The relationship between thoracic spine mobility and shoulder problems in a sample of surfers: A cross-sectional design

Sara de Jong

Declaration

Name of candidate: Sara de Jong

This Thesis entitled: The relationship between thoracic spine mobility and shoulder problems in a sample of surfers: A cross-sectional design is submitted in partial fulfillment for the requirements for the Unitec degree of Masters of Osteopathy

Principal Supervisor: Rob Moran

Associate Supervisor: Megan McEwen

Candidate’s declaration

I confirm that:

- This Thesis represents my own work;
- The contribution of supervisors and others to this work was consistent with the Unitec Regulations and Policies.
- Research for this work has been conducted in accordance with the Unitec Research Ethics Committee Policy and Procedures, and has fulfilled any requirements set for this project by the Unitec Research Ethics Committee.

Research Ethics Committee Approval Number: 2017-1082

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Candidate Signature………………………….. Date: 24/04/2019

Student number: 1417535
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Thesis Introduction

Surfing is a dynamic sport enjoyed both recreationally and competitively. Surfing originated in ancient Hawaii and was of great spiritual importance (Nendel, 2009). The sport of surfing involves intimate human connection with the ocean and various coastal surroundings (Lazarow, Miller, & Blackwell, 2009), and is therefore not only good for physical wellbeing, but can also improve mental health of individuals (Wheaton, Roy, & Olive, 2017).

Surfing is steadily increasing in popularity both in Aotearoa New Zealand, (Moran & Webber, 2013) and on a global scale (Lazarow et al., 2009). Most individuals participate purely from a leisure perspective; however, competitive surfing has also progressed to an exceptional level, with emphasis being placed on professional surfing, particularly with regard to the media, social media and the surf industry. The decision to include surfing in the 2020 Tokyo Olympics has attracted worldwide attention to surfing as a sport (Kojima et al., 2018). In addition to this, in professional surfing women are being recognised more than ever before, with equal pay being announced for Women and Men in the World Surf League (WSL) starting in 2019 (World Surf League, 2019a).

With the growing population of surfers, the number of injuries associated with surfing has also grown. In New Zealand, the Accident Compensation Corporation (ACC) are spending substantial amounts of money on surfing injuries each year, and this number is increasing (Accident Compensation Corporation, 2019a). The prevention of surfing injuries is of interest to ACC, as their aim is to return individuals back to activity and work within the quickest possible timeframe.
The TRIPP framework (Figure 1) is a six step framework for research of sports injury prevention, with an evidence based approach to each stage leading to the prevention of sports injuries when applied (Finch, 2006). The four stage model by van Mechelen et al. (1992) emphasises risk of injury and aetiology in addition to mechanisms of injury in the first two steps. The third and fourth steps suggest the introduction of preventative measures and the assessment of their effectiveness. This study focused on Stage 2 of both of these models: Establish aetiology and mechanisms of injury in surfing. Sports injury prevention in surfing is a key area that has not previously had much attention, potentially due to the recreational and lifestyle factors that comes with the sport, resulting in a lack of injury reporting. Figure 1 contrasts the stages by Finch (2006) and van Mechelen, Hlobil, and Kemper (1992). Finch’s research built on the research of van Mechelen et al, modifying and adding two stages (Stage 5 and 6) to ensure injury prevention methods developed in the earlier stages are implemented and effective in the desired context resulting in real-life sports injury prevention (Finch, 2006; Van Mechelen, Hlobil, & Kemper, 1992).
Shoulder injuries are common in overhead sports, such as surfing (Nathanson, 2013), and recently Remnant (2017) identified that gradual-onset shoulder injuries were common among New Zealand surfers, and that these injuries frequently took longer to heal than other gradual-onset injuries. The prevalence of shoulder injuries among surfers of all ages is high, but those of older age are affected more than young surfers, possibly due to time spent in the water and cumulative exposure (Remnant, 2017). While Remnant’s study is Stage 1 in terms of Finch model, understanding the aetiology (ie Stage 2 in Finch et al. model) of these injuries is useful in the prevention of future injuries. This thesis is an extension from Remnant's (2017) thesis investigating gradual-onset injuries in New Zealand surfers.

The aims of this thesis were to (1) investigate differences in thoracic mobility between surfers with, and without past or current, shoulder region injury or pain; (2) to examine the correlation between past and current shoulder pain intensity or duration and thoracic mobility. This research measured the thoracic mobility of surfers in various positions; with shoulder pain and disability levels retrospectively reported from the previous surf session. Other details such as surfing frequency, level of surfer, age, height, weight, gender, board type, stance, handedness etc. were recorded to investigate relationships between these factors and shoulder pain or disability in surfers.
This thesis is structured in three parts: Section 1 is a Literature Review, Section 2 the Manuscript reports the main study, and Appendices are presented in Section 3 including ethics documentation, advertising to recruit participants, and questions and questionnaires regarding study eligibility. In the Literature Review, the history and importance of surfing are introduced, in addition to surfing injuries and their treatment costs. Emphasis is placed on the prevalence of shoulder injuries in surfing, a body region of particular interest in previous studies of surfing related injury (Dimmick, Patterson, Sheehan, Anderson, & MacDougal, 2018; Furness et al., 2014; Hohn, Robinson, Merriman, Parrish, & Kramer, 2018; McBride & Fisher, 2012; Remnant, 2017). The prevalence of shoulder injuries among surfers shows a need for an investigation looking at potential anatomical, biomechanical and physiological links. The anatomical and functional links between the shoulder and thoracic spine are explored in the context of surfing. Lastly, methods of measuring spinal mobility in the sagittal plane are critically reviewed. The manuscript in Section 2 reports the results of a cross-sectional study of 41 participants, measuring thoracic mobility in surfers with or without shoulder pain or disability. Participants were recruited, and levels of current shoulder pain and disability were enquired about, in addition to surfing skill and frequency of surfing during the previous summer months. Thoracic mobility was measured using an electrogoniometer, and participants were asked to produce a number of movements to assess thoracic mobility and measures of thoracic mobility were analysed.
Section 1: Literature Review
Introduction to literature review
This literature review explains the importance of surfing as a recreational and competitive activity, both historically and in modern society. The impact of surfing on society and the cost of injuries associated with surfing is explored, as well as the aetiology and epidemiology of these injuries. In particular, shoulder injuries are highlighted as a problem in surfing. Anatomical and biomechanical functions of the shoulder are explored, and possible links between shoulder injury and thoracic spine mobility are discussed. Methods of measuring thoracic mobility are also reviewed as a basis for the study reported in Section 2.

Historical and Cultural Connections in Surfing

Historical aspects

Polynesian origins
Surfing is a dynamic aquatic recreational and competitive sport that traces its roots back to ancient Hawaii, where Polynesian peoples have surfed for thousands of years (Finney, 1959; Nathanson, Bird, Dao, & Tam-Sing, 2007; Nendel, 2009). The sport of surfing in Hawaii developed to a much higher degree than anywhere else in Oceania (Finney, 1959). Hawaiians have always held a spiritual connection with surfing, the water and waves; Hawaiian surfing events have been likened to a dance on the waves (Nendel, 2009). Hawaiians traditionally surfed longboards crafted from wood (Booth, 1999), but early American missionaries disapproved of the sport, causing a decrease in participation in surfing through the mid-1800s (Booth, 1999). In 1915, Duke Kahanamoku, an Olympic swimmer from Hawaii, re-popularised the sport internationally, when he toured to Australia, New Zealand, and the United States to perform surfing demonstrations (Booth, 1999).

Māori origins of surfing in Aotearoa
Similar to the Hawaiians, early Māori surfed waves as a tradition using different types of equipment: wooden boards (called kopapa), logs, bags of kelp and waka (Swarbrick, 2006). Māori surfing is believed to have begun almost 700 years ago, in Taranaki, New Zealand (Te Kanawa, 2017). From a young age, Māori were socialised to have no fear in the water (Borell & Kahi, 2017), and this was driven by traditional stories of ancestors’ achieving aquatic accomplishments, such as Maui fishing up the North Island of Aotearoa-New Zealand. However, similar to the history of surfing in Hawaii, surfing in Aotearoa-New Zealand declined in participation due to the arrival of missionaries (Swarbrick, 2006), in 1814.
(Middleton, 2007). The introduction of the missionaries’ ways of dressing and behaving upon Māori included discouraging surfing (Swarbrick, 2006). Other than Duke Kahanamoku’s surf demonstrations in 1915 (Booth, 1999), interest in surfing increased in the 1970’s due to the introduction of modern materials including foam and fibreglass which could be made locally providing Māori living near the coast of the North Island renewed access to surfing (Finney & Houston, 1996). Surfing has become an important part of Māori culture, particularly in the North Island including an annual Māori surfing event ‘Aotearoa Māori Surfing Titles’ is held in Taranaki (Surfing New Zealand, 2017).

Surfing as a competitive sport
As a competitive professional sport, surfing is recognised on an international level (Loveless & Minahan, 2010). The sport of surfing is experiencing substantial growth in participation worldwide (Farley, Harris, & Kilding, 2012). The World Surf League runs numerous surfing competitions in which the best surfers are invited to compete. These are held at the best surfing locations around the world, such as Teahupo’o in Tahiti, Jeffreys Bay in South Africa, and Banzai Pipeline in Hawaii (World Surf League, 2019b).

Growth of surfing
In Australia, the growth of surfing followed naturally from surf-lifesaving which was already popular in Australian culture (Booth, 1999). In the 1990s a further rise in interest in surfing resulted from the commercialisation of surf-apparel and the popularity of the ‘surf lifestyle’ that supposedly represents a ‘typical’ surfer (Nathanson, Haynes, & Galanis, 2002; Porter, Orams, & Lück, 2015). The surfing industry has steadily grown each year since the 1990s, and has gained more mass media attention, and culminated in a recent International Olympic Committee decision to include surfing in the 2020 Olympics (Kojima et al., 2018). The inclusion of surfing in the Olympic Games has driven even greater recognition of the sport, but despite this substantial growth, there is limited scientific research investigating surfing compared to other sports (Furness et al., 2014).

Surfing is unique and has been named an ‘extreme’ sport due to several aspects of potential danger. The ocean as a surfing environment poses the potential for danger including external factors such as reefs, rocks, currents, riptides, and wildlife (Moran & Webber, 2013). But surfing is more than a sport and for many people around the world it is a lifestyle; an activity and culture they take part in with friends or by themselves (Lazarow et al., 2009). The
different types of surfing attract differing personalities and characteristics, often expressed through the type of board or the size of the wave surfed, perhaps best typified by “big-wave surfers” (Farrell, 2018).

**Role of surfing in environmental issues**

Historically, coastal urbanisation has negatively impacted on the quality of surf breaks, often unintentionally destroying them in the process (Scarfe, Elwany, Mead, & Black, 2003). Wave quality may be reduced when a sandbar or engineered built structure interferes with the wave-breaking zone (Corne, 2009). The obstruction of quality surf spots negatively impacts the surfing community as they may have to travel further to find suitable surf locations. This impacts their quality of life and can also contribute to an increase in number of surfers in one spot causing overcrowding, and as a result, more traumatic injuries (Usher & Gómez, 2017). Not only can these urban developments be obstructive, but the surfers can also be affected by water pollution as a result of the work being done (Vaughn, Nelsen, & Pendleton, 2007). Surfers are in many cases advocates for the protection of coastal areas and marine environments, therefore, a range of surfing environmental groups have been established around the world for the protection of the environment (Corne, 2009). Many surfers feel a sense of responsibility to protect the environment (Hill & Abbott, 2009). The social and economic benefits of surfing breaks within coastal communities worldwide are now becoming increasingly apparent, often resulting in the preservation and enhancement of these surf breaks (Scarfe et al., 2003). However, better communication between surfers, councils and coastal engineers is required for the preservation of surf breaks and additionally for the construction of artificial surfing reefs (Corne, 2009; Scarfe et al., 2003). Surf culture therefore has an impact on the conservation of the environment and plays a part in the protection of marine areas. This not only results in the preservation of surf breaks but may also protect local economies in coastal communities that may depend on surf tourism to thrive (Vaughn et al., 2007).

**Positive health benefits from surfing**

Physical activities such as surfing have great health benefits and it has also been used to engage troubled youth (Wheaton et al., 2017). Health benefits from surfing include psychological (Partington, Partington, & Olivier, 2009), social and emotional wellbeing (Caddick, Smith, & Phoenix, 2015) and participation can also improve or maintain neuromuscular function in the long term (Frank, Zhou, Bezerra, & Crowley, 2009). Other
health benefits include enhanced aerobic fitness levels (Greever, Groseclose, Denny, & Jones, 2019), and spending time in nature which has well-demonstrated health benefits including reduced stress and improved sense of wellbeing (Depledge & Bird, 2009). Surfing provides a novel method of engaging youth in a way that many team sports are not capable of (Wheaton et al., 2017). Participants are not only engaged in physical exercise, but they are also immersed in the ocean and therefore may experience a sense of freedom from the control of culture and a place to disconnect from their everyday lives (Wheaton et al., 2017). A number of youth developmental surf programs have been established in New Zealand with aims including: improving connection with nature to improve mental health, increased awareness of environmental issues, and catering for special needs (Wheaton et al., 2017). Interestingly, a study performed on war veterans suffering from Post-Traumatic Stress Disorder who participated in a surfing program showed positive results in subjective wellbeing of individuals (Caddick et al., 2015). Additionally, a similar study reported physical activity and sports, in particular those involving the outdoors have been shown to be effective for war veterans suffering from Post-Traumatic Stress Disorder by increasing quality of life and motivation (Caddick & Smith, 2014). An outdoor activity such as surfing therefore has a wide range of benefits that may affect someone emotionally, psychologically, socially and physically and can have a large positive impact on a person’s health and life.

**Novel psychological states associated with surfing**

The term ‘flow’ has been associated with big-wave surfing, a state where the mind is completely still, and an awareness of self is increased (Partington et al., 2009). Flow is a state where the body and mind are said to be ‘in-sync’ and the perception of time is altered. This term is commonly used by big-wave surfers. Although there are potential dangers involved, big-wave surfers express that the benefits from participating far outweigh the risks. Some surfers that participate in big-wave surfing have compared the activity to drugs, and some have admitted that the euphoria of big wave surfing far exceed those of illicit substances (Partington et al., 2009). The explanation of flow within surfing shows the depth of euphoria and sensory fulfilment that can be gained by surfing, to the point where surfing can be addictive (Partington et al., 2009). This may result in people surfing for extended periods regardless of their physical capabilities and may mean that physical boundaries are pushed to the point of injury. Fatigue is a known predisposing risk factor for sports injuries, shown in a study of Youth Baseball Pitchers where muscular fatigue was correlated to the highest percentage of shoulder injuries (Lyman, Fleisig, Andrews, & Osinski, 2002).
The sport of surfing: what it entails

Distribution of surfing phases
Surfing is divided into multiple phases: wave riding, paddling, being stationary and performing miscellaneous activities (Mendez-Villanueva, Bishop, & Hamer, 2006). During a surf session, only a small proportion of the total time is spent riding the wave compared to paddling and being stationary. A study by Mendez-Villanueva, Bishop and Hamer (2006) identified that during a surf session, world-class surfers would spend approximately 51% of the session paddling, 42% of the time sitting on the board and wave riding only consisting of around 4% of the session; the rest of the session was spent performing miscellaneous activities. The distribution of activity in recreational surfing is similar to professional surfing and was found in one study to consist of 44% paddling, 35% stationary, 5% wave riding and 16% miscellaneous activity (Meir, Lowdon, & Davie, 1991).

Competitive surfing
Competitive surfing is undergoing growth in participation possibly as a result of growth in surf population including recreational surfing in addition to increased media attention (Mendez-Villanueva & Bishop, 2005). Competitive surfing is judged on a surfer’s ability to select, catch and ride the best available waves (Coyne et al., 2016). Surfers are also judged on their performance in manoeuvres in the critical part of the wave, closest to where the wave is breaking. Surfing contests are arranged in 15-30-minute heats of usually 2-6 persons per heat; the top surfers are then invited to compete in the next bracket (Nathanson et al., 2007). Contests are held when the surf is most favourable, therefore “holding periods” of 1-10 days are allocated for heats to be run during the best surf conditions (Nathanson et al., 2007). Complex manoeuvres performed in competitive surfing such as aerial manoeuvres are associated with a higher risk of injury (Furness et al., 2014). Additionally, professional competitions are lengthier in duration, often held over a hard ocean floor (eg reef) and conducted in larger waves (Nathanson et al., 2007), which is likely to affect the number of potential acute injuries.
Physiological demands of surfing

Surfing requires both aerobic and anaerobic fitness, muscular strength, and endurance. Riding waves also involves balance and coordination (Frank et al., 2009; Mendez-Villanueva & Bishop, 2005). Surfing demands varying intensities of exercise, such as slow paddling to find the best positioning for a wave, to sprint-paddling to catch a wave. Surfers need to be able to accelerate quickly from a stationary position in order to catch waves. Achieving higher speeds improves one’s ability to catch a variety of waves, such as bigger waves, waves in strong winds, as well as slower or faster breaking waves (Loveless & Minahan, 2010). A study by Farley et al., (2012) found that competitive surfers would achieve a heart rate intensity of over 120 beats per minute for at least 80% of the session during a competition. This is likely due to the intermittent bouts of high intensity paddling and short recovery periods in a surf competition. Low intensity paddling and occasional breath-holding also occurs in competitive surfing (Farley et al., 2012). Maximal intensity paddling to gain speed and the ideal position in front of a wave is a major determinant of whether a wave will be caught. Paddling to gain speed can be accompanied by a kicking-stroke to accelerate faster and is usually when a surfer is trying to catch a wave (Loveless & Minahan, 2010). Furness et al., (2016) found that peak VO$_2$ (aerobic power) and anaerobic power were significantly greater in competitive surfers than recreational surfers.

Anaerobic fitness and surf performance

The importance of anaerobic fitness amongst competitive surfers was highlighted in a study by Farley et al. (2012) who observed a positive correlation between anaerobic fitness and performance for competitive surfers, as indicated by their season ranking. Conversely, it was noted that while aerobic fitness is a crucial aspect of surfing, there was no direct correlation between this and athletic performance for competitive surfers. This study looked at 12 competitive surfers ranked in the top 30 surfers in New Zealand. Each surfer wore a global positioning system (‘GPS’) device and heart rate (HR) monitors and were filmed while competing in two different surf contests. The first contest had onshore winds creating choppy waves whilst the second was more consistent. The choppy conditions may have affected the surfers’ ability to paddle out and to catch and ride waves, potentially requiring more anaerobic and aerobic fitness. Additionally, the conditions are also likely to have affected the effort required to paddle, potentially making it more difficult for participants in the first contest. Farley et al. (2012) compared the difference in conditions during the two surf contests and used this as justification for his results. Furness, Climstein, Sheppard, Abbott,
and Hing (2016) have argued that surfers must possess a high capacity for physiological recovery due to the short rest periods in between high intensity paddling sessions. Fitness levels are crucial to surfing and a lack of fitness may impact surfing technique. This means that the modification of surfing technique could potentially lead to pain or injury (Sheppard, Osborne, Chapman, Andrews, & McNamara, 2013).

**Flexibility/Mobility and Surfing**

Surfing requires a moderate level of flexibility (Mendez-Villanueva & Bishop, 2005). Surfing can also have long-term positive implications on ability to generate muscular force. Frank et al. (2009) demonstrated this in a study of male surfers aged between 57 to 64 with at least 40 years of surfing experience who were compared to active age-matched controls. Muscular force was measured using maximal isometric voluntary contraction, force development rate, and muscle force production steadiness. Due to enhanced neuromuscular adaptations, highly experienced surfers have greater control of force generation of their muscles when compared to active age-matched controls (Frank et al., 2009). One explanation for these results may be the quick response in muscular strength required in surfing to adapt to changes in the waves (Frank et al., 2009).

Flexibility is important in surfing as surfers move from a prone paddling position on the board with a relatively extended spine, to pushing themselves up to a side-on standing position while riding the wave. The process of standing up must be performed quickly whilst maintaining balance and ensuring the surfer’s body is positioned correctly on the board. Therefore, the physical demands on surfing may help to maintain or develop skills that enhance neuromuscular function, which in turn may lead to improved physical function and quality of life (Frank et al., 2009).

In summary, the majority of a surf session is spent paddling, with both aerobic and anaerobic demands. There are also a relatively small recovery periods between high intensity paddling to catch waves and repetitive nature of slow paddling to gain the best position to catch a wave. Not only are these factors significant contributors in being an efficient surfer, but this also places great importance on the shoulder joint. Given the repetitive nature of the sport, it is not surprising that surfers often experience overuse injuries, especially of the shoulder Remnant (2017).
Aetiology and Epidemiology of Surfing Injuries

Cost, onset, and rate of injury

Economic costs associated with surfing accidents
Injuries within the surfing community are common and can often result in time off work as well as time off surfing (Furness et al., 2015). Furness et al. (2015) reported that 1 in 3 surfers will sustain an acute injury that necessitates medical attention or time off surfing and/or work each year. The cost of surfing injuries is increasing yearly, with the Accident Compensation Corporation (ACC), a no-fault accident insurance scheme in New Zealand, paying $7,360,348 (NZD) between July 2017 and June 2018 for treatment of surfing injuries (Accident Compensation Corporation, 2019b). By comparison, surfing injuries cost ACC $4,753,219 (NZD) between July 2013 and June 2014 (Accident Compensation Corporation, 2019b). Nathanson, Haynes and Galanis (2002) suggest that surfing injuries are becoming an increasing problem worldwide due to a rapidly growing surfing population, in addition to modern modifications of surfboard design and the increased number of surfers in the water at one time (Furness et al., 2014; Nathanson et al., 2002). Several surfers in the same locale at one time increases the risk of contact with the board of another surfer, which can cause lacerations or contusions. Modification of surfboard design include lighter boards which allow for faster and more radical manoeuvres to be performed causing more strain on the body (Furness et al., 2014)

Gradual-onset vs chronic injuries
Remnant (2017) indicated that there was a difference between the types of injuries based on injury onset as traumatic or gradual-onset, and duration of injury as acute or chronic. Remnant (2017) suggested the term ‘traumatic’ or ‘gradual-onset’ to define the type of injuries as being more appropriate than the terms ‘acute’ and ‘chronic’ respectively that were commonly used in previous surfing injury studies (Nathanson et al., 2002; Furness et al., 2014). “Gradual-onset” injuries has been defined as “repeated microtrauma without evidence of a single, identifiable event” (Verhagen & van Mechelen, 2010, p. 50-51) as opposed to referring to this type of injury as a “chronic” injury which usually refers to pain lasting longer than the usual healing time (Merskey, 1986). According to Furness et al. (2014) ‘chronic’ (or as Remnant (2017) would suggest ‘gradual-onset’) surfing injuries are often under-reported
and tend to attract less medical and research attention. For the purpose of this literature review injury types in previous studies will be referred to as traumatic (acute) and gradual-onset (chronic) to align with the terminology of Remnant (2017).

**Rate of injury in surfing**

Not surprisingly, traumatic injury rates differ between competitive and recreational surfing with competitive surfers having a much higher incidence rate. It has been suggested that traumatic injury rates in competitive surfing can range anywhere between 6.6 (Inada et al., 2018) and 13 injuries per 1000 hours of surfing (Nathanson et al., 2007). For recreational surfers, traumatic injury research has revealed injury rates ranging from 2.2 to 3.5 per 1000 hours of surfing (Lowdon, Pateman, & Pitman, 1983; Taylor, Bennett, Carter, Garewal, & Finch, 2004) Remnant’s (2017) study estimated the injury rate per 1000 hours of surfing to be 1.72 gradual-onset major injuries.

**Age-related changes and overuse**

**Gradual-onset injuries in aging surfers**

Research suggests that gradual-onset injuries in surfers most often occur in the older population, with Furness et al. (2014) suggesting that surfers over the age of 39 are at a higher risk for developing gradual-onset injuries. Remnant (2017) discovered that older surfers and surfers with more years of surfing experience were more at risk of getting shoulder, lower back or neck injuries than less experienced and younger surfers. Remnant (2017) also suggested that gradual-onset injuries may be more prevalent in the older surfing population due to the amount of time spent surfing over many years, in comparison to the younger population, but more research and data analysis would be required to show this.

**Effects of aging on shoulder rotator cuff injury**

Rotator cuff tears are commonly seen among aging surfers, and commonly thought to be a gradual-onset injury in this population (Dimmick et al., 2018). This may be due to the stress placed on the rotator cuff during high intensity and prolonged paddling (Furness et al., 2014) and the cumulative high volume of time spent surfing over many years (Remnant, 2017). Existing literature suggests that the origin of rotator cuff injury is likely multifactorial: a combination of micro and macro trauma, age-related changes and other factors, such as
smoking, hypercholesteremia and genetics (Tashjian, 2012). Research has indicated that in the fourth and fifth decade of life, 5 to 11% of the population has a partial or full thickness rotator cuff tear (Milgrom, Schaffler, Gilbert, & van Holsbeeck, 1995). By the seventh decade this statistic increases to 50% and then 80% in the 9th and 10th decade (Milgrom et al., 1995). This particular study was performed on asymptomatic adults, showing that many individuals experiencing rotator cuff injuries do not suffer from symptoms. The prevalence of rotator cuff injury in asymptomatic individuals suggests that the incidence of this may be much higher in those who use their rotator for repetitive movements, such as paddling in surfing.

Surfing injuries are increasing in prevalence both in New Zealand and worldwide and are therefore becoming costlier to insurance providers such as ACC. A growing surfing population increases the number of surfers in the water at one time, which may increase the risk of traumatic injuries. Aging surfers are more likely to experience gradual-onset injuries, possibly due to age-related degenerative changes or increased exposure to surfing.
Shoulder Anatomy and Biomechanics

The shoulder is a complex joint and integral to movement of the whole upper extremity and performance of activities of daily living. The following section describes the anatomical make-up of the shoulder girdle and how the multiple structures that make up the shoulder function together as a unit. Movement dysfunction of the shoulder girdle can lead to injury of these structures. The shoulder is especially prone to injury in overhead sports such as surfing, due to prolonged overhead activity causing stress on the shoulder complex.

The joints of the shoulder
Four main joints make up the shoulder, these are the glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic joints (Struyf et al., 2014). Dynamic stability of the shoulder is achieved through a combination of coordinated muscle activity coupled with capsular and ligamentous restraints (Crockett et al., 2002). The shoulder is highly mobile with the vast majority of its stability relying on the musculotendinous cuff and capsuloligamentous structures, particularly the rotator cuff (Culham & Peat, 1993). The glenohumeral joint is a multi-axial, synovial ball and socket joint with three degrees of freedom: flexion/extension, abduction/adduction and internal/external rotation (Culham & Peat, 1993). While the glenohumeral joint is a mobile joint allowing for a range of functions, the glenoid fossa is relatively shallow and the articulating surfaces are incongruent meaning the joint is inherently unstable (Culham & Peat, 1993). The relative incongruency of the glenohumeral joint can result in a lack of stability which may result in overcompensation of the capsuloligamentous structures or the musculotendinous cuff, potentially leading to injury of these structures over time. Optimal function of the shoulder complex and upper extremity is dependent on the coordinated motion of the scapula, clavicle and humerus (Culham & Peat, 1993).

The scapula and shoulder function
The scapula is a flat bone positioned on the posterolateral thorax, approximately between the second and seventh ribs (Culham & Peat, 1993). It is one of the main bones that connects the thoracic spine to the shoulder joint through the scapulothoracic joint. The main movement the scapula produces is upward rotation, which occurs alongside posterior tilting on the thorax during overhead elevation of the arm (Ludewig & Reynolds, 2009). Normal scapulohumeral
rhythm is key for efficient functioning of the shoulder (Kibler & Sciascia, 2010), and is affected by changes in the posture of the cervical or thoracic spine (Michener, McClure, & Karduna, 2003). The position of the scapula on the thorax and its ability to maintain controlled movements are crucial to normal shoulder function (Ludewig & Reynolds, 2009).

The subacromial space
Another important component of the shoulder complex is the subacromial space. The subacromial space is made up of the acromion, coracoacromial and coracoclavicular joint superiorly and the long head of biceps, tendons of the rotator cuff, and head of the humerus inferiorly (Gumina, 2017). The space contains the supraspinatus tendon, the subacromial bursa, long head of biceps brachii tendon and the shoulder joint capsule, all of these structures can be affected by shoulder impingement (Michener et al., 2003). In subacromial impingement syndrome, narrowing of the subacromial space occurs, resulting in the encroachment of tissues within the space (Michener et al., 2003). Participation in overhead sports can be associated with injury of the shoulder joint, with a common injury being shoulder impingement syndrome (Hawkins & Kennedy, 1980). Overhead sports, as the name suggests, are sports that demand repetitive use of the shoulder and upper extremity whilst the hand is positioned above the head (Asker et al., 2018). Tennis, swimming, throwing sports, water-polo and volleyball are all sports involving overhead activity (Borsa, Laudner, & Sauers, 2008), whilst surfing is also considered an overhead sport (Nathanson, 2013).

Overhead sports and shoulder injury

Shoulder impingement
Shoulder impingement is a generalised term for impingement of any structures or tissues around the shoulder complex, generally caused by inflammation, irritation, or degeneration of the bursa or rotator cuff tendons in the subacromial space (Michener et al., 2003). The most common age for shoulder impingement syndrome to occur is between 40 and 60 years (Östör, Richards, Prevost, Speed, & Hazleman, 2005; Van Der Windt, Koes, Jong, & Bouter, 1995). Prolonged exposure to overhead activity of the shoulder results in structural changes of the rotator cuff, ligaments, glenoid labrum, and glenohumeral joint capsule (Meister, 2000; Wilk, Meister, & Andrews, 2002). Repeated overhead movement, such as occurs during paddling a surfboard, is likely to cause a high level of fatigue in the muscles which may increase
susceptibility to scapular dyskinesis (Laudner, Stanek, & Meister, 2008). A study measured muscular activation, motion of the upper extremity, oxygen consumption and heart rate during simulated surf paddling in surfers with and without the use of a wetsuit (Nessler, Silvas, Carpenter, & Newcomer, 2015). Whilst no differences were observed in oxygen consumption and heart rate, the use of a wetsuit during surf paddling contributes to changes in muscular activity, such as peak activity of the middle deltoid. Paddling motion was also modified whilst wetsuits were worn, suggesting improvements in proprioception which may be due to compression of the wetsuit (Nessler et al., 2015). Therefore, wearing a wetsuit is likely to alter upper extremity biomechanics which may affect impingement of the shoulder in surfing. Research by Ludewig and Cook (2000) showed the importance of the activation of the serratus anterior muscle, where all subjects with impingement had decreased activity in their serratus anterior muscle. The study investigated glenohumeral and scapulothoracic kinematics associated activation of the upper and lower trapezius muscle and serratus anterior muscle in people with and without symptoms of shoulder impingement (Ludewig & Cook, 2000). Of particular interest were participants who were exposed to overhead work or overhead sports, such as surfing. Surfers who work in overhead occupations may be at higher risk for shoulder impingement due to the increased time spent in the overhead position.

The supraspinatus and subacromial bursa
During abduction of the shoulder, there is increased stress on the supraspinatus tendon. Additionally, the subacromial space, which is a small area in which the supraspinatus tendon passes through, places pressure onto the tendon, increasing inflammation and potential for tissue injury (Michener et al., 2003). Subacromial bursal irritation is also commonly identified in overhead athletes as this bursa sits inferiorly to the supraspinatus tendon (Wilk et al., 2009).

Rotator cuff tears and scapular kinematics
Rotator cuff tendon tears are common in overhead sports. They are widely considered to be the result of cumulative trauma, and less commonly the result of a single event. Rotator cuff tendon tears commonly stem from a history of rotator cuff dysfunction and/or shoulder impingement (Ludewig & Reynolds, 2009). There is substantial evidence to show that people with shoulder impingement or symptoms of rotator cuff dysfunction have different scapular kinematics compared to asymptomatic populations (Haik et al., 2014; Ludewig & Reynolds, 2009; Nagai et al., 2013; Robert-Lachaine, Allard, Godbout, Tétérault, & Begon, 2016). It is
suggested that the risk of shoulder impingement increases when a person spends time with their shoulder elevated at or above 60 degrees in any plane frequently or for sustained periods (Ludewig & Cook, 2000). The sport of surfing requires frequent paddling with shoulder and elbow elevation and therefore may be at higher risk of shoulder impingement (Sheppard et al., 2013).

*The role of force on shoulder function in overhead athletes*

In overarm athletes such as throwing athletes, the shoulder and surrounding joints are exposed to high torque movements that increase the load on the shoulder joint, which potentially causes joint and associated tissue microtrauma (Albright, Jokl, Shaw, & Albright, 1978). A study by Warner, Micheli, Arslanian, Kennedy and Kennedy (1990) measured shoulder strength in both individuals with and without symptoms of glenohumeral instability and impingement syndrome. Their findings showed that asymptomatic subjects had 30% more shoulder internal rotation strength in their dominant shoulder, when compared to the symptomatic group. This suggests that strength of the internal rotators of the shoulder may be important in the prevention of glenohumeral instability and impingement syndrome. Other findings included posterior capsular tightness and relative external rotator weakness of the shoulder as being associated with impingement syndrome (Warner et al., 1990).

**Shoulder Injuries in surfing**

*Most common and cost of shoulder injuries in surfing*

Shoulder injuries are prevalent in both recreational and competitive surfers (McBride & Fisher, 2012) and in New Zealand, injuries caused by surfing may be eligible for ACC cover (Accident Compensation Corporation, 2019a). Between July 2017 and June 2018 shoulder injuries from surfing cost ACC $1,466,800 with a total of 48 new claims and 74 active claims (Accident Compensation Corporation, 2019c). A recent study surveyed 1473 New Zealand resident surfers showed that shoulder injuries were the most prevalent of gradual-onset injuries with 146 major injuries reported within the sample (Remnant, 2017). Of these shoulder injuries, 80% had been diagnosed by a healthcare professional as rotator cuff damage and/or bursitis. Less prevalent shoulder injuries included osteoarthritis or age-related degeneration, cartilage and/or labral damage. Remnant (2017) also indicated that surfers who predominantly used longboards were more likely to report a shoulder injury compared to those surfing shortboards. This may be due to the increased weight and size of the board.
making it more difficult to manoeuvre through the water, although this may reflect the age of surfers using longboards, as those who rode longboards were older. The main mechanism of gradual-onset shoulder injury to surfers is the combination of repetitive paddling and then pushing up off the board to ride a wave (Dimmick et al., 2018).

In summary, the shoulder joint is crucial for fine movements of the upper extremity; it is a mobile joint made up of 4 separate joints: the glenohumeral, acromioclavicular, sternoclavicular and scapulothoracic joint. To prevent injuries, these joints must work ‘in sync’. In overhead sporting activities, the shoulder is placed in a vulnerable position with repeated overhead movement resulting in specific shoulder impingement injuries. These injuries are also common in surfing; both in the traumatic and gradual-onset setting.

Shoulder Pain and Thoracic Mobility

Regional Interdependence

‘Regional interdependence’ is a term referring to the relationship between seemingly unrelated issues in other parts of the body thought to be associated with a patients’ primary complaint (Wainner, Flynn, & Whitman., 2001). Sueki, Cleland and Wainner (2013) suggested the concept that “a patient’s primary musculoskeletal symptom(s) may be directly or indirectly related or influenced by impairments from various body regions and systems regardless of proximity to the primary symptom(s)” (p. 91). This is important as the shoulder and thoracic spine are often seen as unrelated anatomical structures, thus little research has been done on the relationship between the two (Heneghan & Rushton, 2016).

Thoracic Spine

The alignment of the thoracic spine is crucial to many other structures within the body. The thoracic spine acts as a central attachment point where force transmits from the upper body to the lumbar spine (Liebsch & Wilke, 2018). The thoracic spine is unique to the rest of the spine as it serves as an attachment point for the ribs, which are essential in the protection of important organs (Edmondston & Singer, 1997). The ribs and diaphragm are fundamental to respiratory function (Courtney, 2009), which is another important role of a compliant thoracic spine. Thoracic mobility also plays an important role in shoulder function and
mobility due to the nature of the shoulder’s attachments to the thorax. Movement of the thoracic spine directly affects the position of the shoulder via scapulohumeral articulations and the scapulothoracic joint (Kebaetse, McClure, & Pratt, 1999).

Thoracic Kyphosis and Posture
Like many age-related issues, thoracic kyphosis increases with age (Fon, Pitt, & Thies, 1980), by approximately 3 degrees per decade (Pan, Firouzabadi, Reitmaier, Zander, & Schmidt, 2018). The rate of by which the thoracic kyphosis increases is higher in females than males, and is suggested to be caused by poor posture and the relative inactivity of females compared to males as a result of sedentary occupations, resulting in a decrease in muscle and ligamentous tone (Fon et al., 1980). Another reason was thought to be the amount of breast tissue in aging females accentuating the thoracic kyphosis. Thoracic posture affects both muscle force, and shoulder range of motion during abduction (Kebaetse, McLure & Pratt, 1999). An increase in kyphotic posture as in flexion of the thoracic spine causes relative protraction and internal rotation of the glenohumeral joint. This results in decreased space in the subacromial space for the supraspinatus tendon to glide through, especially during abduction, potentially causing impingement which may ultimately result in decreased range of motion of the glenohumeral joint. An increased thoracic kyphosis has been associated with decreased maximal arm elevation (Bullock et al., 2015). In a person with “good” postural alignment, the shoulder is able to move through 160-180 degrees of motion without soft tissue structures in the shoulder becoming impinged (Gray & Grimsby, 2012). This is crucial to surfing, as surfers rely on adequate shoulder range of motion for paddling, and shoulder impingement syndrome is a prevalent shoulder injury among overhead athletes such as surfers (Allegrucci, Whitney, & Irrgang, 1994; Borsa et al., 2008; Hawkins & Kennedy, 1980).

Functional links between the thoracic spine and shoulder
The concept of regional interdependence is well demonstrated in considering the relationship between the thoracic spine and shoulder (McDevitt, Young, Mintken, & Cleland, 2015). Due to the interconnectedness of shoulder mechanics to other parts of the body, particularly the upper body, it is important to investigate potential links to the thoracic spine as they may give information as to the origin of some shoulder pain. Dysfunctional movement or pain in one region can be due to an underlying complaint, such as shoulder pain originating from a mechanically restricted thoracic spine. This can occur because extension of the thoracic spine
is necessary to maximally elevate the upper extremity with the shoulder in a flexed position (Edmondston et al., 2012). Interestingly, a decrease in mobility in a segment within the body such as the thoracic spine, may cause an increase in mobility in an adjacent area, such as the shoulders (Iveson, McLaughlin, Todd & Gerber, 2010). This may result in injury of the shoulder complex as the shoulder is compensating for the lack of mobility in the thoracic spine (Iveson, McLaughlin, Todd, & Gerber, 2010). The study by Iveson, McLaughlin, Todd and Gerber (2010) was performed on healthy college-aged students measuring thoracolumbar spinal rotation in the side-lying position and was shown to be an effective method. Their findings also showed that a high percentage of participants that presented with a range of musculoskeletal complaints may have asymmetrical spinal rotational movement of over 10-20%.

**Trunk mobility and shoulder injuries in overhead athletes**

Shoulder injuries are common in overhead athletes. A balance of shoulder stability and mobility is required for overhead athletes to meet the functional demands of their sport (Borsa et al., 2008). Force couples are created by the simultaneous contraction of periscapular musculature, increasing the function and stability of the articulation between the scapula and thorax (Borsa et al., 2008). Due to these functional demands, it is of interest whether shoulder stability is compromised as a result of structural adaptations (Borsa et al., 2008). Surfing is an overhead sport as it requires a participant to elevate (abduct) their shoulders overhead to ensure efficient paddling. As the shoulder is in a vulnerable position during repetitive overhead motion, it is understandable that shoulder injuries are prevalent in overhead athletes, such as surfers.

**Softball and Trunk Flexibility**

A cross-sectional study on 80 female American Collegiate softball players suggested that the improvement of trunk rotation mobility may prevent shoulder or elbow injuries (Aragon, Oyama, Oliaro, Padua, & Myers, 2012). Their findings showed that injury prevalence was almost three times higher with participants with low levels of trunk mobility than those with high trunk flexibility. Interestingly, the study also suggested that limited trunk rotation may contribute to a lack of arm deceleration when throwing as the force is not absorbed by the trunk. This would increase the load on the upper extremity and therefore increase the risk of injury. The study by Aragon et al. (2012) used three different methods to measure thoracic rotation using a standard goniometer. Two of these required participants to half-kneel, with a
bar behind their backs tucked into elbows, and one with bar in front of torso. The last was a seated rotation test with hands crossed over onto opposite shoulders.

Swimming as an Overhead Sport
Swimming is a sport that requires a large proportion of overhead activity. It differs from other sports as it demands upper and lower-body strength, performed in an environment that is non-weightbearing (Pollard & Fernandez, 2004). The scapulothoracic joint is important during swimming, especially if the glenohumeral joint is inflexible (Blanch, 2004). The motion requirements are passed onto the scapulothoracic joint or the spine, though this can lead to impingement (Blanch, 2004). Hawkins and Kennedy (1980) describe the symptomatic swimmer’s shoulder as a result of the long head of the biceps brachii and/or the supraspinatus tendon impinging on the coracoacromial arch. These tendons are also believed to be affected by repetitive periods of avascularity, ultimately resulting in microtrauma, degeneration and inflammation.

Normal range of motion in the thoracic spine
A systematic review of 45 studies concluded that the thoracic spine is the least mobile in extension when compared to other thoracic movements, with an average of 13 degrees of extension achieved (Pan et al., 2018). Thoracic range of motion was seen to be greatest in the lower thoracic spine (T8-T12), in flexion and side-bending movements, whereas the mid-thoracic spine (T4-8) was most mobile in rotation and extension. The range of motion of the thoracic spine decreased by 5 degrees in all directions per decade. Thoracic extension is a requirement for surfing, and a reduction in thoracic extension whilst paddling may result in increased pressure placed on the lumbar spine (Furness et al., 2014). A lack of thoracic extension may also result in increased shoulder abduction and extension of the shoulder in order to clear the water ultimately resulting in impingement of the shoulder (Furness et al., 2016).

The scapulothoracic joint and impingement
The scapulothoracic joint is directly affected by the flexibility of musculature surrounding the joint, as well as the movement of the shoulder (Borsa, Laudner & Sauers, 2008). The position of the thoracic spine affects kinematics of the scapula. This is especially so when the shoulder is in an abducted position; a decrease in muscular force can occur due to a slouched
posture (Kebaetse, McLure & Pratt, 1999). Scapular dyskinesis is a common issue in subjects with shoulder impingement. It is characterised by a decrease in acromial upward rotation, increased scapular internal rotation and excessive anterior tilting of the scapula (Ludewig & Cook, 2000).

**Muscular imbalances and shoulder inflexibility**

Muscular imbalances in the shoulder and prolonged poor postures may have a negative effect on the function of the shoulder (Page, Frank & Lardner, 2009; Malmström, Olsson, Baledort & Fransson, 2015). Inflexibility of the glenohumeral joint can also create abnormal scapular biomechanics (Kibler, 1998). In particular, posterior shoulder inflexibility, which can be due to capsular or high levels of muscular tension, prevents the glenohumeral joint from moving smoothly and pulls the glenoid and scapula forward and inferiorly (Fleisig, Barrentine, Zheng, Escamilla, & Andrews, 1999). With increased inferior movement of the scapula, the scapula becomes harder to elevate and impingement becomes more likely (Kibler, 1998).

**Thoracic manipulation to treat shoulder problems**

Though research investigating the relationship between thoracic mobility and shoulder pain is limited, many articles show a positive relationship between manipulative treatment of the thoracic spine to treat shoulder issues (McDevitt et al., 2015; Peek, Miller, & Heneghan, 2015; Strunce, Walker, Boyles, & Young, 2009; Wassinger et al., 2016). Strunce et al., (2009) found that thoracic manipulation increased active shoulder flexion on average by 38.4 degrees in a pain free range. A study of 30 participants with symptoms of rotator cuff tendinopathy found that there was a positive relationship between thoracic spinal manipulations and a reduction in shoulder pain and function (Muth, Barbe, Lauer, & McClure, 2012). Interestingly, the study concluded that this positive relationship is unlikely to be explained by alterations in scapular kinematics or shoulder muscular activity.

In summary, the shoulder and thoracic spine are interconnected anatomical structures; the functioning of the joints that make up the shoulder are crucial in the prevention of shoulder injuries. The shoulder is directly affected by the posture and kyphosis of the thoracic spine. Prolonged kyphotic postures affect the shoulder negatively. Shoulder pain is prevalent in a number of overhead sports due to the functional demands on the shoulder joint.
Surfing, Shoulder Pain and Thoracic Mobility

The necessity of thoracic mobility in surfing
Mobility of the thoracic spine is crucial to the sport of surfing (Furness et al., 2016). A surfer spends most of the time during a session lying prone on the board, paddling, resting or preparing for a wave with their thoracic spine in a slightly extended position, often supported by their arms. In addition to this prolonged thoracic extension, a surfer will also experience prolonged neck extension during a session to hold up the head and allow forward viewing of incoming waves. Surfing requires a high upper body power output, similarly to surf-lifesaving and competitive swimming (Loveless & Minahan, 2010). Hip and trunk flexion help scapular protraction; hip and trunk extension with trunk rotation aid in facilitating scapular retraction (Kibler & Sciascia, 2010).

Effects of prolonged paddling on the shoulder
Due to paddling taking up approximately 51% of a surf session (Mendez-Villanueva et al., 2006), it is unsurprising that surfing may have negative consequences for the shoulder. According to Furness et al. (2014), prolonged paddling is the leading cause of shoulder injuries in surfers. The shoulder is one of the most vulnerable structures in surfing due to its inherent make-up and the body position required for well-executed surfing. Surf paddling technique has had little attention in scientific research, possibly due to the fact that paddling performance is not judged in a surfing competition (Loveless & Minahan, 2010). The repetitive paddling stroke and sustained posture in surfing is said to be associated with the high frequency of shoulder, back and neck issues (Mendez-Villanueva & Bishop, 2005). In one training session or competitive heat, a surfer covers a large distance whilst paddling (Farley et al., 2012; Secomb, Sheppard, & Dascombe, 2015b). Farley et al. (2012) calculated the combined average distance covered from 2 competitive surfing heats of 20 minutes to be 1605 metres whilst average distance travelled in a 2 hour training session was recorded to be 6293.3 metres (Secomb et al., 2015b). Due to this, the likelihood of fatigue developing is high, and this is likely to reduce surf performance through a reduction in sprint paddling ability. A reduction in sprint paddling ability will result in slower entry into a wave, which may reduce the surfers ability to catch the wave (Secomb, Sheppard, & Dascombe, 2015a). Additionally, fatigue is a predictor for shoulder injury (Lyman et al., 2002). In contrast to this, Dimmick et. al. (2018) argued those that surf regularly have more well-developed
Motion of the shoulder and thoracic spine during surfing

It has been suggested that a lack of mobility in the thoracic spine can lead to shoulder injury and pain (Lewis & Valentine, 2010). The relationship of the thorax to the shoulder is important during abduction of the shoulder to reach forward during paddling. Abduction of the shoulder is a crucial aspect of paddling motion (Trevithick, Ginn, Halaki, & Balnave, 2007), as it is required to elevate the upper extremity to reach the arm forward in order to be able to execute the power phase of the paddle (Pollard & Fernandez, 2004). According to Michener, McClure and Karduna (2003), impingement of the shoulder can be directly influenced by a lack of mobility in the thoracic spine through scapulothoracic and glenohumeral kinematics. Normal shoulder girdle function requires thoracic extension mobility (Ludewig & Reynolds, 2009). Additionally, restricted range of motion of joints due to poor rehabilitation of previous injuries can lead to further injuries, muscular atrophy and can add stress to the surrounding joints (Heggie & Caine, 2012). Lack of movement in one area of the body may affect surrounding areas by increasing stress on surrounded joints (Sueki & Chaconas, 2011), and the interrelationship of the shoulder to the thoracic spine allows for controlled reaching movements such as when paddling a stroke. Rotational movements of the thoracic spine are essential to a surfer’s ability to perform turning manoeuvres (Furness et al., 2016). The ability to execute a successful turn is partly dependent on the ability of a surfer to dynamically twist their body using powerful and controlled techniques. Thus, Aragon et al. (2012) suggests that improvement in trunk rotation may lead to the prevention of shoulder or elbow injuries.

Freestyle swimming vs surfing

Shoulder girdle movements during paddling a surfboard can be compared to a freestyle swim stroke, however, with surfing the body is maintained in a fixed position on the board resulting in a decrease in trunk rotation (Dimmick, Patterson, Sheehan, Anderson & MacDougal, 2018). It is possible that this fixed position contributes to the aetiology of shoulder injuries in surfers, compared to other overhead athletes and swimmers (Dimmick et al., 2018). Paddling involves propelling both the mass of the surfer and the surfboard together whilst lying prone on a rigid floating board while maintaining the trunk in an extended position. This is a demanding physical task and has been suggested to place stress on the posterior aspect of the rotator cuff and peri-scapular musculature, possibly leading to the prevention of shoulder injuries within the population.
rotator cuff and sub-acromial bursa (Dimmick et al., 2018). In comparison, swimmers are able to easily increase rotational movement of their body during a stroke as they do not have the buoyant surfboard constraining axial movement. The study by Dimmick et al. (2018) was a prospective study from surfers that were referred to orthopaedic shoulder clinics over a 3-year period with 42 shoulders included in the study from 37 participants. Dimmick et al. (2018) showed the most common presentation was for chronic shoulder pathology with the average age being 48 years. However, due to all participants being referred to a sub-specialty orthopaedic clinic these finding are unsurprising.

**Measurement of thoracic spine mobility**

*Overview of the Electrogoniometer*

Precise measurement of the thoracic spine is technically challenging, particularly without access to advanced biomechanics facilities. The device (‘Spinal Mouse ®’) used in the study reported in Section 2 of this thesis, is a non-invasive electrogoniometer appropriate for practical field-based measurement of segmental angles of the thoracolumbar spine, from T1 to L5, including sacral angles. The device is a computer-aided cordless device that utilises Bluetooth radio to transmit raw data into proprietary software, called Idiag M360 (Kellis, Adamou, Tzilios, & Emmanouilidou, 2008). This software instantaneously portrays individualised angles between segments of the thoracolumbar spine. The electrogoniometer has been demonstrated as a safe, reliable method of measuring spinal mobility in a number of studies (Kellis et al., 2008; Livanelioglu, Kaya, Nabiyev, Demirkiran, & Firat, 2016). The device has satisfactory reliability (Mannion, Knecht, Balaban, Dvorak, & Grob, 2004; Roghani et al., 2017) and validity (Barrett, McCreesh, & Lewis, 2014; Livanelioglu et al., 2016) and has been used to measure spinal mobility in athletes including kayakers (López-Miñarro, Muyor, & Alacid, 2014), elite cyclists (Muyor, López-Miñarro, & Alacid, 2013), canoeists, and tennis players (López-Miñarro, Vaquero-Cristóbal, Alacid, Isorna, & Muyor, 2017). Thoracolumbar curvature has been measured using the Spinal Mouse in adolescents (Livanelioglu et al., 2016), pregnant women (Okanishi, Kito, Akiyama, & Yamamoto, 2012), older women (Roghani et al., 2017) and healthy male adults (Hasebe et al., 2014).
The reliability of thoracic mobility measuring methods in a previous study

In a previous study by Furness et al. (2016), the reliability of methods of measuring thoracic mobility in the sagittal plane were tested using a standard goniometer compared to using a tape measure. Both of these methods have been proven effective in their study which was conducted on 27 participants (Furness et al., 2016). Furness et al.’s (2016) research aimed to investigate a difference in spinal mobility between the elite male surfing population and non-surfers, showing that these techniques are reliable in a surfing population. Although proven reliable in this study, the Spinal Mouse appears to be a more efficient and accurate method compared to a standard inclinometer, as recordings and angles are automatically transferred via Bluetooth to computer software. The computer software displays graphs showing the angles between each vertebra. The study showed that in all movements produced, the elite male surfing population had greater thoracic range of motion, potentially indicating a mobile spine is a requirement of high-level surfing. Although the study showed reliability, inter-rater reliability was not assessed in this study, though an attempt was made at blinding the rater by having a recorder present. The relatively small sample size and lack of female participants limits generalisation across all surfers. These reasons show necessity for efficient measuring of thoracic spine mobility in a surfing population.

In summary, the Spinal Mouse is an efficient tool to utilise for the measurement of mobility of the thoracic spine. It has proven to be an effective method and is easy to use. Previous methods by Furness et al. (2016) showed effective methods of measuring the thoracic spine, however, they are unlikely to be as efficient and accurate as the Spinal Mouse. Furness et al. (2016) did prove these methods were effective in a surfing population.

Conclusion

Surfing is a dynamic sport that requires repetitive shoulder motion in addition to aerobic and anaerobic fitness. Gradual-onset shoulder injuries are common in the surfing population, of which shoulder impingement syndrome is a prevalent injury. Shoulder impingement syndrome is known to be influenced by shoulder kinematics, including the scapulothoracic joint. When scapulothoracic and glenohumeral rhythm are disrupted, increased stress is placed on the rotator cuff and other structures which may over time result in damage of these structures. Mobility of the thoracic spine, especially extension mobility, is crucial for surfing
as it allows for arm clearance of the water during paddling. It appears that no previous study has investigated the relationship between shoulder pain and thoracic mobility in surfing.
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Section 2: Manuscript
The relationship between thoracic spine mobility and shoulder problems in a sample of surfers: A cross-sectional design

Note:
This manuscript has been prepared in accordance with the Guide for Authors for the journal Physical Therapy in Sport. The guidelines for authors (PDF file) for Physical Therapy in Sport can be downloaded here: https://www.elsevier.com/journals/physical-therapy-in-sport/1466-853x/guide-for-authors The manuscript is formatted using Elsevier’s ‘Your Paper Your Way’ initiative as explained in the guideline. Although there is a word limit for original articles, this has been exceeded for the purposes of the thesis. References to the Thesis Appendices are shown in this manuscript within square brackets.
Abstract

**Objectives** Chronic shoulder injuries are prevalent amongst surfers and one potential underlying cause may be a lack of mobility in the thoracic spine. The objective of this cross-sectional study was to investigate the relationship between shoulder pain and thoracic mobility in surfers.

**Methods** Surfers were recruited using emailed invitations to an existing database of surfers, and notices posted to surfing related social media sites. Auckland based surfers participated in a 30-minute measuring session where thoracic mobility was assessed using an electrogoniometer. Participants identified their level of shoulder pain and disability using a modified version of the Sports/Performing Arts Module in the Disability of the Arm, Shoulder and Hand (DASH) questionnaire in addition to identifying descriptive details such as age, height, surfing skill (Hutt Scale), and surfing history.

**Results** Forty-one participants were recruited (n=29 males, n=12 females; mean ± SD age = 38.7 ± 11.9y, range (19-68 years)). No correlation was found between thoracic mobility and DASH scores. Findings showed a positive relationship between age and shoulder pain ($r=0.324*(-0.008, 0.635)$ $p=0.039$); skill level of the surfer and frequency surfed during the previous summer were also found to be correlated ($r=0.490** (0.207, 0.775)$, $p=0.001$). There was a positive relationship between height and seated mobility in the lumbar spine ($r=0.311* (-0.034, 0.573)$, $p=0.048$). Lower thoracic spine symmetry was positively correlated with upper thoracic seated mobility ($r=0.349* (-0.013, 0.612)$, $p=0.025$). Negative relationships included frequency of surf sessions and shoulder pain ($r=-0.374* (-0.653, -0.049)$, $p=0.016$), and age and upper thoracic seated mobility ($r=-0.355* (-0.603, -0.023)$, $p=0.023$). Upper and lower thoracic spine prone mobility was negatively correlated ($r=-0.365* (-0.628, -0.051)$, $p=-0.019$), and this was the same for lumbar spine prone mobility and age ($r=-0.417** (-0.648, -0.137)$, $p=0.007$). Other relationships that correlated negatively were upper thoracic paddling symmetry and frequency surfed during the previous summer ($r=-0.311* (-0.561, -0.023)$, $p=0.048$), and lumbar spine and lower thoracic spine paddling symmetry ($r=-0.415** (-0.676, -0.133)$, $p=0.007$).

**Conclusion** The correlation between DASH scores and thoracic mobility in the seated or prone position in this sample of surfers was small. Further research, such as a prospective longitudinal study exploring risk factors for the development of shoulder symptoms associated with surfing would be beneficial.

**Keywords**: shoulder, surfing, injury, thoracic spine
Introduction

Surfing is a sport requiring high levels of fitness and is enjoyed both recreationally and competitively. The sport of surfing has deep roots in Hawaiian culture and can be traced back hundreds of years (Nendel, 2009). Surfing can benefit the mental health of individuals (Wheaton et al., 2017) in addition to improving physical health. This may also be as a result of time spent in nature emersed in the ocean (Lazarow et al., 2009). Participation in surfing is steadily increasing in New Zealand, (Moran & Webber, 2013) and the rest of the world (Lazarow et al., 2009). Surfing will be featuring in the 2020 Tokyo Olympics and this has attracted worldwide attention to surfing as a sport (Kojima et al., 2018). Surfing as a sport requires repetitive paddling stroke and sustained posture; this is said to be associated with the high frequency of shoulder, back and neck issues (Mendez-Villanueva & Bishop, 2005).

Shoulder injuries are commonly seen in both competitive and recreational surfers (McBride & Fisher, 2012). The shoulder is placed in a vulnerable position in overhead sports such as surfing. Both shoulder stability and mobility are crucial for overhead athletes to meet the functional demands of their sport (Borsa et al., 2008). Therefore, the functioning of the joints that make up the shoulder are vital in shoulder injury prevention. Repeated overhead movement can result in specific shoulder impingement injuries and are common in surfing. In New Zealand, injuries caused by accidents during surfing may be eligible for ACC cover. A lack of thoracic mobility can lead to shoulder injury and pain (Lewis & Valentine, 2010), and the relationship of the thorax to the shoulder is important during abduction of the shoulder to reach forward during paddling. Therefore, investigating the link between thoracic mobility and shoulder pain is a necessary step towards the prevention of future shoulder injuries in surfers.
Methods

Design and ethics
A cross-sectional observational study was conducted in a convenience sample of New Zealand resident surfers with, and without, ongoing shoulder pain. The study was approved by the Unitec Research Ethics Committee (UREC 2017-1082) and all participants gave written informed consent before enrolment.

Participants

Recruitment
Surfers were recruited using emailed invitations and notices posted to surfing related social media sites. Emailed invitations including basic information about the study were distributed to an existing contacts database of surfers who had participated in previous research (Remnant, 2017) and who had consented to be contacted again with invitations for surfing related research. Notices were also posted to an established Facebook group [see Thesis Appendix A] and cross-posted to other New Zealand based surf-related Facebook groups (‘Ultimate Surf Betty’s’, ‘Surfers Trading NZ’ and ‘The Surfing Stock Exchange’) [see Thesis Appendix B, C, and D]. People who were interested in participating were required to send their name and contact phone number using private direct message to the research Facebook group or directly to the researcher by email. All people who volunteered interest in response to advertising were telephoned and eligibility was determined.

Eligibility
Inclusion criteria were: (1) participants that surfed long boards, short boards or mini-malibu boards, and (2) had surfed at least two sessions within the previous month, and at least three times monthly over the previous summer season. (3) Participants were required to be moderate to advanced surfers as defined by a score between 3 and 7 on a modified version of the Hutt Scale [See Thesis Appendix E] (Hutt, Black, & Mead, 2001). Exclusion criteria were: (1) people that used stand-up or other paddleboards, windsurfing boards, and bodyboards. (2) Professional surfers were excluded. (3) Surfers ≤16 years of age were not eligible. There was no upper bound for age. (4) no recent (<3 months) history of surgery or trauma to the shoulder or spine, or history of chronic conditions affecting the thoracic spine such as hypermobility syndrome. All participants satisfying the eligibility criteria were provided with written information sheets, provided written consent and were enrolled in the
study. To determine shoulder pain status, further information about shoulder pain and disability history was gathered.

**Shoulder Pain Categorisation**

To ensure shoulder pain and/or injury was currently relevant the following question was asked of each participant: “If you were to go surfing now, would you expect shoulder pain?” Participants with shoulder pain must have had ongoing pain for at least three months. To identify the level of shoulder pain or disability surfers were experiencing, all potential participants completed a modified version of the Performing Arts and Sports Module of the DASH questionnaire [see Appendix F] (Germann, Wind, & Harth, 1999) presented using an online questionnaire application (SurveyMonkey), with all questions modified to be specific to surfing. Participants were required to recall their shoulder pain and disability based on the last time they went surfing. Participants were then asked to pinpoint the area of pain on the body chart (see Figure 2). Those that scored ≥ 10 points were assigned as ‘moderate’ group. Participants that scored between 6 and 9 on the modified DASH questionnaire were considered ‘mild’, and those participants scoring ≤ 5 were assigned to an ‘asymptomatic’ group. The modified DASH questionnaire differs from the original DASH module where participants are required to recall their physical ability over the past week (Germann et al., 1999). Questions modified for surf specificity included alteration of the wording. For example, in the original DASH questionnaire, Question 1 is phrased: “Did you have any difficulty playing your instrument or sport in your usual way?”, compared to Question 1 in the modified version: “Did you have any difficulty surfing using your usual technique?” The wording of Questions 2-3 substituted ‘surfing’ for the original term “instrument/sport”.

Figure 2. Eligibility and Shoulder Pain Categorisation Flowchart. The Hutt Scale indicates the surfing ability of a participant [see Appendix B]. Less than is indicated by <, more than is indicated by >. Modified DASH is a modified questionnaire regarding Disability of the Arm, Shoulder and Hand. The body chart ensured “shoulder pain” was located around the GH (glenohumeral joint).
Measures

Descriptive Variables
All enrolled participants provided the following information: Date of birth (age), frequency of surf sessions per month the previous summer, bodyweight, handedness, stance (whether they were ‘goofy’ or ‘natural’) and type of board surfed. Height was measured using a stadiometer (Model: 213, Seca GmbH & Co.) without footwear.

Intersegmental spinal angles
A commercially available electrogoniometer (Model: Spinal Mouse, Idiag AG, Fehraltorf, Switzerland) and software package (IDIAG M360pro v7.5.0, Idiag AG, Fehraltorf, Switzerland) was utilised for measurement of all intersegmental spinal angles. The electrogoniometer measures individual angles between vertebral segments and has been shown to have good reliability (Kellis et al., 2008; Livanelioglu et al., 2016) and accuracy (Kiss, 2008) for measurement of the spine. Spinal angles for each intervertebral segment between C7 and S3 were measured during six movement tasks: seated flexion and extension, prone resting, prone extension, and thoracic extension whilst simulated surf paddling in a prone position with either the right, or left arm, forward (see Table 1). Each of the movement tasks was repeated three times. To indicate the spinal levels of C7 and S3 as endpoints for the electrogoniometer, a standard ink pen was used to mark the skin overlying the bony landmarks.
Table 1. Movement tasks

(A) To measure seated flexion in the sagittal plane.
Participants were required to perform maximal flexion of the thorax in the sagittal plane in a seated position. The participant was seated on a height-adjustable table with knees and hips at 90 degrees flexion and feet flat on the floor. Participants were asked to interlace their fingers behind their head, bring their elbows towards each other and flex their spine to its maximal position, whilst preventing using their hips to bend forward. Participants were asked to maintain this position. The Spinal Mouse was placed on the C7 and carefully moved down the spine to S3, whilst maintaining contact with the spine.

(B) To measure seated extension in the sagittal plane.
Whilst maintaining their body and hands in the same position, participants were asked to extend their spine as far back as possible, ensuring to keep their feet flat on the floor and elbows together whilst the Spinal Mouse was moved down their spine. If the Spinal Mouse was unable to reach the necessary landmark (C7), the participant was asked to place their interlaced hands slightly higher on their head to create enough space for the Spinal Mouse.

(C) To measure prone resting in the sagittal plane.
Participants were required to lay prone on a plinth with their forehead in contact with the plinth and their arms resting either side of their body. They were instructed to rest in this position.

(D) To measure prone extension in the sagittal plane.
Participants were required to be in the prone position again, but with hands placed flat underneath their shoulders, pressing their upper body upwards whilst their anterior superior iliac spines maintain contact with the table. Participants were instructed to look ahead of them with their head in a neutral position. If the Spinal Mouse was unable to roll down the spine smoothly due to the musculature around the scapula compromising the space of the posterior spine, the participant was asked to relax their shoulders and move their elbows laterally. This created enough space for the measuring to continue.
To measure thoracic form during a paddling stroke.

(E) Laying prone on the plinth, participants were instructed to simulate their usual padding position for two stokes, pausing with their right arm in the most maximal forward reach position, whilst moving their spine into maximal extension. Participants were instructed to maintain this position while prone thoracic extension was assessed with the Spinal Mouse, and to look neutrally ahead rather than directly downwards. (F) The same movement was repeated with the left arm forward.
Measurement procedures

Participants were asked to participate in one session of approximately 30-minutes duration. Each participant was instructed to perform every movement to their maximal range. Prior to data collection, participants were shown the electrogoniometer and were then familiarised with how to perform each movement. If participants performed the movements incorrectly, the researcher would immediately explain how to repeat the movement correctly. Participants were asked to remove clothing from their upper body to ensure the skin over their spine was exposed. Participants were also asked to fold their shorts down to ensure the mark on S3 was exposed during the measurements. Females were asked for permission to undo the latch on their bra and these were taped either side of the spine to ensure the spine was fully exposed from C7 to S3. Female participants that wore a bra that was unable to unclip at the back were provided with a gown that exposed the spine only. Prior to measuring, participants were asked to flex and extend their cervical spine to identify C7 (Póvoa, Ferreira, Zanier, & Silva, 2018). C7 was identified by palpating the lower cervical spinous processes (SP), noting which SP moved forward relative to the one below. The SP that moved relatively more than the SP below was identified as C6, and therefore the SP palpated just below was identified (Póvoa et al., 2018), and the skin marked as C7 using a whiteboard marker. The lower landmark was S3 (Battaglia et al., 2014). This was identified through identifying the levels of the posterior superior iliac spines, moving medially in the horizontal plane, then measuring two centimetres below this mark.

Data Analysis

Angles between each spinal segment were measured and automatically saved in the Idiag M360pro 7.5.0 software before later being exported and raw values tabulated in an excel spreadsheet. For analysis the spine was divided into ‘upper thoracic’ (T1-2 to T5-6), ‘lower thoracic’ (T6-7 to T11-12, and ‘lumbar spine’ (T12-L1 to L4-5). The variable ‘mobility’ was calculated from the difference in angle between seated flexion and extension, and prone resting and extension. Assumptions of normality for all data were explored using the Shapiro-Wilk statistic, and considering whether the z-score for skewness and kurtosis lay within ±2.58 (Laerd Statistics, n.d.). Contrasts between males and females for age, height, weight, frequency of surfing during the previous summer were calculated using independent samples t-tests, and equality of variance determined using Levene’s test. Contrasts between males and females for Hutt score, and DASH scores were calculated using Wilcoxon-signed rank
test. Difference in proportion between females and males for stance (goofy or natural) were calculated using the z-score test of proportions. Correlations between variables were calculated using either Pearson’s $r$ when both variables were normally distributed, or Spearman’s rho when one or both variables were non-normally distributed. Confidence intervals (95% confidence intervals (CI)) and $p$-values were calculated to aid interpretation of each correlation coefficient. The magnitude of correlation coefficients was interpreted using Hopkins descriptors (Hopkins, 2002) where $r$ of 0 to 0.1 was ‘trivial’, 0.1 to 0.3 was ‘small’, 0.3 to 0.5 was ‘moderate’, 0.5 to 0.7 was ‘large’, 0.7 to 0.9 was ‘very large’, and 0.9 to 1.0 was ‘nearly perfect’. All statistical analyses were undertaken using SPSS v25 (SPSS IBM, Armonk, NY).
Results

Demographics

Table 2 shows participant descriptive characteristics. A total of 41 surfers participated in the study, 12 females and 29 males. The mean ± SD age for females was 31.5 ± 9.2 years, whilst the mean age for males was 41.7 ± 11.7 years. On average, males had surfed more than twice the frequency than females during the previous summer, mean ± SD of 11.3 ± 7.0 times per month, compared to 6.1 ± 3.6 times per month for females (mean difference 5.2, 95% CI 1.8 to 8.6, \( p = 0.003 \)). Males also had a significantly (\( z = -4.32, p < 0.001 \)) higher mean self-rated Hutt score than females (mean 6.03 ± 0.9 for males, and 4.5 ± 0.7 for females). There was no significant difference (\( z = -0.979, p = 0.342 \)) between mean DASH scores between males (6.7 ± 3.2) and females (6.9 ± 2.2). On average, males were significantly older (\( p = 0.011 \)), taller (\( p < 0.001 \)) and heavier (\( p < 0.001 \)) than females. The majority of participants primarily surfed shortboards (30), had a natural stance (28), and were right handed (33). There was a significant difference (\( p < 0.001 \)) in stance between males and females with six out of 12 female participants were goofy, compared to only 7 goofy male participants from 29.

Thoracic Spine Mobility and DASH Score

Table 3 shows weak correlations found between thoracic mobility and DASH score. These findings applied to both seated mobility and prone mobility in the upper and lower thoracic spine. The correlation coefficients for seated mobility and DASH were small negative (\( r = -0.241 \)) for the upper thoracic spine, and minor positive (\( r = 0.114 \)) for the lower thoracic spine. This shows a negative relationship between upper thoracic seated mobility and shoulder pain, suggesting that a high level of shoulder pain or disability is correlated with decreased thoracic mobility, although this correlation is small in magnitude. For prone mobility in the thoracic spine, the correlation coefficients were practically zero, with upper thoracic and lower thoracic mobility being positive (\( r = 0.028 \)) and negative (\( r = -0.095 \)), respectively.
**Additional Findings**

DASH scores were correlated with both frequencies surfed during the previous summer and age. A *moderate* negative correlation \((r = -.374)\) was found between DASH score and frequency surfed during the previous summer; DASH and age were *moderately* positively correlated \((r = .324)\). Hutt scale and frequency surfed during the previous summer had a *moderate* correlation of .490. The highest mobility correlation was between upper thoracic and lower thoracic prone mobility, with a *moderate* negative correlation of \((r = -.365)\). Age had a *moderate* negative correlation with upper thoracic seated mobility \((r = -.355)\). Age also had a *moderate* negative correlation with prone lumbar spine mobility \((r = -.417)\). A *moderate* negative correlation was found between paddling symmetry in the lower thoracic and lumbar spine \((r = -.415)\).
Table 2. Participant descriptive characteristics

<table>
<thead>
<tr>
<th></th>
<th>Overall (n=41)</th>
<th>Female (n=12)</th>
<th>Male (n=29)</th>
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<td>Age (yr)</td>
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<td>Height (cm)</td>
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<td>Weight (kg)</td>
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<td>6.1 ± 3.6</td>
<td>11.3 ± 7.0</td>
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<td>DASH Score</td>
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<td>Hutt Score</td>
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<tr>
<td>Right</td>
<td>33</td>
<td>9</td>
<td>24</td>
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Notes

* value is median (IQR)

Freq Prev Summer = frequency of surf sessions over the previous summer

DASH Score = DASH Score refers to The DASH Sports/Performing Arts Module, modified for surf-specificity [See Appendix F]

Hutt Score = Hutt Score refers to a modified version of the Hutt Scale (Hutt et al., 2001) modified by Remnant (2017) [See Appendix E]
<table>
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<tr>
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<th>DASH</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Hutt</th>
<th>Freq</th>
<th>UT Seated Mobility</th>
<th>LT Seated Mobility</th>
<th>LS Seated Mobility</th>
<th>UT Prone Mobility</th>
<th>LT Prone Mobility</th>
<th>LS Prone Mobility</th>
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<th>LT Paddling Symmetry</th>
<th>LS Paddling Symmetry</th>
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Notes: Values are correlation coefficients, 95% confidence interval for correlation coefficients to shown in parentheses. P values for each correlation shown in each cell. * indicates p < 0.05; ** indicates p < 0.01.

Abbreviations: DASH = the Disability of the Arm, Shoulder and Hand questionnaire; Hutt = Hutt Scale; Freq = frequency of surf sessions the previous summer; UT Seated Mobility = Seated Mobility in Upper Thoracic Spine; LT Seated Mobility = Seated Mobility in Lower Thoracic Spine; LS Seated Mobility = Seated Mobility in Lumbar Spine; UT Prone Mobility = Prone Mobility in Upper Thoracic Spine; LT Prone Mobility = Prone Mobility in Lower Thoracic Spine; LS Prone Mobility = Prone Mobility in Lumbar Spine; UT Paddling Symmetry = Paddling Symmetry in Upper Thoracic Spine; LT Paddling Symmetry = Paddling Symmetry in Lower Thoracic Spine; LS Paddling Symmetry = Paddling Symmetry in Lumbar Spine.
Discussion

Main findings
The aim of this study was to investigate the relationship between shoulder pain and thoracic spine mobility in surfers. To the author’s knowledge, this is the first study to have investigated this relationship. The findings of this cross-sectional study did not identify a significant relationship between thoracic mobility and shoulder pain in this sample of surfers. Based on previous literature (Aragon et al., 2012; Edmondston et al., 2012; Sueki & Chaconas, 2011), it was expected that lower thoracic mobility would be associated with higher DASH scores. Previous studies suggest various links between the thoracic spine and shoulder including structural (anatomical) and functional (biomechanical) links (Culham & Peat, 1993), including successful intervention with manipulation of the thoracic spine as a successful treatment of shoulder pain (Sueki & Chaconas, 2011). However, we did not find a significant correlation between these variables. It was expected that there would be a positive correlation between increasing age of participants and DASH scores and a ‘moderate’ positive relationship was observed. A positive relationship between frequency of surf sessions during the previous summer and DASH score was expected based on the premise that hours of exposure to surfing is likely to increase the chances of developing injuries (Nathanson et al., 2002). However, the findings here indicated that increased frequency of surfing was associated with lower DASH scores. These findings may be due to general physical conditioning of surfers who surf more regularly (Frank et al., 2009) and could be a result of improved paddling technique (Johnson, Gauvin, & Fredericson, 2003). Also, frequency of surf sessions during the previous summer was positively correlated with Hutt Scale scores.

Significant Predictions
Older age and lower thoracic mobility were predicted to be negatively associated. This relationship was evident for seated mobility in the upper thoracic spine, and prone mobility in the lumbar spine but interestingly, there was no significant correlation between the lower thoracic spine, or lumbar spine (in seated mobility) with age. There was also no significant relationship between thoracic spine (both upper and lower) mobility in the prone position and age.
These were interesting findings as the negative relationship between age and mobility have been well established in previous literature (Battaglia et al., 2014; Ensrud, Black, Harris, Ettinger, & Cummings, 1997; O’Gorman & Jull, 1987; Pan et al., 2018).

**Thoracic spine paddling symmetry**

A positive relationship was found between paddling symmetry in the lower thoracic spine and upper thoracic seated mobility. This was an interesting finding as this may indicate that those who previously surfed less, are more likely to have an asymmetrical thoracic spine during the reach phase of a paddling stroke whilst extending their thoracic spine. Asymmetry is a known risk factor for overuse injury and has been evaluated in a number of studies in samples of different sporting groups including American Football players (Kiesel, Butler, & Plisky, 2014), female collegiate athletes competing in weightbearing varsity sports (Knapik, Bauman, Jones, Harris, & Vaughan, 1991), and national collegiate athletes in rowing, volleyball and soccer (Mokha, Sprague, & Gatens, 2016). These studies have shown that muscular imbalances and asymmetries predispose athletes to overuse injuries, although to date this relationship between asymmetry and risk of overuse injury has not been explored in surfers.

A negative relationship was found between upper thoracic paddling symmetry and the frequency of surf sessions during the previous summer. In plain language, those who surfed more were more likely to demonstrate greater spinal symmetry. Although spinal symmetry has not been previously investigated in the context of surfing, a similar finding has been noted in kayakers. For example, Rynkiewicz and Starosta (2011) explored asymmetry of paddling technique in kayak athletes and found that in males, paddling symmetry decreased when paddling with maximal strength and frequency. In female kayak athletes, paddling symmetry increased with increasing distance. Paddling asymmetry was also higher in female participants competing in lower levels, suggesting that skill and level of performance may be related to asymmetrical patterns.

**Comparisons with other studies**

The correlation between thoracic mobility (in the sagittal plane) and DASH scores was not significant in both seated and prone mobility in the sagittal plane. There appear to be no previous studies directly investigating the relationship between thoracic mobility and shoulder pain in surfers, however, some general insights into the nature of the relationship
between the shoulder and thoracic spine has been shown in studies investigating other sports involving overhead movements including swimming (Almeida et al., 2011; Pollard & Fernandez, 2004; Tovin, 2006), water-polo (Tainha & Pascoal, 2000) baseball, volleyball (Tate, McClure, Kareha, & Irwin, 2008), and surf-lifesaving (Carter, Marshall, & Abbott, 2014).

An improvement of pain and functional capacity was achieved through manual therapy applied to the thoracic spine among other areas of the body for the successful treatment of shoulder injury in a young competitive swimmer (Almeida et al., 2011). Another study suggests manual therapy such as mobilisation to the thoracic spine is effective for the treatment of shoulder injury in swimmers (Tovin, 2006). Pollard and Fernandez (2004) explained the importance of thoracic spine extension for the prevention of shoulder injury in swimming.

Baseball, swimming, volleyball and water polo all require differing elements of overhead activity and can all be affected by shoulder impingement syndrome. Water polo combines elements of swimming and throwing, combining adduction and internal rotation of the shoulder with the arm elevated (Tainha & Pascoal, 2000). The study by Tate, McClure, Kareha and Irwin (2008) showed positive results with overhead athletes suffering from shoulder impingement symptoms. The study utilised the Scapula Retraction Test (SRT) to stabilise the scapula against the thorax, encouraging posterior tilting and external rotation of the scapula as well as thoracic spine extension. Pain rating post SRT during shoulder impingement provocation testing resulted in pain reduction in nearly half of the athletes, showing the importance of scapulothoracic kinematics in shoulder pain.

Carter, Marshall and Abbott (2014) showed that surf-lifesavers (who often paddle various water craft and are also often involved in surfing) with a history of shoulder pain did not have a lower combined elevation test score and therefore did not lack mobility. The combined elevation test, a test both measuring thoracic extension, shoulder flexibility and strength was used to measure young surf-lifesavers with shoulder pain (Carter et al., 2014). This study was performed on surf lifesavers between ages 10-18. Our participants were all over the age of 18 and therefore possessed increased skeletal maturity. Skeletal immaturity is likely to impact general flexibility and thus may not represent an equal comparison to our study (Maffulli & Baxter-Jones, 1995).
Pain and disability self-rating

One explanation for the lack of strength of our findings may be due to the self-reporting of pain and disability via the modified DASH questionnaire. Due to pain being comprised of sensory and emotional dimensions (Cohen, Quintner, & Van Rysewyk, 2018), if a person has a positive mindset, their perception of pain is mitigated (McIver, Kornelsen, & Stroman, 2018), and their pain rating is likely to be lower. This may also apply to their disability rating, if a person is not emotionally attached or concerned by a certain amount of disability their rating may be lower. A possibility is also that due to pain and/or disability, a surfer may modify their usual technique, and this may even occur without the individual taking notice. Many surfers are passionate about surfing and therefore may choose to ignore symptoms if they do not directly prevent them from being able to surf. This is particularly common in big wave surfing, where surfers may continue to participate despite injuries (Partington et al., 2009). Self-reported pain and disability levels in our study therefore may not be representative of the actual pain and disability levels experienced. Another reason may be due to the low numbers of participants with moderate shoulder pain and disability that participated in the study. It might be that surfers with moderate shoulder pain prevent further pain or injury by allowing themselves to rest, and therefore they did not participate in this study.

DASH Score and Age

We expected a positive relationship between the reporting of shoulder pain and disability (DASH) and age. Interestingly, Cooper, Powell and Rasch (2007) stated that previously it was thought that aging resulted in certain physiological changes, whereas they suggested that these physiological changes were partly due to disuse, and that these changes may be slowed down with ongoing exercise (Cooper et al., 2007). There are a number of reasons as to why there is a moderate relationship between the two and these are increased hours of exposure, decreased healing capacity and potential for past history of injury. Aging surfers are more likely to develop gradual-onset injuries as they generally have higher number of hours of exposure (Bahr & Holme, 2003); resulting in more overuse and potential for gradual-onset shoulder injuries. In general, healing decreases with aging (Kannus & Natri, 2007). The body may be unable to keep up with the physical demands of surfing, which include both high intensity and low intensity exercise, with only small intermittent breaks (Furness et al., 2016). Despite older surfers having high levels of fitness (Lalanne et al., 2017), the ability to heal
from minor sprains or strains decreases. Healing time is prolonged with aging (Tashjian, 2012); however, it is possible that aging surfers with a high level of experience are continuing to surf with minor injuries, leading to a minor ‘niggle’ becoming more problematic. This may be avoidable, if aging surfers tended to their minor issues earlier. Older surfers are also more likely to have had shoulder injuries in the past, predisposing them to future shoulder injuries, as a past history of injury is a predictor for future injury (Garrison & Johnson, 2015). Surfing and swimming share characteristics (Furness, Johnstone, Hing, Abbott, & Climstein, 2015), and physical benefits of surfing in an aging population are benefits such as decreased weightbearing, which may result in decreased stress in conditions such as osteoarthritis of the knee and hip (Cooper et al., 2007). Vocational exposure (such as those that work in trades such as construction) are exposed to increased physical work and this may affect surfing injuries. Therefore, aging surfers that have been exposed to increased hours of surfing and work in an occupation requiring overhead shoulder movements, may be at higher risk of gaining injuries whilst surfing.

**DASH Score and Frequency Surfed Previous Summer**

The workload-injury aetiology model describes the resilience of individuals exposed to particular physical challenges, and why they might avoid getting injuries when exposed to extrinsic and intrinsic risk factors. The workload balance describes how optimal training loads disrupt the athlete’s homeostasis, and adaptation occurs during the recovery period (Windt & Gabbett, 2016). Our findings showed a negative relationship between DASH scores and the frequency surfed during the previous summer. A possible reason for the negative relationship between shoulder pain and frequency surfer during the previous summer may be explained via the workload-injury aetiology model (Windt & Gabbett, 2016). The workload-injury aetiology model may apply to surfers, as increased surfing exposure often results in the surfers becoming stronger, fitter, and more coordinated, and therefore preventing injuries. This is also argued by Stovitz and Johnson (2006), who state that injuries are predisposed by a lack of training, in contrast to other research findings stating the cause of injury is overuse of body parts (Greenfield et al., 1995; A. Nathanson et al., 2002). Due to our inclusion criteria requiring each participant to have surfed at least twice in the preceding month, and beginner surfers being excluded from the study, those that were less skilled, perhaps less surf-fit or surfed irregularly were excluded from the study. According to the work-load injury aetiology model, this group of people would be more likely to have gained a shoulder injury (Windt & Gabbett, 2016).
Remnant (2017) found that surfers with shoulder injuries spent 42% more time surfing in the previous 12 months than those without shoulder injuries. Similar to aging surfers, the frequency surfed in the previous summer means more exposure, which may result more chances of overuse injury occurring, although this was not shown in our study. Due to the repetitive nature of paddling, the shoulder muscles can be subject to fatigue, undergoing changes that result in shortening of the muscle units (Kannus & Natri, 2007). Respondents from Remnant’s (2017) study indicated that prolonged paddling was the mechanism that caused or aggravated their gradual-onset shoulder injury, with 79% of gradual-onset shoulder injuries being attributed to prolonged paddling. Poor biomechanics and weakness in the rotator cuff and paraspinal musculature can magnify the effect of the repetitive exercise, leading to shoulder issues (Cooper et al., 2007). Although the frequency of sessions a surfer participated in during the previous summer may not represent their recent exposure to surfing, it suggests a negative relationship between exposure to surfing and shoulder pain.

Due to the nature of surfing depending on the quality of the waves, when the surf is favourable, surfers take the opportunity to surf as much as possible during a limited window of opportunity. It is possible that surfers may continue to surf despite feeling a sense of discomfort or pain during the days where the surf is favourable, rather than resting or seeking treatment. This is likely to aggravate symptoms and may promote symptom ignoring behaviours. The relative inconsistency of surf conditions and undesirable surf also correlates to extended breaks where surfers do not surf, causing them to become deconditioned; this may result in gradual-onset injuries (Renneker, 1987).

Wetsuits are worn by surfers in New Zealand all year around due to cooler ocean temperatures. Modern wetsuit design uses thinner and more flexible materials allowing for extended surfing sessions (Nessler et al., 2015), and help surfers to thermoregulate in the water (Wakabayashi, Hanai, Yokoyama, & Nomura, 1992). This may lead to increased metabolic cost due to repetitive paddling motion with resistance from the wetsuit (Nessler et al., 2015) and may be a predisposing factor to shoulder pain or injury. Lowdon, Pateman and Pitman (1983) predicted an increase in shoulder injuries in surfers due to improvements in wetsuit technology, which may increase hours of exposure to surfing.
**Hutt & Frequency**

Surf conditions are dependent on many factors, like wind conditions for example; ideally these are light and offshore (Scarfe et al., 2003). When swells arrive, surfing conditions can be consistent for a number of days, or even weeks. Our findings that surfers who spent more time surfing in the previous summer, were also better surfers is unsurprising. There are a few reasons to explain this finding. Those who are more passionate surfers, gain enjoyment or want to improve are more likely to organise to surf regularly. To become a highly skilled surfer, like any sport, requires extensive practise. Everline (2007) argues that better conditioned surfers are also able to engage in longer surf sessions and therefore become better at surfing. This increases overall exposure to surfing and is likely to increase skill level. The irregular nature of these conditions means that surfers have to be flexible to make the most of the surf when it is favourable (Wheaton, 2016). Surfers are generally known to be spontaneous individuals by nature. This may mean that surfers purposefully arrange their working hours to be flexible, so they can go surfing during optimal conditions.

**Age and Mobility – Seated Thoracic Mobility in the Upper Thoracic Spine**

The mobility of the upper thoracic spine is known to decrease with aging. The natural kyphosis of the thoracic spine increases with age, affecting posture and function. A study has highlighted the importance of the role of spinal extensor muscles on the preservation of normal spinal alignment and mobility (Mika, Unnithan, & Mika, 2005). The spinal extensor muscles are the main supportive muscles of the spine (Ensrud et al., 1997; Sinaki, Itoi, Rogers, Bergstrahl, & Wahner, 1996), and are important to surfing as a surfer spends prolonged periods in a prone position whilst contracting spinal extensor muscles. A study by Pan, Firouzabadi, Reitmaier, Zander and Schmidt (2018) showed that the thoracic kyphosis increased 3 degrees per decade. Similarly, range of motion was reduced by approximately 5 degrees for every decade of aging. Their findings showed that changes in kinematics and thoracic shape was more prevalent in the lower thoracic spine (T6-12) compared to the upper thoracic spine (T1-6).

**Age and Mobility – Prone Mobility in the Lumbar Spine**

A negative relationship was found between age and prone mobility in the lumbar spine. This is not surprising, as discs generally become less mobile with age. Intervertebral disk height
reduces with age due to a reduction in hydration and a progressive loss of osmotic pressure (Bibby, Jones, Lee, Yu, & Urban, 2001). The lumbar spine is extended for prolonged periods of time during surfing. The natural lordotic curve of the lumbar spine is accentuated during extension (Cooper et al., 2007); this in turn places pressure on the posterior structures of the lumbar spine. In aging surfers, prolonged extension may lead to injuries of the pars interarticularis (Cooper et al., 2007).

**Paddling Symmetry**

Although paddling symmetry was only investigated in the sagittal plane in the present study, asymmetries were calculated in the thoracic spine between paddling with the left arm forward and paddling with the right arm forward. Furness, Climstein, Sheppard, Abbott and Hing (2016) found that there was no significant different between trunk rotation range of motion left or right in an elite surfing group. A different study by Furness et al. (2016) tested for asymmetry in power output during paddling in both recreational and competitive surfers and found no difference in symmetry for power output in dominant versus non-dominant arms. Furness et al. (2016) also suggested the possibility of using a swim bench ergometer for rehabilitative purposes for those with shoulder injuries and asymmetry whilst paddling.

**Thoracic and Lumbar Spine Paddling Symmetry**

Hand dominance may have influenced imbalances during rotation of the spine in paddling in our study. The present findings showed a moderate negative relationship between paddling symmetry in the lower thoracic spine and lumbar spine. This suggests that increased asymmetry in a surfer’s lower the thoracic spine increased the likelihood of symmetry in their lumbar spine during a paddling stroke of left versus right, and vice versa. If the thoracic spine maintained symmetrical positioning, the lumbar spine was more likely to be asymmetrical. This is an interesting relationship as it shows that asymmetry is common among surfers and may not be a negative finding. Muscular imbalances, and handedness influence the symmetries involved in the spine during motion, though this may not have negative consequences such as shoulder pain or injury.

**Paddling Symmetry and Frequency Surfed**

The negative relationship between paddling symmetry in the upper thoracic spine and frequency surfed during the previous summer may be correlated to surfers that are less experienced or skilled, and therefore show asymmetries during paddling. This is consistent
with the study by Limonta et al. (2010) in kayakers, who showed that less experienced kayakers had less symmetry during paddling than elite kayakers. However, this study did find that elite kayakers maintained more trunk range of motion than novice kayakers.

Methodological issues

The methodological design of this cross-sectional study did not identify a correlation between shoulder pain and thoracic mobility. With appropriate time and funding, a prospective longitudinal study following surfers without a history of shoulder pain would have been an effective method to investigate the aims. This could be done by following a group of surfers without initial shoulder pain or injury over a period of time whilst measuring thoracic mobility at various intervals. Asking questions about shoulder pain and disability at these intervals would indicate a clear picture of the aetiology of potential shoulder pain or injury. The study was designed to investigate whether a relationship exists between thoracic mobility and shoulder pain in surfers. The aim was to compare thoracic mobility in surfers with shoulder pain to those without shoulder pain. Although the sample size was adequate with 41 participants, only a small number of participants reported moderate shoulder pain and disability.

Shoulder pain and time off surfing

The small number of participants with moderate shoulder pain could be argued to be a result of our inclusion criteria; surfers must have surfed at least twice in the preceding month, in addition to surfing three times monthly in the previous summer months. Surfers with moderate pain may have reduced their exposure to surfing and may be resting or rehabilitating their shoulders in order to get back to surfing or prevent further injuring themselves through surfing. It is possible that as a result of their injury, their online presence (such as on surfing Facebook pages), where the majority of surfers were recruited in this study, may have decreased and therefore they may not have seen the opportunity to participate.

Sample size and gender

A limitation of this study was the number of participants (41), and the number of participants with moderate shoulder pain. Only 29 males and 12 females participated. When divided into gender, the small sample of females is unlikely to be representative of the female surfing population. Mobility measures were analysed without dividing genders as the total number of
participants was small. The sample used was not a random sample from a population, and the surfing population was only from Auckland region surfers, and therefore not representative of whole surf population in New Zealand.

**Equipment and Processes**

A standard treatment plinth was used for participants to perform each of the movements on, for the purpose of measuring mobility of the thoracic spine. However, this was not representative of prone lying on a surfboard in the water and therefore mobility during these movements may not have been fully representative of paddling in the water and participants are unlikely to have used normal paddle stroke. Previous studies have attempted more sophisticated simulation of surf paddling. For example, Farley et al. (2012) performed an observational study on physiology of surfers vs their surfing performance as per season ranking, where participants lay on a surfboard that was at an inclination to simulate the weight of the surfer on the board (Farley et al., 2012). The use of a plinth is likely to have affected the paddling movements, due to the lack of plinth inclination and lack of potential rotational movement that can be associated with paddling on a surfboard. This is likely to have had an effect on paddling movements participants were instructed to perform, and therefore may have affected spinal symmetry during the paddling stroke. There are also differences between paddling whilst wearing a wetsuit and without, with additional resistance from the wetsuit likely affecting arm motion during a paddling stroke (Nessler et al., 2015).

We also did not account for relative fatigue during a surf session as participants held positions for up to 5 seconds and each movement was repeated three times. Prior to commencing data collecting, pilot work was tested with movements performed on a surfboard placed on a treatment plinth. There were only minor differences highlighted between movements performed on a static surfboard and manual therapy plinth. Surfers generally use boards that differ in type, size and weight, and therefore it is likely that paddling technique is slightly different on each individual board. As a result of each participant surfing different types, sizes and weights of boards, and the lack of resources to simulate the buoyancy and relative instability of a surfboard in the water, the plinth was a more reasonable option.

**Sample heterogeneity**

The approach to participant recruitment needed to be pragmatic due to the scope of the research project. A heterogeneous sample (age, weight, gender, experience etc) participated...
due to the availability and voluntary basis of this study. This shows that the relationship we investigated may exist, but due to a lack of a homogeneous sample, it was not detected. With $n=41$ participants in the study, and both male and females with a range of surfing experience, age, weight, and occupations, homogeneity was not achieved. Homogeneity in surfing is difficult to achieve as surfing conditions can vary greatly and this may affect the type of board a surfer chooses to use and may affect exposure to surfing. A more homogeneous sample may also include surfers that primarily use the same type of surfboard, are exposed to similar sizes or type of wave (i.e. surf at the same surf spot) and have similar occupations.

Electrogoniometry
Due to the size of the electrogoniometer, some movements were modified to allow for the device to maintain complete contact with the participant’s spine. This occurred primarily in the prone extension movement and seated extension. With affected participants, individuals were asked to prevent extending their cervical spine excessively to allow enough space for the electrogoniometer. With the prone extension movement, affected participants were instructed to relax their shoulders and move their elbow laterally to prevent the contraction and bulging of their rhomboids. This potential problem was identified prior to data collection during pilot work and was therefore easily modified during data collection.

The accuracy of the researcher probably increased throughout the data collection period, as did the instructions, modifications and skill of learning application. The use of the electrogoniometer allowed the efficient measuring of each participant as it is a valid and reliable tool (Kellis et al., 2008; Livanelioglu et al., 2016).

Recommendations for further research
Due to the nature of this cross-sectional study, further research is necessary to further investigate the relationship between thoracic mobility and shoulder pain in surfers. Future studies should aim to recruit a larger sample including homogenous sub-groups of surfers as this may aid in detecting relationships. Due to the prevalence of gradual-onset shoulder injuries in surfers, a prospective longitudinal study may be beneficial to investigate a potential relationship between shoulder pain and thoracic mobility.
Conclusion
This cross-sectional study of surfers did not identify a strong relationship between thoracic mobility and shoulder pain in surfers, however, the data is not representative of a whole surfing population and therefore should not be used to generalise all surfers. The burden of shoulder injuries in surfers is increasing each year with the growing population of surfers worldwide. Further research is necessary to determine the relationship between thoracic mobility and other risk factors for the development of shoulder pain in surfers.
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Section 3: Appendices
Section 3

APPENDICES

Appendix A…………Facebook Advertisement
Appendix B…………Hutt Scale
Appendix C…………DASH Questionnaire: original vs modified
Appendix D…………Pilot Testing
Appendix E…………Ethics Committee Approval
Appendix A

A Facebook page, ‘The Surfing and Shoulder Pain Study’ (https://www.facebook.com/TheSurfingandShoulderPainStudy/) was specifically designed for this study and used to recruit participants. The main post inviting participation was placed on the research Facebook page, with the intention that it would be shared to other surf-specific Facebook pages in New Zealand, including ‘The Ultimate Surf Bettys’ (Figure 1), ‘The Surfing Stock Exchange’ (Figure 2), ‘Surfers Trading NZ’ (Figure 3).
The recruitment post was shared to ‘Ultimate Surf Bettys’, a female only surf Facebook group.
Figure 1. The recruitment post was shared to ‘Ultimate Surf Bettys’, where female surfers share surf content and surf reports.
Figure 2. The post was also shared to ‘The Surfing Stock Exchange’, a page to sell surf gear in NZ.
Figure 3. The recruitment post was also shared to ‘Surfers Trading NZ’, another surf gear trading page in NZ.
Appendix B

The ‘Hutt Scale’ rates the skill level of surfers. This was originally developed by Hutt, Black, & Mead (2001). Rating are independent of surf break quality or the degree of difficulty of the waves (Hutt et al., 2001). Remnant (2017) modified this scale for her study to improve clarity of surfing ability. This study used Remnant's (2017) version.

1. Beginner surfers not yet able to ride the face of a wave and simply moves forward as the wave advances.
2. Learner surfers able to successfully ride laterally along the crest of the wave.
3. Surfers that have developed the skill to generate speed by ‘pumping’ on the face of the wave.
4. Surfers beginning to initiate and execute standard surfing manoeuvres on occasion.
5. Surfers able to execute standard manouevres consecutively on a single wave.
7. Top amateur surfers able to consecutively execute advanced manouevres.
8. Professional surfers able to consecutively execute advanced manouevres.
9. Top 44 professional surfers able to consecutively execute advanced manouevres.
10. Surfers in the future.
Appendix C

The modified DASH questionnaire used in the questionnaire, modified from the original DASH Sports/Performing Arts Module (Figure 1, Panel A) (Institute for Work & Health, 2006). The modified DASH was calculated out of 20. No difficulty scored 1, mild 2, moderate 3, severe 4, and unable 5 (Figure 2, Panel B)

Figure 1, Panel A. Original DASH

<table>
<thead>
<tr>
<th>Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:</th>
<th>NO DIFFICULTY</th>
<th>MILD DIFFICULTY</th>
<th>MODERATE DIFFICULTY</th>
<th>SEVERE DIFFICULTY</th>
<th>UNABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Playing your instrument or sport in your usual way?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. Playing your musical instrument or sport because of arm, shoulder or hand pain?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. Playing your instrument or sport as well as you would like?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. Spending your usual amount of time practising or playing your instrument or sport?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

*Scoring the optional modules: add up the assigned values for each response; Divide by 4 (number of items); subtract 1; multiply by 25.*

*An optional module score may not be calculated if there are any missing items.*
**Figure 2, Panel B. Modified DASH**

<table>
<thead>
<tr>
<th>Did you have any difficulty:</th>
<th>No difficulty</th>
<th>Mild difficulty</th>
<th>Moderate difficulty</th>
<th>Severe difficulty</th>
<th>Unable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Surfing using your usual technique?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Participating in surfing because of arm, shoulder or hand pain?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Surfing as well as you would like?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Spending your usual amount of time surfing?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix D

Prior to data collection, pilot work to test the movements on a Mini-Malibu surfboard for surf-specificity. Subjects lay prone on the Mini-Malibu surfboard and were filmed whilst simulating paddling whilst surfing.
Appendix E

The Ethics Committee approval letter:

November 15 2017

Dear Sara De Jong,

Your file number for this application: 2017-1082
Title: Thoracic Mobility and Shoulder Pain in Surfers

Your application for ethics approval has been reviewed by the Unitec Research Ethics Committee (UREC) and has been approved for the following period:

Start date: November 15 2017
Finish date: November 15 2018

Please note that:

1. The above dates must be referred to on the information AND consent forms given to all participants.

2. You must inform UREC, in advance, of any ethically-relevant deviation in the project. This may require additional approval.

We wish you every success with your project.

Yours sincerely,

[Signature]

Nigel Adams
Deputy Chair, UREC

cc: Asher Lewis
Full name of author: ………Sara de Jong………………………………………….

ORCID number (Optional): ……………………………………………

Full title of thesis/dissertation/research project (‘the work’):
‘The relationship between thoracic spine mobility and shoulder problems in a sample of surfers: A cross-sectional design’

Practice Pathway: Community Studies
Degree: Master of Osteopathy
Year of presentation: 2019

Principal Supervisor: Robert Moran
Associate Supervisor: Megan McEwen

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Signature of author:
Date: 30/04/2019
Declaration

Name of candidate: Sara de Jong

This Thesis entitled: *The relationship between thoracic spine mobility and shoulder problems in a sample of surfers: A cross-sectional design* is submitted in partial fulfillment for the requirements for the Unitec degree of Masters of Osteopathy

**Principal Supervisor:** Rob Moran

**Associate Supervisor:** Megan McEwen

Candidate’s declaration

I confirm that:

- This Thesis represents my own work;
- The contribution of supervisors and others to this work was consistent with the Unitec Regulations and Policies.
- Research for this work has been conducted in accordance with the Unitec Research Ethics Committee Policy and Procedures, and has fulfilled any requirements set for this project by the Unitec Research Ethics Committee.

Research Ethics Committee Approval Number: 2017-1082

Candidate Signature: [Signature] Date: 30/04/2019

Student number: 1417535