing inflated vest. Wearing the vest decreases back extensor muscles activation and results in increased passive back extension, which alters compressive forces in the lumbar spine area. It might also be that increased passive back extension and decreased activity in extensors of the spine over longer period of time result in lower endurance of back extensor muscles.

Isometric endurance of postural stabilizer muscles is, in fact, important in management of chronic low back pain. Contrarily, erector spinae muscle was found to be still relatively active while paddling with inflated vest. Previous research (Jeff A. Nessler et al., 2017) showed that activation of only 30% of maximal voluntary contraction (MVC) is sufficient to improve muscle endurance and maintain lumbar stability, which suggests that this decrease in erector spinae muscle activity should not lead to its endurance reduction.

However, as the aetiology of low back pain is multiform (Jeff A. Nessler et al., 2017), it cannot be omitted that there are more variables that can influence low back pain in surfers. Sudden perturbations can occur while riding a surfboard or during impact with a wave. Thus, in some surfers, there might be increased delay in the onset of muscle activation in response to perturbation, changes in reflex activity and local dynamic stability or lumbar stiffness. It was found out that all these variables correlate with low back pain (Jeff A. Nessler et al., 2017). The anatomy of our body (structure of joints and position of human eyes) and habitual movement patterns emphasize space in front of us. As a result of our lifestyle and technology this emphasize restricts our ability to move in space behind us (Studdová & Coxová, 2014). When paddling on a surfboard the most part of the movement happens also in space in front of us. Thus, some exercise intervention focusing of posterior muscle chain should be done to compensate for this phenomenon.

Low back pain is a common problem in amateur surfers. Lying prone on surfboard and paddling requires shoulder, back and neck extension which can lead to overuse injuries. Little attention to injury prevention and rehabilitation has been paid. Only few products that would improve comfort and reduce injury in surfers have been developed (Jeff A. Nessler et al., 2017). Many researchers focused on mechanism of lower back pain in the general population (Balagué et al., 2012; Ehrlich, 2003; Hoy et al., 2010; Nguyen et al., 2018; Paraskevas, 2018).

However, little research on chronic back pain or subacute low back pain that can occur immediately following bouts of prone activities like surfboard paddling has been done.

To sum up, although there were findings in regards to equipment that might help to reduce the risk of low back pain in surfers, more research should be conducted in paddling technique adjustment, back extensors strengthening and its relationship with low back pain. Problems with low back pain should be better solved by finding the right technique of paddling or some exercise intervention which would actually solve the cause without aid of any product. Also, EMG should be used to compare muscle activity in paddling with high-arched and low-arched back and its correlation with low back pain. Study should be done, which would use EMG and examine, whether the activation pattern of back muscles is changing with fatigue onset. It may be that with increasing fatigue, the paddling technique is deteriorating and weak muscles are substituted by strong ones, which become overloaded. If this process repeats again and again, it may result in injury. Suggested study might help to correct the paddling technique and to plan training intervention which would release overloaded muscles and activate the weak muscles, whose function is vital, however for the healthy paddling technique.

3.4. Correlation between experience, frequency and load of surfing with posterior chain endurance

No correlation between the surfing experience in years and the isometric prone chest hold to exhaustion was found in this study. The difference in frequency, duration and intensity of surfing sessions might be the reason for that. There might be difference in the paddling technique, as some surfers might use the back muscles more to make the propulsion phase more efficient and some of them use just muscles of their arms. Further, it might be

interesting to look at the association between the paddling technique of participants in the ocean and the posterior muscle chain endurance of surfers. The extent to which their back is arched would be assessed. That could be achieved through time-motion analysis of all the participants.

It was assumed that there will be positive relationship between the frequency, volume of surfing and posterior chain endurance. The results of the research support this statement, as strong positive correlation was found between the surfing load, frequency and posterior-chain-muscle endurance. The correlation between the time spent surfing and upper body strength training with the posterior-chain-muscle endurance was even stronger. That suggests that surfing and upper body strength conditioning is associated with the endurance of the muscles of the posterior chain. This implies that surfing might have a strengthening effect on the muscles of posterior chain. Given that people with low back pain might have weak back muscles, surfing could be actually prescribed to them as a form of rehabilitation. There is a need to conduct more research in this area, as surfing may also cause low back pain as mentioned earlier. When thinking about surfing as a form of exercise for strengthening back muscles, patients would need to be taught the correct and safe paddling technique so that it actually does not exaggerate back problems in these patients. Thus, the correct technique needs to be examined. Although the aetiology of low back pain is complex, increased activation of erector spinae muscle actually generates intervertebral compression, which may be the reason for low back pain in surfers (Jeff A. Nessler et al., 2017) . Its activity might be decreased by lowering the arch of the back. As mentioned before, this decrease in activity of back muscles should not lead to lower endurance of these muscles. However 30% MVC should be maintained (Jeff A. Nessler et al., 2017).

As mentioned before (A. Mendez-Villanueva & Bishop, 2005; Jeff A. Nessler et al., 2017) low back pain is a common problem in surfers. Thus, it would be beneficial for them to

include holistic programs such as Feldenkrais method, Laban movement analysis or Body-Mind Centering (BMC) in their training as a compensation for surfing which does not contribute to balanced muscular development (A. Mendez-Villanueva & Bishop, 2005).

3.5. Posterior chain endurance tests in surfing

There has been few studies found that measured paddling peak power output. However, these studies examined only professional surfers. Moreover, there has been no study on the endurance of posterior muscle chain of surfers.

Studies measuring the strength of back extensors used mainly Biering-Sorensen test. However, due to the nature of this study, isometric prone chest hold test was used. It was modified version of the test used by McIntosh, Wilson, Affleck and Hall (1998) in their study. The modified version of this test was more suitable for the purpose of this study.

Compared to the study of McIntosh et al. (1998), according to which a mean result in static chest hold in 19-29 year-old women was 99 seconds and in 30-39 year-old women was 106 seconds, a mean performance in isometric prone chest hold endurance test was 178.6 (n = 14) seconds in female surfers. Five subjects were able to achieve 200 seconds and the best result was 427 seconds. That shows, that endurance of posterior-chain muscles in female surfers is greater compared to the rest of the population. However, it should also be considered, that the tests measuring posterior chain muscles in the study of McIntosh et al. were slightly different compared to this study.

The fact, that surfers have better posterior chain endurance than the rest of the population, could be used as inspiration in competitive surfing research. Comparing competitive surfers on national and international level with surfers on local level of

competition would assist the talent identification programs or performance assessment in competitive surfing.

3.6. Paddling technique with increased back extension

Some authors say, that high arch in the back causes biomechanical advantage and thus, results in more efficient paddling (Babič, 2008; Bryant, 2014; Guisado, 2011; Wisewell, 2013). Paddling with the chest high allows surfers to pull more water, thus maximizing the power of the arm strokes (Guisado, 2011; Wisewell, 2013). It is the key to powerful paddling. When the chest is up, surfers are able to pull water more easily because their shoulders are in stronger position. Keeping their head up will help them keep their shoulders relaxed and their stroke fluid (Guisado, 2011). However, based on the data from paddling strokes videoanalysis, Rob Case (2017) argues that paddling with chest high off the board is inefficient. Case declares that lower arch in the surfer's back results in 25% increase in paddling efficiency. The stroke rate lowers but the paddling speed remains the same, which allows surfers to save energy when paddling. Generally, it is said that high-arched back provides more leverage in the stroke. In fact it does provide leverage in the power portion of the stroke. However, gaining leverage through arching the back is too energy consuming. There are other less energy consuming ways to provide leverage this technique refers to and to get even more speed and power from the stroke than arching the back higher and higher (Rob Case, 2017).

This actually corresponds with the finding of this thesis, in which no correlation between posterior chain endurance and paddling peak power was found. These findings might bring radical change in paddling technique, as the general belief of relationship between arched back and paddling efficiency still prevails. The low-arch paddling technique might be of great importance, as it results not only in increase of paddling efficiency but it can

also be related to health issues linked to surfing. This change in paddling posture might decrease the incidence of chronic low back pain in surfers. Also, considering the argument that paddling technique on swimbench differs from surfboard paddling technique, as surfboard paddling distinguishes from paddling on a swimbench by back extension (Loveless & Minahan, 2010b), could be less relevant when lowering the arch in back. However, more research in this area is needed.

3.7. Limitations of this study

Since the link between surfing and muscles of posterior chain is unexplored, there is a big room for research. Fourteen females were recruited to participate in this research, which is not enough to establish association between variables. Due to time and transport restrictions of addressed females, many of them could not participate in the study. Moreover, to establish strong association between posterior chain endurance and paddling peak power, test-retest method should be used. Participants would have to complete the testing two times on two different days but in the same time of the day. However, this might be a problem because the participants could be training for the posterior chain endurance test at home, which would significantly affect the results. For the purpose of the research more homogenous cohort of participants, females with the same amount of surfing experience in years, similar frequency and volume of surfing sessions, would be beneficial.

On the other hand, this thesis also shows that there are some discrepancies in surfboard paddling technique and need for more research in this field. This thesis also suggests adding some holistic movement program into the training to provide for balanced development of surfers, increase performance and reduce injury risk in surfers. This thesis found correlation between posterior chain endurance and surfing load, which might mean that surfing increases endurance of posterior chain. As previous studies showed relationship

between weak back muscles and low back pain, surfing could be prescribed as training intervention for people whose low back pain is caused by weak back muscles. However, as mentioned before, surfing might also generate low back pain. Thus, there is a need for more research on this topic to reduce contradiction of this intervention and to be able to prescribe surfing to these patients safely and without exacerbating their low back pain.

4. CONCLUSION

The aim of this project was to investigate whether there is correlation between posterior-muscle-chain endurance with the arm paddling peak power and change in the peak power after posterior-chain muscles fatiguing exercise. This research was also focused on association between the frequency and volume of surfing with posterior chain muscle endurance and paddling peak power.

This research disproved the expectations that the posterior-chain muscles endurance correlates with paddling peak power and change in paddling peak power after fatiguing exercise of muscles of posterior chain. The expectations that the volume and frequency of surfing affect paddling peak power were also disproved. It was found out, however, that the frequency and volume of surfing sessions correlate with the endurance of muscles of posterior chain.

There is great opportunity for further research. Further research efforts in this area should examine the chronic application of a posterior chain training program, and its influence on arm paddling peak power. It would be also interesting to examine the postural control in the prone paddling position and its association with injury risk. That would be contributive to injury prevention in surfing and thus increasing surfers' performance. As paddling represents more than half time spent in the water, progress in paddling performance would be highly beneficial. Additional research could be done to evaluate paddling posture and its effect on paddling efficiency and energy expenditure. Researches could also examine the association between trunk mobility and posterior chain endurance, as better flexibility might correspond with different paddling kinematics and efficiency. Interesting association might be found between posterior chain endurance and lower back and shoulder pain in amateur surfers. As

this thesis dealt with posterior chain endurance and peak power, it should be also examined how endurance of posterior chain affects endurance paddling.

As surfing is quite time consuming and demanding when it comes to conditions, not many amateur surfers have the convenience of regular practice. Thus, implementing a few exercises that would improve posterior chain endurance could be helpful at times when they cannot practice in the water.

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