

The relationship between clinical measures of scapular dyskinesis and pectoralis minor muscle length: An exploratory, cross-sectional study

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Declaration

Name of candidate: Conner Bond

This thesis entitled '*The relationship between clinical measures of scapular dyskinesis and pectoralis minor muscle length: An exploratory, cross-sectional study*' is submitted in partial fulfilment for the requirements for the Unitec degree of Master of Osteopathy.

Candidates Declaration:

I confirm that:

- This thesis represents my own work;
- 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: 2015-1041

Candidate Signature:

Date:

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Table of Contents

The relationship between clinical measures of scapular dyskinesis and pectoralis minor muscle length: An exploratory, cross-sectional study

Declaration	i
Acknowledgements	ii
Abbreviations	vi
Introduction to thesis	1
SECTION I: Literature review	3
1) Overview of shoulder pain: The incidence, burden and costs	4
1.1) Epidemiology of shoulder injuries in sport and physical activities	5
1.2) Epidemiology of shoulder pain in an occupational or vocational setting.....	6
2) Overview of the function of the scapula	8
2.1) Overview of scapular dyskinesis	9
2.2) Theoretical link between scapular mechanics and shoulder pain through altered glenohumeral position and activity.....	10
2.3) The contentious role of scapular dyskinesis	11
2.4) The relationship between scapular dyskinesis and shoulder pain among athletes	13
2.5) Scapular reposition test indicate relevance of scapular function in shoulder pain	16
2.6) Reduced scapular upward rotation is a potential factor in shoulder pain.....	17
2.7) Review papers investigating the relationship between common shoulder conditions and scapular dyskinesis.....	18
2.8) Measures of scapular dyskinesis.....	21
2.8.1) The 4-Type System.....	21

2.8.1.1)	Reliability and validity of the 4-Type System	23
2.8.1.2)	Limitations of the 4-Type System and the issue of symmetry.....	25
2.8.1.3)	The prevalence of scapular dyskinesia types.....	27
2.8.1.4)	The ‘yes/no’ system: An attempt to address the issues with the 4-Type System	27
2.8.12)	The Scapular Dyskinesia Test: Ratings based on magnitude.....	29
3)	Pectoralis minor muscle overview	30
3.1)	Pectoralis minor muscle assessment	30
3.1.1)	Pectoralis Minor Index	31
3.1.2)	Pectoralis Minor Length Test	32
3.1.2.1)	Kendall secondary test.....	33
3.2)	Comparison of the Pectoralis Minor Index and Pectoralis Minor Length Test.....	34
3.3)	The relationship between pectoralis minor muscle shortness and pain.....	35
3.4)	The link between the pectoralis minor muscle and scapular dyskinesia.....	36
4)	Summary and rationale for further investigation.....	38
5)	References.....	39
 SECTION II: Manuscript		 49
	Abstract	51
	Introduction.....	52
	Methods.....	54
	Design and ethics	54

Participant recruitment and eligibility.....	54
Measures	54
Procedures	57
Reliability of the 6-Type System, Scapular Dyskinesis Test, and angle measurements.....	59
Data analysis	59
Results.....	60
Participant descriptive characteristics	60
Univariate correlation of pectoralis minor length, shoulder pain and upward rotation.....	61
Logistic regression of predictor variables for types and magnitude of dyskinesis.....	64
Discussion	68
Limitations	70
Implications and future research	71
Conclusion	71
References.....	72

SECTION III: Appendices.....	76
Appendix A) Ethics approval letter	77
Appendix B) Ethics application amendment.....	78
Appendix C) Information sheet.....	79
Appendix D) Consent form.....	81
Appendix E) Scapular Dyskinesis Test rating criteria	83
Appendix F) Measurement blinding	84
Appendix G) Shoulder Pain and Disability Index	85
Appendix H) Additional results tables.....	86

Abbreviations and symbols

3D – Three dimensional

AC1 – Agreement Coefficient

CI – Confidence interval (95% unless otherwise stated)

CT – Computed tomography

ICC – Intra-class correlation coefficient

κ – Kappa coefficient

p – Probability value

PMLT – Pectoralis Minor Length Test

PMI – Pectoralis minor index

r – Correlation coefficient

R^2 – Nagelkerke

SDT – Scapular dyskinesis test

UR – Upward rotation (of the scapula)

χ^2 – Chi square

Introduction to thesis

Shoulder pain is a common musculoskeletal complaint (Pribicevic, 2012), and is associated with substantial financial implications (Accident Compensation Corporation, 2016b) and consumption of health care services (Feleusa et al., 2008). While many divergent groups experience shoulder pain (Harcombe, McBride, Derrett, & Gray, 2009; Kumar, Chakrabarti, Patel, & Chowdhuri, 2016; Pribicevic, 2012), people involved in occupational (Hanvold, Wærsted, Mengshoel, Bjertness, & Veiersted, 2015) and sporting pursuits (Pribicevic, 2012) involving upper extremity elevation are particularly affected.

‘Scapular dyskinesis’ refers to visibly apparent deviations from ‘normal’ scapular positioning and motion (Kibler et al., 2013). Although poorly understood, scapular dyskinesis is thought to contribute to shoulder dysfunction and pain (Kibler et al., 2013). Scapular dyskinesis occurs more frequently in symptomatic shoulders (Tate, McClure, Kareha, Irwin, & Barbe, 2009), and has been shown to be a predictive factor in the development of shoulder pain (Clarsen, Bahr, Andersson, Munk, & Myklebust, 2014; Kawasaki, Yamakawa, & Kaketa, 2012). However, other studies have reported contrary findings (Myers, Oyama, & Hibberd, 2013; Struyf et al., 2014), making the causal link unclear (Kibler et al., 2013). The primary clinical methods for assessing scapular dyskinesis are the ‘4-Type System’, with ratings based on the *vector* of dysfunctional movement (Kibler et al., 2002), and the ‘Scapular Dyskinesis Test’, with ratings based on the *magnitude* of dyskinesis (McClure, Tate, Kareha, Irwin, & Zlupko, 2009)

Clinically, shortness of the pectoralis minor muscle is thought to contribute to scapular dyskinesis (Yeşilyaprak, Yüksel, & Kalkan, 2016), with anterior tilting of the scapula around a medial-lateral axis (Borstad & Ludewig, 2005), and may be associated with shoulder pain (Harrington, Meisel, & Tate, 2014). However, there are contrasting reports which suggest shortness of the pectoralis minor muscle is not associated with shoulder pain (Lewis & Valentine, 2007), or altered scapular motion (Cools et al., 2010).

The two primary clinical methods for assessing pectoralis minor muscle length are the ‘Pectoralis Minor Index’ (a direct measurement, more suited to research) (Borstad, 2008), and the ‘Pectoralis Minor Length Test’ (an indirect measurement, more clinically applicable) (Lewis & Valentine, 2007). Borstad (2006), found these two measurements correlated to a ‘very small’ degree, although they were measured in supine and standing positions (Borstad,

2006). Without comparison in a standardised position, the relationship between the Pectoralis Minor Index and Pectoralis Minor Length Test remains unclear. Burkhart et al. (2003), assert that pectoralis minor muscle shortness is causative of Type 1 scapular dyskinesis (anterior tilting) from the 4-Type System. To date, there have been no investigations of the proposed relationship between Type 1 scapular dyskinesis and clinical measures of pectoralis minor muscle length.

These unclear relationships between scapular dyskinesis, pectoralis minor muscle length and shoulder pain indicate a need for further investigation, which is addressed in this thesis. The primary aims of the research aspect of this thesis, presented in Section II were: 1) to determine the correlation between the Pectoralis Minor Index and the Pectoralis Minor Length Test when measured in a standardised position, and 2) to determine the extent to which the Pectoralis Minor Index and Pectoralis Minor Length Test are associated with the type (modified 4-Type System) or magnitude (Scapular Dyskinesis Test) of scapular dyskinesis. The secondary aims of this study were to: 3) investigate the correlation between shoulder pain and scapular dyskinesis, Pectoralis Minor Index or Pectoralis Minor Length Test measurements; and 4) determine the association between scapular upward rotation and scapular dyskinesis.

Note about thesis structure

This thesis is divided into three sections. Section I will consist of a literature review, Section II contains the manuscript formatted to the requirements of the *Journal of Bodywork and Movement Therapies* (available for viewing here: <https://goo.gl/SRfJOG>). Supplementary information can be found in Section III (appendices). The literature review aspect of this thesis, presented in Section I will investigate the relationship between scapular dyskinesis, the pectoralis minor muscle and shoulder pain. It will consist of three primary sub-sections, addressing shoulder pain, scapular dyskinesis and the pectoralis minor muscle respectively. The first sub-section will consist of an overview of the prevalence, burden and costs of shoulder pain and will outline those at risk. The next sub-section will introduce and discuss scapular function and dyskinesis. Physical examination of the scapula and the relationship between scapular dyskinesis and shoulder pain and will be discussed in depth. The final sub-section will pertain to the pectoralis minor muscle consisting of key physical examinations for determining pectoralis minor muscle length, and the clinical relevance and relationship to both scapular dyskinesis and shoulder pain.

SECTION I: Literature review

1) Overview of shoulder pain: The incidence, burden and costs

Shoulder pain is a common musculoskeletal complaint with a lifetime prevalence of 13.3% to 40% in New Zealanders (Taylor, 2005), 19% in Europeans (Pribicevic, 2012), 20.9% to 40.9% in Australians (Hill, Gill, Menz, & Taylor, 2010) and up to 66.7% across multiple countries¹ included in a systematic review of 18 papers (Luime et al., 2004). Shoulder pain is the most common non-traumatic, musculoskeletal, upper body complaint in general medical practice (Feleusa et al., 2008) and the third most common presenting complaint to chiropractors in New South Wales, Australia (Pribicevic, Pollard, & Bonello, 2009). The incidence of shoulder pain in general medical practice increases with age and peaks at 45 to 64 years of age (Greving et al., 2012).

The resultant cost and absence from work associated with shoulder pain are of societal concern. Studies in Sweden (Virta, Joranger, Brox, & Eriksson, 2012), Denmark (Rudbeck, Jensen, & Fonager, 2013) and the United States (Mroz et al., 2014) have identified that shoulder pain is associated with substantial economic impact directly through costs, and indirectly through lost productivity. In New Zealand, the Accident Compensation Corporation (ACC) is funded by tax payers and is responsible for subsidising some or all costs related to accidental injury including treatment, surgery, time absence from work and other aspects of the injury claims process (Accident Compensation Corporation, 2016). Shoulder pain is a substantial expense to ACC and New Zealand tax payers. The total cost of the 153,525 active claims made to ACC for soft tissue injuries of the shoulder totalled \$204,461,688 between July 2014 and June 2015 (Accident Compensation Corporation, 2016b). To put these figures in perspective, the 318,681 claims for soft tissue injuries to the back and spine totalled \$311,194,068 over the same time period (Accident Compensation Corporation, 2016b). The common complaint of shoulder pain is associated with negative impact on both personal and national levels, with decreased quality of life, personal suffering and economic impact.

¹ Including: United States, United Kingdom, Europe and Africa.

1.1) Epidemiology of shoulder injuries in sport and physical activities

While injuries are generally an accepted part of sport and physical activities, especially at high level, certain groups are more susceptible to shoulder pain. A narrative review of the epidemiology of shoulder pain indicates that those participating in sport and physical activities with an overhead component (hereby referred to as ‘overhead athletes’) such as swimming and throwing are particularly susceptible to shoulder pain and dysfunction with a greater incidence than the general population (Pribicevic, 2012). Swimmers are particularly at risk of shoulder pain, and this reflects the high volume of overhead movements expected to be performed during competition and training (Tate et al., 2012). Weekly and lifetime exposure to their sport has been associated with a proportional increases in shoulder pain, disability, and dissatisfaction with swimming (Tate et al., 2012).

Because of the repetitive nature of overhead movements, the risk of overuse injury to the shoulder is particularly high in swimmers. This was reflected in the findings of an epidemiological study of overuse injuries in high school athletes which found the prevalence of shoulder pain to be as high as 30.1% in wrestlers, 43.4% in baseball players and 72.7% in swimmers (Schroeder et al., 2015). Shoulder pain can be disruptive to training and competition for some swimmers, as indicated by Walker, Gabbe, Wajswelner, Blanch and Bennell (2012), who found ‘significantly interfering shoulder pain²’, which was reported in 38% of competitive swimmers over a 12 month cohort study. The issue of shoulder pain in swimming persists into high levels of competition. For example, among 42 swimmers competing in the world championships, the prevalence of reported shoulder pain was 19%, with those performing backstroke most affected (Martins, Paiva, Freitas, Miguel, & Maia, 2014). Swimming is a high risk activity for shoulder pain, with impact on participation, performance and enjoyment of the sport.

Throwing, racquet and other overhead sportspeople are also thought to be affected by shoulder pain (Pribicevic, 2012). Cricketers and baseball players are at risk groups because of the high volume of throwing associated with their sports. Three main studies indicate that shoulder pain is common across varying levels of competition in

² Requiring cessation or modification to training or competition (Walker et al., 2012).

these sports (Fronek et al., 2014; Matsuura, Suzue, Iwame, & Sairyō, 2014; Ranson & Gregory, 2008). Twenty-three percent of 158 professional cricketers in England and Wales, reported shoulder pain during the 2005 season (Ranson & Gregory, 2008). Among 1563 young baseball players in Japan, 16% reported episodic shoulder pain (Matsuura et al., 2014). Similarly, over a 12 month period 12.3% of minor league pitchers had missed games due to shoulder injury (Fronek et al., 2014). While missed games at a recreational level may only be an annoyance, at professional levels missed play time may result in significant revenue loss, negatively impact on team success (Hägglund et al., 2013), and threaten career prospects.

Participation in other overhead sports such as badminton (Arora, Shetty, Khedekar, & Kale, 2015), water polo (Webster, Morris, & Williams, 2010) and volleyball (Reeser et al., 2010) are associated with the development of shoulder pain, as indicated by three key studies of shoulder pain epidemiology in these sports (Arora et al., 2015; Reeser et al., 2010; Webster et al., 2010). Arora et al. (2015) found that over 50% of badminton players (recreational or elite) reported current or previous shoulder pain, with ongoing shoulder pain in 20%. Similar reported rates have been found among elite water polo players, with respective rates of 58.4% and 15.7% for current and chronic shoulder pain (Webster et al., 2010). Greater frequencies of shoulder pain were found among collegiate volleyball players (n = 422) by Reeser et al. (2010), who reported a history of shoulder pain in 58% and current shoulder pain in 43%. Of those players currently in pain, 46% reported their volleyball performance was adversely affected (Reeser et al., 2010). Additionally, Reeser et al. (2010) found 57% of those who performed the underhand float serve experienced shoulder pain compared with 67% to 79% of those utilising overhead serving techniques (P = 0.03). The high prevalence of shoulder pain across sportspeople from particular sporting disciplines represents a substantial risk for those participating and indicates a need for a greater understanding of perpetuating factors to more effectively prevent and manage shoulder pain.

1.2) Epidemiology of shoulder pain in an occupational or vocational setting

The risk and impact of shoulder pain in an occupational setting may lead to loss of income and financial difficulty. As with sport, the risk of developing shoulder pain

has been directly related to the amount of time spent working with upper extremities elevated above 60° (Hanvold et al., 2015). Specific occupations such as hairdressing (Hanvold et al., 2015) or house painting (Svendsen, Bonde, Mathiassen, Stengaard-Pedersen, & Frich, 2004) may predispose workers to shoulder pain. To determine which areas of the workforce are most at risk, Hanvold et al. (2015) tracked time spent working with upper extremities elevated above 60° in those with various vocations including hairdressers, electricians and students. Exposure to upper extremity elevation was linked to a five-fold increase in the prevalence of shoulder pain compared with those without exposure (Hanvold et al., 2015). Hairdressers experienced the greatest elevation exposure and highest prevalence of shoulder pain, supporting the notion that work with the arms elevated increases the risk of shoulder pain (Hanvold et al., 2015). Similarly, the prevalence of shoulder pain in house painters was double that reported by machinists or car mechanics (Svendsen et al., 2004). Svendsen et al. (2004) also demonstrated that for every 1% increase in duration of work over 90° of arm elevation there was an increased risk of shoulder pain with disability represented by an odds ratio of 1.16 (95% CI 1.08 to 1.24). Heavy manual labour appears to be another occupational risk factor for the development of shoulder pain. Roudsari and Ghodsi (2005) found farmers were the workers most affected by shoulder pain across all sectors of work. Repetitive manual labour may be a predisposing factor for shoulder pain as indicated by the high prevalence of 41.1% among heavy manual labourers (Kumar et al., 2016). These studies indicate a need for greater understanding of the development of shoulder pain in those performing manual work, especially involving tasks performed overhead.

It might be expected that physical work would more commonly produce shoulder pain however, there is some evidence that those engaging in sedentary work including computer or office based work may also experience shoulder pain. The prevalence of shoulder pain has been documented among sedentary workers in multiple countries including: Thailand (16%) (Janwantanakul, Pensri, Jiamjarasrangsi, & Sinsongsook, 2008), Estonia (30%) (Oha, Animägi, Pääsuke, Coggon, & Merisalu, 2014) and Sri Lanka (34.3%) (Ranasinghe et al., 2011). In New Zealand, Harcombe et al. (2009) have reported a 38% prevalence of shoulder pain in office workers. It is unclear whether a distinction was made between pain in the trapezius muscle and the glenohumeral joint in these studies.

Collectively, these findings are suggestive of a U-shaped relationship between shoulder pain and the frequency of overhead movement, indicating too little or too much may predispose individuals to shoulder pain (Fredriksson et al., 2002). This may be explained in part by adaptive shortening of the anterior trunk musculature with weakness of their antagonists, which is thought to occur with prolonged desk and computer work (Yoo & An, 2009). These changes may impair overhead mechanics relative to those who regularly perform overhead tasks, potentially lowering the volume of overhead movement required to produce shoulder pain (Morais & Cruz, 2016). To summarise this section, shoulder pain is not exclusive to those regularly participating in physical or overhead tasks and is a problem facing a wide range of people.

2) Overview of the function of the scapula

The scapulothoracic articulation links the upper extremity to the thorax and must balance the functions of mobility and stability (Veeger & van der Helm, 2007). The scapula is connected to the cervical, thoracic and lumbar spine, ribcage, cranium, pelvis, humerus, clavicle, radius, ulna and hyoid bone via muscular attachments (Gilroy et al., 2012). Because of the numerous muscular attachments, the scapula is subject to many complex biomechanical influences with substantial variability of movement. The scapula is free to rotate and translate in all planes of movement and around instantaneous centres of rotation (McClure, Greenberg, & Kareha, 2012), which allows for energy transfer and absorption and accommodates positioning of the hand in space (McQuade, Borstad, & de Oliveira, 2016).

For biomechanically efficient overhead movements without undue mechanical strain of the glenohumeral soft tissues, the scapula must undergo a complex combination of movements (Kibler, Ludewig, McClure, Uhl, & Sciascia, 2009). Upward rotation of the glenoid cavity around an anterior-posterior axis and posterior tilting around a medial-lateral axis are thought to be the most critical (Kibler, Ludewig, McClure, Uhl, & Sciascia, 2009). Coordinated movement between the glenohumeral joint and scapula is considered to be important for successful overhead movement of the upper extremity. Classically, the ratio between humeral and scapular motion in abduction is understood to be 2:1 (Inman, Saunders, & Abbot, 1944). More recently, with the advent of improved measurement technologies this relationship has been demonstrated to be more complex. Using more advanced 3D motion

capture technology, the ratio of humeral to scapular motion proved to differ between elevation and return with respective non-linear ratios of 2.3:1 and 2.7:1 (Braman, Engel, LaPrade, & Ludewig, 2009). Additionally, the scapula has been found to undergo internal rotation until $\sim 125^\circ$, followed by external rotation until terminal elevation (Braman et al., 2009). Ratios of movement between the humerus and scapula represent a small portion of the complexity of scapular motion, which varies across planes of movement and at different degrees of elevation. According to leading researchers in the field, the kinematics of normal healthy or symptomatic shoulders are not fully understood at this stage (Kibler et al., 2013; McQuade et al., 2016; Willmore & Smith, 2016).

2.1) Overview of scapular dyskinesis

This section will outline the definition and appearance of scapular dyskinesis, explore aetiological factors, identify important anatomical structures and discuss their clinical relevance. Scapular dyskinesis is defined as impaired control of resting position and movement of the scapula and is considered to be clinically important because of a proposed link with shoulder pain (Kibler et al., 2013). Scapular dyskinesis is primarily a clinical concept, without a standard quantifiable threshold of scapular kinematics between normal and abnormal movement. The classic visual manifestation of scapular dyskinesis is increased prominence of one or more aspects of the scapula as it loses congruence with the thoracic wall (Kibler et al., 2013). Other features of scapular dyskinesis include excessive, abrupt or altered vectors of movement, with loss of fluidity (McClure, Tate, Kareha, Irwin, & Zlupko, 2009). Scapular dyskinesis is more commonly displayed in overhead athletes, possibly suggesting a link to shoulder pain in that susceptible group. A recent systematic review of the prevalence of scapular dyskinesis in athletes (total participants $n = 1401$) found 61% of overhead and 33% of non-overhead athletes displayed scapular dyskinesis (Burn, McCulloch, Lintner, Liberman, & Harris, 2016).

Dyskinetic scapular motion can arise as a result of several dysfunctional or pathological conditions, including: neurological deficits of the long thoracic nerve or spinal accessory nerve (Roren et al., 2013), bone and joint derangement (Kibler & Sciascia, 2010), in response to pain (Falla, Farina, & Graven-Nielsen, 2007) and/or biomechanical factors including altered muscle strength or length (Kibler et al., 2013).

Biomechanical factors are the focus of this paper. All structures attaching to the scapula have potential to influence scapular motion, notable muscles thought to exert the most influence include the pectoralis minor, trapezius and serratus anterior (Kibler et al., 2013). The influence of the pectoralis minor muscle on scapular dyskinesis is a topic of growing interest among shoulder researchers and will be discussed in literature review sub-section 3. Effective strength and activation timing of the serratus anterior and lower trapezius muscles are associated with the production of scapular posterior tilt and upward rotation (Ebaugh & Spinelli, 2010). Improved scapular control is often inferred based upon the activation magnitude and/or ratios of these muscles in relation to the upper trapezius muscle (Ha et al., 2012; Huang, Lin, Guo, Wang, & Chen, 2013; Ludewig & Braman, 2011; Mottram, Woledge, & Morrissey, 2009; Phadke & Ludewig, 2013). However, this has been challenged in recent expert commentary, with the assertion that this approach is too reductionist for such a complex system and the low level of voluntary motor control available to the scapular muscles makes optimisation of their activation ratios a difficult, if not impossible task (McQuade et al., 2016; Willmore & Smith, 2016). Further, McQuade et al. (2016) argue that, ensuring the maximum range of the scapula is available and unimpeded by tight or shortened muscles is of greatest clinical relevance. While these muscles are undoubtedly important, attempting to isolate them may not be a productive approach to optimizing scapular function. Scapular dyskinesis is a complex phenomenon with multiple influencing factors including: participation in overhead activities, injury, pain and alterations of muscle length and strength. Because of this complexity, further research is required to better understand these relationships.

2.2) Theoretical link between scapular mechanics and shoulder pain through altered glenohumeral position and activity

Scapular dyskinesis is commonly cited as a factor related to shoulder pain, although it is not known if scapular dyskinesis is the cause or effect (Kibler et al., 2013, 2009). Scapular dyskinesis is often present in the absence of pain but is more commonly observed in those with symptomatic shoulders (Green, Taylor, Watson, & Ardern, 2013; Tate, McClure, Kareha, Irwin, & Barbe, 2009).

The dynamic model of aetiology in sports injury describes circumstances where intrinsic factors predisposing athletes to injury including biomechanical inefficiency (such as scapular dyskinesis), age and previous injury are magnified through external risk factors such as volume of exposure to overhead movements (Meeuwisse, Tyreman, Hagel, & Emery, 2007). These events lead to maladaptation of affected tissues manifesting themselves as either a gradual onset overuse injury; or an acute injury, with an inciting event which challenges these already compromised tissues (Meeuwisse et al., 2007). In the shoulder, scapular dyskinesis may be a predisposing factor, limiting the amount of overhead movement that can be safely performed.

The concept of relative stiffness or flexibility is central to the 'Movement Impairment Syndromes' (Sahrmann, 2002) and 'Kinetic Control' (Comerford & Mottram, 2012) models of movement dysfunction. When structures in a kinetic chain lengthen with movement, those with the least stiffness will lengthen first and with greater amplitude (Sahrmann, 2002). In the presence of dysfunctional scapular movement, the glenohumeral joint may move abnormally to achieve the desired function of the shoulder complex (Sahrmann, 2002).

The shoulder complex is an interdependent kinetic chain requiring synergy for optimal function. Changes in scapular position and motion are thought to alter the position of the glenohumeral joint and the function of the rotator cuff and other associated muscles (Picco, Fischer, & Dickerson, 2010; Smith, Dietrich, Kotajarvi, & Kaufman, 2006). Altered rotator cuff activity may be a precursor to shoulder pain and can be observed when scapular mechanics are compromised (Picco et al., 2010; Smith et al., 2006). This has been demonstrated with scapular protraction, which has been shown to reduce glenohumeral strength in internal rotation by 13% to 24% and external rotation strength by up to 20% (Smith et al., 2006). Disruption to the synergy of the shoulder girdle through scapular dyskinesis, has the potential to affect function and may result in pain.

2.3) The contentious role of scapular dyskinesis

As indicated in the consensus statement from the 2013 'Scapular Summit', the role of scapular dyskinesis is poorly understood and largely theoretical, but remains an important factor in shoulder pain (Kibler et al., 2013). Kibler et al. (2002) were early

figures in the recognition of scapular dyskinesia and the role it plays in shoulder pain. For the next decade, the concept of scapular dyskinesia gained momentum as a strong factor in shoulder pain, perhaps with clinical popularity not justified by the available literature and understanding (Kibler et al., 2013). Recent developments in scapular dyskinesia research have demonstrated the relationship between scapular dyskinesia and pain may not be as clear as the earlier models would suggest (Kibler et al., 2013; McQuade et al., 2016; Willmore & Smith, 2016). Recently, experts in the field have suggested scapular dyskinesia may represent advantageous movement variability and redundancy related to the dynamic nature of the instantaneous centres of rotation of the scapula and muscular length-tension relationships of the scapular muscles (McQuade et al., 2016). This redundancy helps explain the results of Madsen, Bak, Jensen and Welter (2011), who found scapular dyskinesia was induced by fatigue among pain free competitive swimmers, the incidence of which increased from 37% to 82% by the end of a single training session. Similarly, Willmore and Smith (2016) suggest that scapular dyskinesia falls within the wide range of physiological normal and argue that because significant variability of scapular movement exists between those with asymptomatic shoulders, a true definition of 'normal scapular motion' has not been established. McQuade et al. (2016) have recently challenged the notion of scapular 'instability', arguing that with scapular dyskinesia, the scapula never exceeds the physiological limits of range and is able to return to the intended trajectory following perturbation, making clinical and therapeutic efforts to control or restrain scapular movements counterintuitive. This point has been supported by a number of papers reporting little to no change in scapular kinematics after a course of scapular focused treatments and exercise protocols over a number of weeks (Hibberd, Oyama, Spang, Prentice, & Myers, 2012; McClure, Bialker, Neff, Williams, & Karduna, 2004; Struyf et al., 2012). In a randomized controlled trial of healthy, competitive swimmers, a 6 week protocol of stretching and strengthening the scapular muscles, 3 times per week, did not alter scapular kinematics compared with controls who did not receive an exercise programme (Hibberd et al., 2012). Two separate studies investigating the effectiveness of scapular focused approaches in those with subacromial impingement, reported similar results with regard to scapular kinematic change (McClure, Bialker, Neff, Williams, & Karduna, 2004; Struyf et al., 2012). McClure et al. (2004) reported no change to scapular kinematics measured with

motion capture technology, following a 6 week protocol of daily stretching and strengthening of the scapular muscles and weekly treatment by a physiotherapist. A randomized controlled trial by Struyf et al. (2012) compared scapular focused treatment to rotator cuff focused treatment over a 4 to 8 week course of 9 manual therapy sessions with home exercises. Scapular kinematics measured using clinical tests and inclinometry remained unchanged in both groups following intervention and at 3 months follow up (Struyf et al., 2012). Participants in both studies who received scapular focused treatment reported decreased shoulder pain despite the absence of change in scapular motion. It has been suggested that the improvement to pain in these studies was a result of improved overall synergy of the shoulder complex (Willmore & Smith 2016). These challenging views indicate a need for further research to better understand the scapular dyskinesis phenomenon and the role it plays in the prevention and management of shoulder pain.

2.4) The relationship between scapular dyskinesis and shoulder pain among athletes

There is mixed evidence relating scapular dyskinesis to shoulder pain in athletes. A handful of studies have shown scapular dyskinesis to predict or correlate with current or future shoulder pain, while a similar number of studies have shown the opposite to be true. This section will review the predictive and diagnostic value of scapular dyskinesis and the correlation with shoulder pain.

Predictive value for the development of shoulder pain

Two studies involving athletes participating in rugby (Kawasaki et al., 2012) and handball (Clarsen et al., 2014) demonstrated scapular dyskinesis was a predictor of shoulder pain during the competitive season. Preseason testing of 120 national level rugby players in Japan found that scapular dyskinesis (4-Type System, see section 2.8.1) had a ‘moderate’ association with shoulder complaints with an odds ratio of 4.4 (95% CI = 1.8 to 10.7) (Kawasaki et al., 2012). Of the players with asymptomatic shoulders, those with scapular dyskinesis were more likely to develop shoulder complaints during the season with an odds ratio of 3.6 (95% CI = 1.0 to 12.5) vs 1.0 for those without

scapular dyskinesis (Kawasaki et al., 2012). Similar results were found in handball players but with stronger predictive value (Clarsen et al., 2014). ‘Obvious’ scapular dyskinesis (Scapular Dyskinesis Test, see section 2.8.2) was found to be a ‘moderate’ to ‘large’ factor in the development of shoulder problems in national level Norwegian handball players with an odds ratio of 8.4 (95% CI = 1.47 to 47.1) (Clarsen et al., 2014). These studies indicate moderate predictive value of scapular dyskinesis for the development of shoulder pain in athletes. In contrast, two studies did not establish the same predictive value of scapular dyskinesis for shoulder pain (Myers, Oyama, & Hibberd, 2013; Struyf et al., 2014). In a two year cohort study, observed scapular winging³ and tipping⁴ – both signs of scapular dyskinesis – did not predict the development of shoulder pain in recreational overhead athletes (Struyf, Nijs, et al., 2014). Similar results were also found at a higher level of competition. A study consisting of university level baseball players failed to find statistically significant odds ratios between ‘obvious’ scapular dyskinesis identified by pre-season visual screening (Scapular Dyskinesis Test, see section 2.8.2) and shoulder injury during the season (0.30, 95% CI 0.04 to 2.4, P = 0.62) (Myers et al., 2013). A bias in the design of this study was the exclusive criteria for ‘injury’, which required a specific mechanism involving throwing or pitching, and resulted in missed play time with a formal diagnosis by the athletic trainer or physician. (Myers et al., 2013). This criterion may not have been sensitive enough to detect the early stages of shoulder pain. Additionally, both increased age and exposure to overhead sport are extrinsic risk factors for developing shoulder pain (Greving et al., 2012; Meeuwisse et al., 2007). Because Myers et al. (2013) collected data over only one season with young participants, it is questionable whether there was adequate exposure to extrinsic risk factors for overt shoulder injuries to manifest. Nevertheless, there is mixed evidence largely in favour of the predictive value of scapular dyskinesis for the development of shoulder pain.

³ Prominence of the medial border of the scapula

⁴ Prominence of the inferior angle of the scapula

Diagnostic value for identifying current shoulder pain

Three cross-sectional studies investigating the predictive value of scapular dyskinesia for current pain were available with mixed results (Green et al., 2013; Hickey, Milosavljevic, Bell, & Milburn, 2007; Wright, Wassinger, Frank, Michener, & Hegedus, 2012). Notably, a recent systematic review of 8 papers concluded scapular physical examination was not useful in identifying current shoulder pain (Wright et al., 2012). Consistent with Wright et al. (2012), a group of New Zealand physiotherapists demonstrated observation of scapular motion had poor diagnostic value for identifying symptomatic shoulders (30% to 71% correctly identified, intra-rater reliability: $\kappa = 0.17$ to 0.34) (Hickey et al., 2007). In contrast, researchers found downward rotation of the scapula to be an effective differentiating factor in identifying elite young cricketers with shoulder pain (Green et al., 2013). The findings of the preceding studies do not speak to the actual association with shoulder pain, as they only represent the diagnostic value of observed scapular dysfunction.

Cross-sectional correlation with shoulder pain

The literature is particularly divided when it comes to the relationship between scapular dyskinesia and current shoulder pain. Scapular dyskinesia appears to be more prevalent in those with shoulder pain as indicated by Uhl, Kibler, Gecewich and Tripp (2009), who found multiplane scapular dyskinesia to be present in 54% of participants with symptomatic shoulders, while only 14% of asymptomatic shoulders were affected. This was supported by a study involving kayakers ($n = 31$), which identified scapular dyskinesia in 15 of the 17 participants reporting shoulder pain (Johansson, Svantesson, Tannerstedt, & Alricsson, 2016). When investigating risk factors for shoulder pain in competitive swimmers across all age groups, Tate et al. (2012) found small differences in the prevalence of 'obvious' scapular dyskinesia (Scapular Dyskinesia Test, see section 2.8.2) in select age groups between those with and without shoulder pain (age 8 to 11 = 63.6% and 77.8%, age 23 to 77 years = 46.3% and 53.8%). Two primary studies have reported results that conflict

with these findings (Reeser et al., 2010; Struyf, Nijs, De Graeve, Mottram, & Meeusen, 2010). In a sample of 276 competitive volleyball players, scapular dyskinesis (4-Type System, see section 2.8.1) was not a differentiating factor between those with shoulder pain and those without (Reeser et al., 2010). Consistent with Reeser et al. (2010), no differences in observed scapular ‘winging’ or ‘tipping’ were noted between athletes with and without shoulder pain (Struyf, Nijs, De Graeve, Mottram, & Meeusen, 2010). To further confuse the topic, two studies have shown subacromial anaesthetic injections to paradoxically *increase* scapular dyskinesis in those with subacromial impingement syndrome: the opposite of what is clinically expected (Ettinger, Shapiro, & Karduna, 2014; Kolk et al., 2016). Collectively, these mixed and paradoxical findings indicate gaps in the current understanding of scapular dyskinesis and shoulder pain and should prompt further research into this relationship.

2.5) Scapular reposition tests indicate relevance of scapular function in shoulder pain

While the link between scapular dyskinesis and pain remains contentious due to the conflicting nature of the supporting evidence, the literature clearly supports the use of scapular reposition tests when evaluating shoulder pain (Rabin, Irrgang, Fitzgerald, & Eubanks, 2006; Tate, McClure, Kareha, & Irwin, 2008). These tests help identify scapular involvement in shoulder pain, primarily in cases of subacromial impingement syndrome (Kibler et al., 2009). Scapular reposition tests involve practitioner-delivered manual support of the scapula to encourage upward rotation and posterior tilting (Rabin, Irrgang, Fitzgerald, & Eubanks, 2006) or external rotation and posterior tilting (Tate, McClure, Kareha, & Irwin 2008). These tests have been shown to reduce pain during active overhead movement and clinical tests for subacromial impingement in 50% of symptomatic individuals, in addition to increasing glenohumeral rotation strength in 26% of asymptomatic and 29% of symptomatic individuals (Tate et al., 2008). The immediate reduction in pain and increase in strength associated with a positive scapular reposition test demonstrates a direct and tangible relationship between the scapula and glenohumeral joint, which may direct practitioners to address the scapula in order to assist with shoulder function.

2.6) Reduced scapular upward rotation is a potential factor in shoulder pain

While hypomobility can affect the scapula in any plane, reduced upward rotation will be the focus of this part of the review. Upward rotation was selected because it is more easily determined without specialised equipment in a typical clinical setting (Lewis & Valentine, 2008) and because insufficient scapular upward rotation is thought to contribute to painful shoulder conditions including subacromial impingement and labral tears (Burkhart, Morgan, & Kibler, 2003; Ludewig & Braman, 2011).

While scapular dyskinesis, muscle activation ratios, and scapulohumeral rhythm comprise the bulk of the literature, the role of scapular hypomobility has not been studied to the same extent. Upward rotation is typically measured, in research settings with electromagnetic motion capture or inclinometry (Borstad & Ludewig, 2005; Struyf et al., 2014). Without specialized equipment, upward rotation can be determined by measuring from landmarks on the scapula at start and end range of abduction including; the inferior angle and root of the spine of the scapula and their corresponding thoracic spinous processes on a horizontal plane (Lewis & Valentine, 2008). Intra-rater reliability of these measures is high with intraclass correlation coefficients (ICCs) in excess of 0.9 (Lewis & Valentine, 2008). Similar measurements have also been made using photographs (Kim, Yun, & Ha, 2013; O'Shea, Kelly, Williams, & McKenna, 2016), which have been shown to be a valid method of determining scapular position (ICC = 0.76 to 0.92) compared with live measurements (O'Shea et al., 2016). Measurements from the medial border of the scapula to the corresponding thoracic spinous process taken from photographs have been shown to be equally reliable to *in vivo* physical measurements with 'very high' inter (ICC = 0.76) and intra-rater reliability (ICC = 0.76) (Kim et al., 2013). These studies indicate that measurements of scapular position, using observation based clinical methods are both reliable and valid.

Clinical measurement of scapular upward rotation is of particular importance because of the proposed link to shoulder pain. Sarhmann (2002) describes the 'scapular downward rotation syndrome', which occurs when the scapula remains downwardly rotated at rest, with the inferior angle closer to the thoracic spine than the superior angle. Additionally, the scapula fails to achieve sufficient upward rotation of 60° in

an overhead position, predisposing the glenohumeral joint to injury (Sahrmann, 2002). This clinical model was supported by a longitudinal study which found reduced scapular upward rotation at baseline was the only predictive physical factor in the development of shoulder pain over a two year period (Struyf, Nijs, et al., 2014). This easily quantifiable and potentially important predisposing factor to shoulder pain may offer clinicians utility in physical examination.

Insufficient scapular upward rotation has also been shown to occur concurrently with scapular dyskinesis. Tate et al. (2009) measured scapular upward rotation in competitive overhead athletes and found a mean maximal upward rotation of 55° with a 9 degree deficit in those with 'obvious' scapular dyskinesis (Scapular Dyskinesis Test, see section 2.8.2) (Tate et al., 2009). These findings warrant further investigation to determine the strength of association between insufficient scapular upward rotation and both scapular dyskinesis and shoulder pain.

2.7) Review papers investigating the relationship between common shoulder conditions and scapular dyskinesis

In the current literature, there are six review papers pertaining to the relationship between scapular dyskinesis and common shoulder conditions including subacromial impingement, glenohumeral instability and rotator cuff related shoulder pain. This section will consider these review papers independent of primary studies.

Subacromial impingement and instability are two common conditions of the shoulder which contribute to, and are caused in part, by rotator cuff disease (Longo et al., 2015; Mackenzie, Herrington, Horlsey, & Cools, 2015). Subacromial impingement occurs when the supraspinatus tendon and subacromial bursa are subject to microtrauma within the subacromial space (Mackenzie, Herrington, Funk, Horsley, & Cools, 2016). With glenohumeral instability, normal translatory arthrokinematics are disrupted, typically with excessive anterior and/or superior migration of the humeral head and crepitus with recurrent subluxation or dislocation (Longo et al., 2015).

Ludewig and Reynolds (2009) conducted a review investigating the association between glenohumeral pathology and scapular kinematics using cross-sectional data. It was found that those with glenohumeral instability consistently displayed decreased upward rotation and increased internal rotation of the scapula (Ludewig & Reynolds,

2009). Subacromial impingement was associated with inconsistent alterations of upward rotation, posterior tilting and external rotation of the scapula (Ludewig & Reynolds, 2009). Because Ludewig and Reynolds (2009) was not a systematic review, there was no quality appraisal and no explicitly stated selection criteria. Struyf, Nijs, Baeyens, Mottram and Meeusen (2011) conducted a similar review investigating the role of scapular positioning in glenohumeral instability and subacromial impingement syndrome, with similar results to those of Ludewig and Reynolds (2009). In the presence of glenohumeral instability there was consistently decreased scapular upward rotation and increased scapular internal rotation (Struyf et al. (2011). There was inconsistent data with regard to scapular upward rotation, external rotation and posterior tilt in the presence of subacromial impingement (Struyf et al., 2011). While Struyf et al. (2011) encompassed 30 papers with topical inclusion criteria, quality appraisal was not conducted. Because of the low quality of these two studies and lack of longitudinal data, these studies alone cannot conclusively demonstrate a relationship or lack thereof between scapular kinematics and shoulder injuries. However, there has been one systematic review of 10 papers investigating the relationship between subacromial impingement and scapular orientation by Ratcliffe, Pickering, McLean and Lewis (2013), who failed to find sufficient evidence of a connection. The papers included by Ratcliffe et al. (2013) reported conflicting results, particularly with scapular upward rotation, which was increased, decreased and unchanged with impingement, although the reports of decreased upward rotation came from a larger proportion of high quality studies. Ratcliffe et al. (2013) employed robust methods, using the Downs and Black quality appraisal tool (Downs & Black, 1998) and utilising a third reviewer in cases of disagreement between the primary raters. Ratcliffe et al. (2013) conclude that there is insufficient evidence of a consistent positional change of the scapula with subacromial impingement. In light of the quality of this systematic review, these findings appear to be robust.

As with scapular kinematic change, alterations of scapulothoracic muscle activation and timing are thought to occur with subacromial impingement (Phadke & Ludewig, 2013). One high quality systematic review by Struyf et al. (2014), was available on this topic. Twelve case-control studies of scapulothoracic muscle recruitment and timing and subacromial impingement were reviewed using a quality appraisal tool and multiple raters (Struyf et al., 2014). While there were conflicting results, the literature

mostly supported the model of increased upper trapezius muscle activity and decreased lower trapezius and serratus anterior muscle activity in the presence of subacromial impingement (Struyf et al., 2014). No consensus was found among the included papers for altered scapulothoracic muscle activation timing in subacromial impingement (Struyf et al., 2014). Changes in scapulothoracic muscle activation or timing in the presence of glenohumeral instability were found to be inconclusive (Struyf et al., 2014). While the evidence is mostly in support of a relationship between scapular dyskinesis and common shoulder pathologies, the conflict in findings of individual studies indicates the relationship may not be as clear as clinical models have suggested.

Contrasting results have been found with the use of scapular focused treatment for various shoulder pathologies. In a systematic review of 4 papers on the topic of scapular focused treatment for patients with subacromial impingement, Reijneveld, Noten, Michener, Cools and Struyf (2016) found conflicting evidence for the use of scapular focused rehabilitation. Reijneveld et al. (2016) utilised the PEDro⁵ quality appraisal scale (de Morton, 2009), with 'very high' absolute agreement between multiple raters (ICC = 0.76) and a best evidence synthesis. Similarly, Bury, West, Chamorro-Moriana and Littlewood (2016) conducted a systematic review of scapular focused treatment for rotator cuff related shoulder pain. They found statistically significant evidence for the use of scapular focused rehabilitation but without clinical significance, as the mean difference in pain was only 0.7/10 on the visual analogue scale (Bury et al., 2016). The studies with the highest risk of bias reported statistically significant changes in favour of the groups receiving scapular focused approaches, whereas the studies with low risk of bias did not (Bury et al., 2016). The conflicting nature of this body of literature indicates a need for additional primary research to more conclusively determine the relationship between scapular orientation and shoulder pain.

⁵ Physiotherapy Evidence Database (de Morton, 2009)

2.8) Measures of scapular dyskinesis

There are numerous methods used by researchers to detect, quantify or classify scapular dyskinesis. Equipment assisted methods often afford the user with increased precision, although this tends to be at the expense of utility in a clinic situation. Equipment assisted methods include inclinometry, motion capture, and computer assisted tomography (Larsen, Juul-Kristensen, Lund, & Sjøgaard, 2014). Clinical methods for assessing scapular function and position have been categorised as static, semi-dynamic and dynamic/functional (Larsen et al., 2014). Static methods include observation and measurements at rest (Larsen et al., 2014). Semi-dynamic methods include the lateral scapular slide test (measurement of medial border displacement from the spine in 3 positions of abduction) and measurements of scapular upward rotation at various degrees of upper extremity elevation (Larsen et al., 2014). Dynamic / functional methods of scapular assessment primarily include observation of full range upper extremity elevation but also include the wall push up (observing for winging) and scapular reposition tests (Larsen et al., 2014). Observational methods of identifying scapular dyskinesis will be the primary review focus of the next section.

2.8.1) The 4-Type System

The 4-Type System was the first clinical method for observational classification and assessment of scapular motion and has attracted substantial research attention (Kibler et al., 2002, 2013). Assessment is performed by visually observing repetitions of weighted upper extremity movements (flexion and either abduction or ‘scaption’⁶) from a posterior vantage point and by using the contralateral scapula as a point of reference (Kibler et al., 2002; Uhl et al., 2009). Scapular movement is then assigned a type based on the direction of dysfunctional movement, most prevalent across both planes of observed movement (see Table 1) (Kibler et al., 2002).

⁶ Arm elevation in the plane of ‘scapular abduction’, 30° anterior to the plane of abduction (Uhl et al., 2009).

Table 1. Description of Kibler et al. (2002) 4-Type System of Scapular Dyskinesis

Type 1: The inferior angle of the scapula is prominent at rest and with movement the scapula tips forward about a horizontal axis in the sagittal plane.

Type 2: The medial border of the scapula is prominent at rest and with movement the scapula tilts dorsally about a vertical axis in the frontal plane (external rotation).

Type 3: The superior border of the scapula is elevated and displaced anteriorly at rest and shrugging of the scapula initiates movement with abnormal movement about a sagittal axis. This description is somewhat ambiguous and does not distinguish between excessive upward or downward rotation as ‘abnormal’.

Type 4: Normal symmetrical movement of the scapulae with sufficient upward rotation about a sagittal axis (Kibler et al., 2002).

The specific descriptive aspect of the 4-Type System may offer useful information to help formulate clinical treatment plans more specific to the individual. Different ‘types’ are thought to be associated with different underlying shoulder girdle muscle function. For example, Type 1 is thought to be linked to shortness of the pectoralis minor muscle with weakness of the serratus anterior and lower trapezius muscles, while Type 2 is thought to be associated with trapezius and rhomboid muscle weakness (Burkhart et al., 2003).

Dominance of the scapular elevator muscles may be associated with Type 3 because of the direction of dysfunctional movement displayed in that type. With support by the notion that scapular mechanics are disrupted by increased activation magnitude and timing of the upper trapezius in relation to serratus anterior and lower trapezius (De Mey et al., 2013; Huang, Lin, Guo, Wang & Chen, 2013; Wegner, Jull, Leary, & Johnston, 2010). In an earlier study, it was asserted that Type 3 is associated with

impingement and rotator cuff lesions (Burkhart et al., 2003). The shoulder ‘shrug sign’ may be seen as an advanced stage of Type 3, in which the patient is unable to reach 90° of abduction without elevating the shoulder girdle (Jia, Ji, Petersen, Keefer, & McFarland, 2008). The shoulder shrug sign is a compensatory strategy commonly seen with increasing frequency in those with severity of shoulder pathology (Jia et al., 2008). Those with rotator cuff tendinosis display the shrug sign in 33.3% of cases, whereas with massive rotator cuff tears, glenohumeral arthritis and frozen shoulder, the shrug sign is present in 74.5%, 90.5% and 94.7% of cases respectively (Jia et al., 2008). The parallels between Type 3 and the shoulder shrug sign again raise the question of whether scapular dyskinesis is causative or compensatory in the presence of shoulder pain.

2.8.1.1) Reliability and validity of the 4-Type System

The 4-Type System has been the subject of several studies with a reliability component. There have been 5 key studies pertaining to the reliability of the 4-Type System (Ellenbecker et al., 2012; Kibler et al., 2002; Park et al., 2013, 2014; Uhl et al., 2009) and 3 key studies investigating validity of the dysfunction associated with each type using kinematic analysis (Uhl et al., 2009) and computer tomography (Park et al., 2013, 2014).

The original study conducted by Kibler et al. (2002) investigated the inter-rater and intra-rater reliability of the 4-Type System as performed by licensed physical therapists and experienced orthopaedic surgeons. The two physical therapists rated with greater inter-rater reliability than the two experienced orthopaedic physicians ($\kappa = 0.31$ for physicians, and $\kappa = 0.42$ for physical therapists) (Kibler et al., 2002), however the orthopaedic surgeon ($n = 1$) demonstrated greater intra-rater reliability ($\kappa = 0.59$) than the physical therapist ($n = 1$, $\kappa = 0.49$). Insufficient briefing of the raters has been identified as a known flaw with this study (Kibler et al., 2002).

Convergent validity of the 4-Type System has been addressed by correlating observed types of dyskinesis with the expected kinematic

change using imaging or motion capture technology. The first study investigating the validity of the 4-Type System compared observed types from the 4-Type System to kinematic analysis of overhead arm movements with mean kinematic data collected from 8 participants determined to have symmetric normal scapular motion (Type 4) as a baseline for normal movement (Uhl et al., 2009). The sensitivity of the 4-Type System for detecting the corresponding directional movement fault ranged from 10% to 54%, while the specificity ranged from 62% to 94% (Uhl et al., 2009).

In 2013, Park et al. compared the use of the 4-Type System to 3 dimensional (3D) wing computed tomography (CT) of scapular orientation for validation (Park et al., 2013). The expected aberrant movement for each type of dyskinesia was confirmed, despite the positional discrepancy between prone during 3D tomography and the observed standing active movements (Park et al., 2013). Inter and intra examiner reliability of the 4-Type System was determined to be 'very high' (ICC = 0.78 and 0.80) (Park et al., 2013). In 2014, Park et al. conducted another CT validation study but with participants in a supine position and with a larger sample (n = 165) with 'very high' inter-rater reliability (ICC = 0.78) and movement faults in the expected vectors for each type of dyskinesia from the 4-Type System were consistent with Park et al. (2013).

In contrast to the other studies, Ellenbecker et al. (2012) found 'very low' reliability for the 4-Type System. In a sample of asymptomatic professional baseball players, the inter-rater reliability of the 4-Type System demonstrated 'very low' reliability ($\kappa = 0.26$) for left limb, ($\kappa = 0.16$) for right limb and ($\kappa = 0.08$) for appraisal of bilateral symmetry. The exclusive use of healthy participants is a major point of difference, because this group may have more subtle dyskinesia with low prevalence of some types, potentially biasing reliability calculations where the prevalence of the trait is known to be a potential source of bias when calculating kappa (Cicchetti & Feinstein, 1990). Also, arm elevation was only performed in scaption, which has been

shown to elicit dyskinesia less than flexion (Uhl et al., 2009). The differences in reported reliability of the 4-Type System between studies is indicative of the influence exerted by the background and training of raters, the shoulder pain and athletic profile of participants, the plane of movement and individual interpretation of the criteria.

2.8.1.2) Limitations of the 4-Type System and the issue of symmetry

The 4-Type System requires raters to decide between types based on prevalence across multiple repetitions and two planes of movement. The guidelines for the 4-Type System appear to operate on the assumption that a clean delineation between types can be made, without a clear solution for how to address the issue of conflicting types. This may potentially lead to disagreement when rating those with a combination of multiple dyskinesia types in different planes (Kibler et al., 2002). Type 4 dyskinesia also requires ‘sufficient’ upward rotation, although the criteria for what is ‘sufficient’ has not been described (Kibler et al., 2002). Additionally, there is no type to classify a scapula with hypomobility in upward rotation but without characteristics of Type 1 to Type 3.

While the 4-Type System requires symmetry of scapular motion for a rating of Type 4 (no dyskinesia) (Kibler et al., 2002), many studies have demonstrated the scapula on the dominant side behaves differently from the non-dominant side with varied results (Crosbie, Kilbreath, Hollmann, & York, 2008; Matsuki et al., 2011). Morais and Pascoal (2013) found the dominant scapula in healthy participants displayed greater retraction and upward rotation in all phases of arm elevation on kinematic analysis. This asymmetry was undetectable by observation, which led them to caution against side-to-side comparison of the scapulae (Morais & Pascoal, 2013). Yoshizaki et al. (2009) failed to find more than a negligible difference between the amount of upward rotation between dominant and non-dominant shoulders, while

Schwartz et al. (2014) found no differences in scapular positioning between sides at rest. However, during upper extremity elevation, Schwartz et al. (2014) found kinematic results similar to Morais and Pascoal (2013), where the dominant scapula displayed greater upward rotation in both flexion and abduction, with greater internal rotation during flexion. In contrast, Crosbie et al. (2008) found there was 20% more scapular upward rotation on the non-dominant side during abduction and scaption. To add further confusion, Matsuki et al. (2011) noted the dominant scapula was 10° more downwardly rotated at rest but 4° more upwardly rotated with elevation of the upper extremity. When Matsuki et al. investigated clavicular motion in 2014, they found less clavicular elevation and posterior rotation on the dominant side during arm elevation. The conflicting evidence indicates scapular asymmetry is both common and variable making side-to-side comparison unadvisable.

Only one method of assessing scapular dyskinesis (Scapular Dyskinesis Test, see section 2.8.2) explicitly instructed examiners to rate each scapula independently, without bilateral comparison (McClure et al., 2009). Because other methods neglected to emphasise this point, bias created by using the contralateral scapula as a point of reference may influence the decisions made by raters. The criteria for assigning Type 4 includes symmetrical scapular movement (Kibler et al., 2002), however symmetrical scapular motion is not common. Scapular asymmetry has been shown to be small, ranging from 4° to 10° and varies with degrees of arm elevation (Matsuki et al., 2011). Ellenbecker et al. (2012) may have had difficulty visualising these small differences reliably. Because asymmetry is common, this may have meant there were very few ratings of symmetry which could have biased the ‘very low’ reliability by Ellenbecker et al. (2012). The use of side-to-side comparison and the requirement for symmetry for a Type 4 rating are potential problems with the 4-Type System. There is need for modification of both the assessment protocol and rating criteria, with an additional category to account for combinations of

scapular dyskinesis. In research settings, 5th and 6th types of scapular dyskinesis may be used for combinations including or not including one specific type of dyskinesis (expanded upon in Section II).

2.8.1.3) The prevalence of types of scapular dyskinesis

While there have been no large scale studies specifically reporting the distribution of scapular dyskinesis types, some authors have reported the prevalence of individual types of scapular dyskinesis in their findings, and these are displayed in Figure 1. While there is some variability between studies, it appears Type 1 and Type 4 are most commonly displayed.

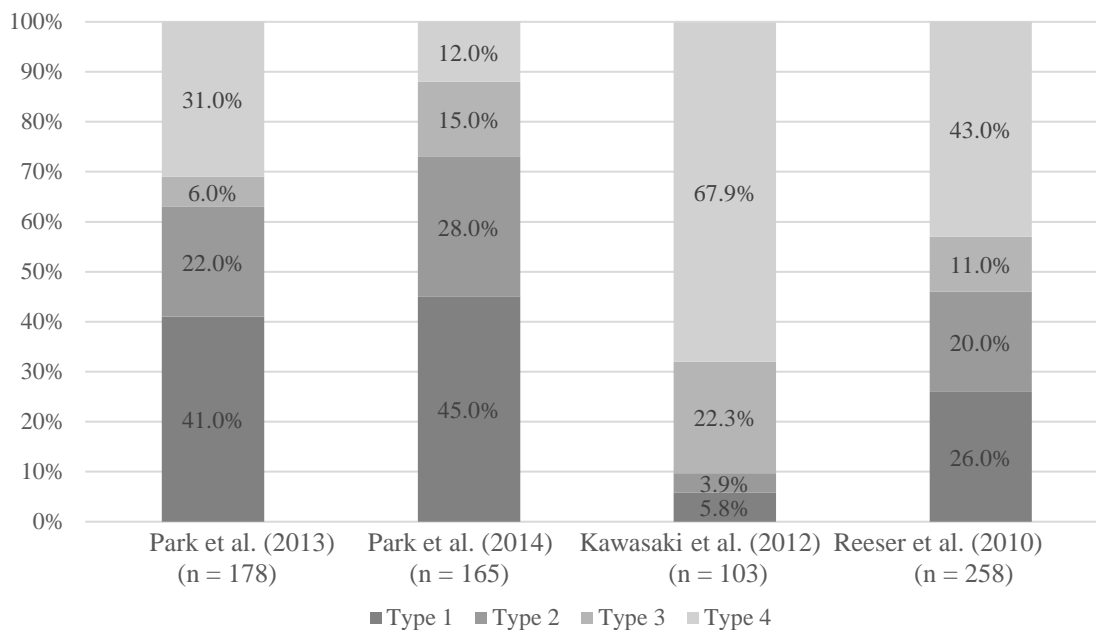


Figure 1: Reported 4-Type System dyskinesis distributions

2.8.1.4) The ‘yes/no’ system: An attempt to address the issues with the 4-Type System

The forced choice within the 4-Type System is thought to negatively impact on reliability, leading some researchers to attempt to simplify the process (McClure et al., 2009; Uhl et al., 2009). Using a similar design to Kibler et al. (2002), Uhl et al. (2009) compared the 4-Type

System to a dichotomous ‘yes/no’ system and validated the findings by comparing the observational findings with kinematic motion analysis. Dysfunctional categories (Type 1, Type 2 and Type 3) became the ‘yes’ category, while Type 4 became the ‘no’ category (Uhl et al., 2009). Raters using the ‘yes/no’ system had 79% agreement in contrast to 61% between raters using the 4-Type System (Uhl et al., 2009). Between respective ratings in scaption and flexion, the simplified ‘yes/no’ system afforded an advantage in sensitivity for the detection of scapular asymmetry as recorded by kinematic analysis at 74% and 79% over the 10% and 54% sensitivity with the 4-Type System (Uhl et al., 2009). With respect to specificity, the 4-Type System was superior at 62% and 94% compared with just 31% and 38% (Uhl et al., 2009).

The ‘yes/no’ system had similar reliability ($\kappa = 0.41$) to the 4-Type System ($\kappa = 0.44$) (Uhl et al., 2009). A more recent study demonstrated ‘very high’ inter-rater reliability of the ‘yes/no’ system ($\kappa = 0.75$) in scaption (Madsen et al., 2011). Despite improved sensitivity compared to 4-Type System, the ‘yes/no’ method provides no specific description of movement which may limit the clinical usefulness in assisting treatment planning. The kinematic analysis by Uhl et al. (2009) identified that scapular dyskinesia commonly occurs in multiple planes, thus a combination of scapular dyskinesia types can manifest simultaneously in the same scapula. Additionally, asymmetric scapular motion was present in 71% of asymptomatic and 76% of symptomatic shoulders, making a rating of Type 4 rare (Uhl et al., 2009). The findings of this study elucidate issues with the 4-Type System and indicate the ‘yes/no’ system may be a useful screening tool. However, without ascribing descriptors of movement, the ‘yes/no’ system lacks the utility of the 4-Type System, making it a questionable replacement for more in depth examination of scapular dyskinesia.

2.8.2) The Scapular Dyskinesis Test: Ratings based on magnitude

The Scapular Dyskinesis Test (SDT), classifies scapular dyskinesis on the basis of observed magnitude during 5 repetitions of weighted, bilateral flexion and abduction (McClure, Tate, Kareha, Irwin, & Zlupko, 2009). The inter-rater reliability of the SDT was determined to be ‘moderate’ ($\kappa_w^7 = 0.54$ for video rating, and $\kappa_w = 0.57$ for live rating) (McClure et al., 2009). Those with ‘obvious’ dyskinesis underwent electromagnetic kinematic testing and were found to display altered scapular motion compared with controls without dyskinesis (Tate et al., 2009). Of 142 participants, 52 displayed ‘obvious’ dyskinesis on the left, 37 on the right and 32 bilaterally (McClure et al., 2009).

The SDT assigns a rating of ‘obvious’, ‘subtle’ or ‘no’ dyskinesis (McClure et al., 2009). Scapular dyskinesis is described by McClure et al. (2009), as ‘dysrhythmia observed as excessive, premature, stuttering or non-smooth movement, and/or winging’, characterised by the features of Type 1 and Type 2 (McClure et al., 2009).

For a rating of ‘no’ dyskinesis, the scapula must smoothly and continuously rotate upwards on elevation and downwards on return without winging or other abnormality present (McClure et al., 2009). Subtle abnormality is defined as ‘mild’ or ‘uncertain’ abnormality and may not be present on every repetition, while obvious abnormality must be seen on at least 3 of 5 repetitions with marked dysrhythmia or winging of greater than “1 inch” (2.54cm) from the thorax (McClure et al., 2009).

‘No’ dyskinesis is assigned to participants with no abnormality in one movement and either no abnormality or subtle abnormality in the other.

‘Subtle’ dyskinesis is assigned when subtle abnormality is observed in both movements. ‘Obvious’ dyskinesis is assigned when obvious abnormality is observed in either movement (McClure et al., 2009). This system is attractive for both clinicians and researchers because it allows for differentiation of

⁷ McClure et al. (2009) used a weighted kappa (κ_w) in order to determine the maximum possible kappa score (after Sim and Wright, 2005) on the premise that a standard kappa calculation can be artificially low with inadequate variation in the data (Sim & Wright, 2005).

scapular dyskinesia based on magnitude, with unambiguous criteria for rating which does not rely on side-to-side comparison.

3) Pectoralis minor muscle overview

Structure and function of the pectoralis minor muscle is a topic of increasing interest among shoulder researchers. For decades, clinicians have speculated and worked under the assumption that ‘tightness’ or ‘shortness’ of this muscle can alter scapular positioning, thereby increasing protraction and anterior tilting with negative implications for shoulder health (Kendall, Kendall, & Wadsworth, 1971).

The pectoralis minor muscle attaches to the inferomedial aspect of the coracoid process of the scapula, inferiorly and anteriorly onto the anteromedial aspects of the 3rd, 4th and 5th rib (Gilroy et al., 2012). The pectoralis minor muscle has dual functions as a ‘mover’ and ‘stabiliser’ of the scapula in the directions of anterior tilting, downward rotation, depression and protraction (subsequently limiting antagonist movements), as well as elevation of the upper ribs during effortful or dysfunctional inspiration (Borstad & Ludewig, 2005; Gilroy et al., 2012; Hooper & Denton, 2010). The anatomic course of the brachial nerve plexus, which runs beneath the pectoralis minor muscle is also of clinical interest as hypertonicity of the muscle may contribute to the aetiology of thoracic outlet syndrome (Hooper & Denton, 2010).

3.1) Pectoralis minor muscle assessment

In this section, physical examination of pectoralis minor muscle will be reviewed to provide context for discussion in subsequent sections. There are two main physical examination based measures of pectoralis minor muscle length, these are the Pectoralis Minor Index (PMI) and the Pectoralis Minor Length Test (PMLT). The PMI has the largest body of evidence supporting its use (Borstad, 2008; Struyf, Meeus, et al., 2014), while the PMLT is a classic clinical test with a longer history of clinical use but less evidence supporting its use (Kendall et al., 1971). Besides the PMLT and PMI, other methods of pectoralis minor muscle assessment include the use of a bubble level to determine asymmetry (Reeser et al., 2010), the scapular backward tipping test for resting tension (Sebastian, Chovvath, & Malladi, 2016) and the

forward scapular posture measurement (Lee, Cynn, Yi, Kwon, & Yoon, 2015). Aside from forward scapular posture which will be discussed in relation to the PMLT, these other measures are not commonly used, are not validated and will therefore not be reviewed further.

3.1.1) Pectoralis Minor Index

The PMI involves measuring the distance from the surface landmarks of the inferior, medial coracoid process to the caudal aspect of the 4th rib at the sternum using a tape measure or callipers (Borstad, 2006; Struyf et al., 2014). This process was validated on fresh cadavers using electromagnetic motion capture and was shown to have an ICC of 0.96 compared with the actual length of the muscle which was measured after dissection (Borstad, 2008). Technically, this measurement only becomes the pectoralis minor *index* once it has been normalised⁸ against height (Borstad & Ludewig, 2005) or clavicle length (Tate et al., 2012). In participants with symptomatic and asymptomatic shoulders, the PMI (taken in the supine position) demonstrated ‘high’ to ‘very high’ inter-rater reliability (ICC = 0.65 to 0.93) (Struyf, Meeus, et al., 2014). The reliability of the PMI has proven to be higher still among overhead athletes. Rondeau, Padua, Thigpen, and Harrington (2011) investigated clinical measurement of the PMI and electromagnetic motion capture in overhead throwing athletes. They found ‘nearly perfect’ intra-rater reliability using the clinical PMI measurement (ICC = 0.98 to 0.99) and ‘very high’ correlations between clinical PMI measurement and PMI measurement using electromagnetic motion capture ($r = 0.7$ to 0.84) (Rondeau et al., 2011). The PMI is a robust and highly researched measure of pectoralis minor muscle length, with ‘nearly perfect’ reliability, and acceptable validity.

⁸ For the purpose of clarity and flow, all references to the measurement taken from the coracoid process to the 4th rib will be referred to as the Pectoralis Minor Index (PMI).

3.1.2) Pectoralis Minor Length Test

The PMLT is a commonly used measure, sometimes referred to as the ‘Kendall pectoralis minor length test’ (Kendall et al., 1971). The PMLT involves taking a measurement of the distance from the posterior, lateral aspect of the acromion to the table while the participant is supinely positioned (Lewis & Valentine, 2007). Greater PMLT measurements are thought to represent shorter pectoralis minor muscle length (Kendall et al., 1971). Struyf et al. (2014), have normalized the PMLT against participant height, similar to the method used by Borstad (2006), although this is not commonly performed. Without normalisation, natural variation in body size within a sample may bias results. Despite the name, the relationship between the PMLT and the actual length of the pectoralis minor muscle has called into question by a recent study. Following a surgical release (tenotomy) of the pectoralis minor tendon in patients with glenohumeral instability, only a small increase of 0.46 to 0.5cm in PMLT measurement was observed, indicating the PMLT may not represent the length of the pectoralis minor muscle (Weber, Enzler, Wieser, & Swanenburg, 2016). The PMLT appears to be a measure of scapular anterior tilt and protraction rather than pectoralis minor muscle length, however this alone does not negate clinical value.

The forward scapular posture measurement is a variant of the PMLT and is measured by determining the distance from the anterior acromion to the wall against the participant’s back using a double square (Peterson et al., 1997). This measure has been validated against radiographs ($r = 0.55$ to 0.73) and has ‘very high’ intra-rater reliability ($ICC = 0.89$) (Peterson et al., 1997). While it is plausible that forward scapular posture may correlate with the PMLT, the relationship has not been investigated.

The PMLT has demonstrated ‘very high’ to ‘nearly perfect’ reliability across a number of studies (Lewis & Valentine, 2007; Nijs, Roussel, Vermeulen, & Souvereyns, 2005; Struyf et al., 2009). In participants with shoulder pain, the PMLT demonstrated ‘very high’ inter-rater reliability both at rest ($ICC = 0.91$) and with active scapular retraction ($ICC = 0.88$) (Nijs et al., 2005). A similar study involving various musicians without shoulder pain found PMLT ‘very high’ inter-rater reliability in a relaxed position ($ICC = 0.72$) and with active

scapular retraction (ICC = 0.75), taken with participants standing (Struyf et al., 2009). Greater reliability of the PMLT has been demonstrated by Lewis and Valentine (2007), who found ‘nearly perfect’ intra-rater reliability (ICC = 0.92 to 0.96) in participants with and without shoulder pain. The delineation between short or long PMLT measurements is unclear, though Sahrman (2002), has suggested a threshold of $>2.6\text{cm}^9$ for a short pectoralis minor muscle. However it has been consistently shown that the average measures of PMLT exceed this threshold by more than double (Lewis & Valentine, 2007; Nijs et al., 2005; Weber et al., 2016). While the PMLT has been demonstrated to be a reliable measure, it is not advisable to use a measurement threshold to determine a short or long PMLT because of the apparent lack of utility and individual variation in body morphology.

3.1.2.1) Kendall secondary test

According to Kendall et al., (1971), shortness or stiffness of the upper brachial muscles including the short head of biceps and coracobrachialis is thought to produce false positives for pectoralis minor shortness when using the PMLT. They suggest the use of a secondary test in addition to the PMLT to help interpret findings (Kendall et al., 1971). The Kendall secondary test involves moderate pressure over the anterior shoulder with the participant’s arm straight at their side (Kendall et al., 1971). Flexion of the elbow and shoulder are passively introduced until maximal elbow flexion and approximately 30° of shoulder flexion are achieved (Kendall et al., 1971). If the shoulder girdle markedly drops towards the plinth, positive findings from the PMLT may be attributed to shortness of the short head of biceps and coracobrachialis (Kendall et al., 1971). The Kendall secondary test is absent from the current body of research on pectoralis minor measurement and therefore the validity and reliability of this method is unknown. It is not currently known what effect if

⁹ The rationale for this threshold has not been explicitly stated.

any, the length of the short head of biceps and coracobrachialis have on the PMLTs correlation with PMI and pain. Further research involving the Kendall secondary test is required to determine reliability, validity and clinical utility.

3.2) Comparison of the Pectoralis Minor Index and Pectoralis Minor Length Test

While the relationship between the PMI and PMLT has been investigated, the methods used in the two conflicting key studies have failed to provide conclusive results. Borstad (2006) compared standing PMI measurements with supine PMLT measurements taken with the arms in supine, neutral and pronated positions. It was found that the correlation between the two tests was 'very low' ($r = 0.11$ to 0.15), which may be attributed to taking the PMI standing and the PMLT supine (Borstad, 2006). Additionally, the secondary test described by Kendall et al. (1971) was not performed. While standing measurements are more representative of standing daily activities, accurate standardisation of 'normal posture' between participants may be challenging. Subsequently, the PMI has been measured with participants supine, allowing for resting tension to influence scapular orientation (Struyf, Meeus, et al., 2014). The PMI performed with participants supine is advantageous from an internal validity perspective, as it does not require any conscious control or postural calibration.

To better understand the determinants of forward shoulder posture, Lee et al. (2015) investigated predictor variables including PMI, serratus anterior strength, thoracic spine angle and posterior shoulder tightness in those without shoulder pain. It is unclear why only the participants with forward shoulder posture ($n = 18$) of the small initial sample ($n = 28$) were included in the study (Lee et al., 2015). Logistic regression identified that PMI accounted for 78% of the variance in forward scapular posture, while the complete model explained 93% of forward scapular posture (Lee et al., 2015). The deliberate exclusion of those without forward shoulder posture precluded the collection of normative baseline data, which would have given context to findings. With little statistical power because of the small sample size, the generalisability of these findings is questionable. While the PMLT and forward scapular posture are very similar, they are not exactly the same. Because of this, the

results of Lee et al. (2015) only indicate the possibility of a correlation between PMI and PMLT measurements. To date, there have been no studies comparing the PMI and PMLT, both taken in the supine position with a standardised arm position to help minimize confounding factors. Until this research is undertaken, the relationship between the PMI and PMLT will remain unknown.

3.3) The relationship between pectoralis minor muscle shortness and shoulder pain

Dysfunction of the pectoralis minor muscle is thought to be a factor in the development of shoulder pain (Morais & Cruz, 2016). The ‘SICK’ scapula syndrome (Scapular malpositioning, Inferior angle prominence, Coracoid malposition and pain and scapular dyskinesia) is a clinical model of shoulder dysfunction linking shortness of the pectoralis minor muscle with Type 1 scapular dyskinesia and shoulder pain (Burkhart et al., 2003). The ‘SICK’ scapula syndrome is hypothesized to be prodromal to glenohumeral pathologies, particularly labral injury (Burkhart et al., 2003) and has been ‘moderately’ correlated with self-reported shoulder pain and disability in volleyball players ($r = 0.35$ to 0.39) (Reeser et al., 2010).

The evidence is mixed but in general does not support an association between shoulder pain and dysfunctional¹⁰ pectoralis minor muscle length measurements. Harrington, Meisel, and Tate (2014) found a difference in PMI measurements between those with and without shoulder pain in female swimmers on the dominant side only ($P = 0.003$). Tate et al. (2012) found a small difference in PMI length between competitive swimmers with and without shoulder pain or disability in certain age groups (8 to 11 years, $P = 0.09$ and 15 to 19 years, $P < 0.01$). Conversely, no difference in PMI measurements were found between those with and without subacromial impingement (Rosa, Borstad, Pires, & Camargo, 2015).

Currently, no evidence exists to support a connection between short PMLT measurements and current or future shoulder pain. Struyf et al. (2014) followed recreational overhead athletes for two years and determined shortness of the PMLT at baseline was not a predictor for the development of shoulder pain. Lewis and

¹⁰ Dysfunctional PMI measurements are ‘short’, while dysfunctional PMLT measurements are ‘long’.

Valentine (2007) found trivial difference in PMLT measures between those with and without shoulder symptoms, indicating the PMLT is unlikely to be associated with shoulder pain. Similarly, 'very low' but non-significant correlations were found between the PMLT and self-reported shoulder pain and disability ($r = -0.20$ to 0.20 , $p = 0.35$ to 0.94) (Nijs et al., 2005). Apart from Harrington et al. (2014), who demonstrated a difference in PMI length between those with and without shoulder pain on one side only and Tate et al. (2012), who found small differences in select age groups, the evidence does not support a relationship between reduced pectoralis minor length and shoulder pain.

3.4) The link between shortness of the pectoralis minor muscle and scapular dyskinesis

Shortness of the pectoralis minor muscle has long been thought to alter scapular position by tilting the coracoid process anteriorly and increasing the prominence of the inferior angle at rest (Kendall et al., 1971; Sahrman, 2002). This may be an important contributing factor in clinically observed scapular dyskinesis, with implications for management. This section will cover six key papers comparing pectoralis minor muscle length to: kinematic analysis of scapular motion (Borstad & Ludewig, 2005), clinical measures of scapular position (Borstad, 2006), observational assessment of scapular dyskinesis and the effect of treatment plans including pectoralis minor muscle stretching on scapular kinematics McClure et al., 2004; Struyf et al., 2012; Williams, Laudner, & McLoda, 2013).

This relationship was initially investigated by comparing the PMI to kinematic analysis of scapular motion (Borstad & Ludewig, 2005) and measures of static scapular and thoracic position (Borstad, 2006). For both studies, 50 asymptomatic participants from the initial sample of 81 were separated into short and long PMI groups by excluding participants who fell within one standard deviation of the median PMI (Borstad, 2006). 'Moderate' correlations were found between the PMI and scapular internal rotation ($r = -0.39$), thoracic kyphosis ($r = 0.29$) and scapular protraction ($r = 0.48$) (Borstad & Ludewig, 2005). The short PMI group, displayed a mean decrease of 9.1° to 10.5° of scapular internal rotation and 6.4° to 10.4° of posterior tilting compared with the long PMI group, indicating a short PMI produces

movement faults associated with both Type 1 and Type 2 dyskinesia (Borstad & Ludewig, 2005). Borstad and Ludewig (2005) concluded shortness of the PMI was associated with alterations in both static and dynamic positioning of the scapula. Contrary to these conclusions, Williams, Laudner and McLoda (2013) found that either of two passive stretches to the pectoralis minor muscle held for 30 seconds twice, increased PMI, but without any effect on scapular kinematics as determined by electromagnetic motion capture in asymptomatic participants. Similarly, scapular focused interventions involving the pectoralis minor muscle have failed to alter scapular kinematics over a 6-week period (McClure, Bialker, Neff, Williams, & Karduna, 2004; Struyf et al., 2012). Additionally, adolescent elite tennis players were shown to simultaneously display greater scapular upward rotation (increased by up to 13%) and shorter PMI (reduced by up to 10%) on their dominant side (Cools et al., 2010). The mixed results from these studies indicates an unclear relationship between pectoralis minor muscle length and scapular position. Recently, PMI, upper trapezius muscle length and their association to the SDT was investigated (Yeşilyaprak et al., 2016). This study determined sample size by power analysis (n = 148, 296 shoulders), and utilised strict exclusion criteria including: current or history of shoulder or cervical dysfunction, pain, pathology, fracture or surgery and regular sporting activity, exercise or overhead work, with additional screening using orthopaedic tests (Yeşilyaprak et al., 2016). A ‘very large’ association¹¹ (odds ratio = 0.041, 95% CI 0.02 to 0.1) between PMI and ‘obvious’ scapular dyskinesia was found (Yeşilyaprak et al., 2016). The overall model explained 58.3% of ‘obvious’ scapular dyskinesia (Yeşilyaprak et al., 2016). Despite the ‘very large’ association demonstrated by Yeşilyaprak et al. (2016), further research is required to determine the relationship between pectoralis minor muscle length and scapular dyskinesia.

¹¹ Conventionally, odds ratios are reported as numbers greater than 1. Odds ratios less than 1 may be converted to a number greater than 1 by dividing 1 by the odds ratio for greater ease of interpretation (McHugh, 2009). So, for Yeşilyaprak et al: $1 / 0.041 = 24.39$.

4) Summary and rationale for further investigation

Despite mixed findings in the research and incomplete understanding of scapular dyskinesis (Kibler, Ludewig, McClure, et al., 2013; Morais & Cruz, 2016), scapular dyskinesis and pectoralis minor shortness are generally thought by clinical practitioners to contribute to shoulder pain. Recent expert commentary suggests scapular dyskinesis may represent natural biomechanical variability and not dysfunction (McQuade et al., 2016). Because of the dynamic axes of movement and multidirectional synergy of the musculature, McQuade et al. (2016) suggest scapular dyskinesis is not likely to be influenced by muscle strength or motor control and may be more affected by muscle stiffness or shortness. While there has been a shift towards more simplified systems for observational analysis of scapular dyskinesis, the 4-Type System may be more predictive of muscle shortness by identifying dysfunction associated with specific muscles. Dysfunctional scapular movement and positioning identified by kinematic analysis and CT scans have correlated with their respective type of dyskinesis from the 4-Type System (Park et al., 2013, 2014; Uhl et al., 2009). However, understanding the relationship between individual dyskinesis types and clinical muscle length tests may be of more use to clinicians reliant on clinical observation because these tests are used to help guide intervention and management. Studies investigating the correlation between PMI and PMLT, the two most widely used clinical tests for pectoralis minor length have demonstrated contradictory results, although the methods have sufficient bias to make interpretation of the findings unclear. Borstad (2006) took the PMI measurement standing and the PMLT supine, while Lee et al. (2015) compared forward scapular posture (a variant of the PMLT) with the PMI. While the PMI better represents the actual length of the pectoralis minor muscle than the PMLT (Borstad, 2008; Weber et al., 2016), further research is required to determine whether one is more predictive of scapular dyskinesis than the other. Exploration of the correlation between these measurements and their relationship to types of scapular dyskinesis using the 4-Type System would benefit clinicians and researchers. In response to these gaps in the literature, the aim of the study reported in Section II of this thesis was to investigate the relationship between the PMI and PMLT when measured in a standardised position. The second aim of this thesis was to explore the correlation between types of dyskinesis using the 4-Type System, SDT and clinical measures of pectoralis minor length, including the PMI and PMLT.

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SECTION II: Manuscript

Note to reader:

The manuscript presented in this section follows the Instruction to Authors for *The Journal of Bodywork and Movement Therapies*, available for viewing here: <https://goo.gl/SRfJ0G>.

The relationship between clinical measures of scapular dyskinesis and pectoralis minor muscle length: An exploratory, cross-sectional study

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ABSTRACT

The relationship between clinical measures of scapular dyskinesis and pectoralis minor muscle length: An exploratory, cross-sectional study.

Background: Scapular dyskinesis and pectoralis minor muscle shortness are of clinical interest in relation to shoulder rehabilitation. The extent to which scapular dyskinesis and pectoralis minor muscle shortness affect the shoulder and interact with each other is not fully understood.

Objectives: 1) To determine the correlation between the pectoralis minor index (PMI) and the pectoralis minor length test (PMLT) when measured in a standardised position; 2) To determine the extent to which the PMI or PMLT is associated with the type or magnitude of scapular dyskinesis; 3) To investigate the correlation between shoulder pain and scapular dyskinesis, PMI or PMLT measurements; and 4) To determine the association between scapular upward rotation and scapular dyskinesis.

Design: Cross-sectional study.

Participants: Females (n = 41) and males (n = 29) with and without current or history of shoulder pain (n = 70, 140 shoulders).

Methods: PMI and PMLT were measured in all participants. Videos of scapular motion were rated by one observer using a modification of the 4-Type System (6-Type System) and the Scapular Dyskinesis Test (SDT). Upward rotation of the scapula was calculated from video screen captures. A Shoulder Pain and Disability Index (SPADI) questionnaire was completed for each shoulder. Pearson's correlations were calculated between the PMI and PMLT, and for both PMI and PMLT in relation to both shoulder pain and upward rotation. Logistic regressions were undertaken to identify predictors for each type of dyskinesis (6-Type System) and for 'obvious' dyskinesis (SDT).

Results: 'Very small' but significant associations were found between shorter PMI and Type 1 dyskinesis. 'Very low' non-significant correlations were found between the PMI and PMLT. Increased PMLT (thought to be indicative of 'shorter' muscle) showed a 'very small' negative association with 'obvious' dyskinesis but PMLT demonstrated a 'low' to 'moderate' significant correlation with pain. Upward rotation and pain showed 'very small' non-significant associations between each type (4-Type System) and the magnitude of dyskinesis (SDT).

Conclusion: The PMI and PMLT are not analogous measures, each correlated with different variables but not each other. There appears to be a link between a shorter PMI and Type 1 dyskinesis, while increased dysfunction with the PMLT is associated with less magnitude of scapular dyskinesis. A combination of both the PMI and PMLT may be more useful than one measure in isolation.

MeSH Keywords: Upper Extremity; Shoulder; Diagnosis; Musculoskeletal; Manual Therapy

INTRODUCTION

Shoulder pain is a common musculoskeletal complaint with lifetime prevalence as high as 66.7% (Luime et al., 2004) and is also associated with substantial economic impact (Accident Compensation Corporation, 2016). People involved in occupational (Hanvold, Wærsted, Mengshoel, Bjertness, & Veiersted, 2015) and sporting pursuits (Pribicevic, 2012) involving upper extremity elevation are particularly affected. Scapular dyskinesis encompasses deviations from ‘normal’ scapular motion or resting position (Kibler et al., 2013) and has been found to occur more frequently in athletes who participate in sports with an overhead component compared with athletes who do not (Burn, McCulloch, Lintner, Liberman, & Harris, 2016). Clinical observations suggest scapular dyskinesis is linked to shoulder pain, although the causal relationship is not clear (Kibler et al., 2013). While scapular dyskinesis is more frequently exhibited in the presence of shoulder pain, it is also commonly observed in asymptomatic shoulders (Tate, McClure, Kareha, Irwin, & Barbe, 2009). Scapular dyskinesis is clinically detected by visual observation using the 4-Type System (Kibler et al., 2002) and the Scapular Dyskinesis Test (SDT) (McClure, Tate, Kareha, Irwin, & Zlupko, 2009). The 4-Type System and SDT have demonstrated conflicting results for correlation with current and future shoulder pain (Clarsen, Bahr, Andersson, Munk, & Myklebust, 2014; Kawasaki, Yamakawa, & Kaketa, 2012; Myers, Oyama, & Hibberd, 2013; Reeser et al., 2010), indicating a need for further research to better understand this relationship. Issues with the 4-Type System include; a forced choice of a single type of scapular dyskinesis (Kibler 2002), and the requirement of symmetry for a rating of Type 4 / no scapular dyskinesis (Uhl, Gecewich, & Tripp, 2009). A modified 4-Type System was devised to address these issues and to more sensitively identify Type 1 scapular dyskinesis / anterior scapular tilting, which is thought to occur with pectoralis minor muscle shortness (6-Type System, discussed in Methods).

The function of the pectoralis minor muscle is of increasing clinical interest (Morais & Cruz, 2016) and clinicians have long considered that pectoralis minor muscle shortness is associated with protracted and anteriorly tilted scapular positioning, with negative consequences for the shoulder complex (Kendall, Kendall, & Wadsworth, 1971; Sahrmann, 2002). However, there is conflicting evidence regarding the relationship between pectoralis minor muscle length and both scapular dyskinesis (Cools et al., 2010; Yeşilyaprak, Yüksel, & Kalkan, 2016) and shoulder pain (Harrington, Meisel, & Tate, 2014; Rosa, Borstad, Pires, & Camargo, 2015). Some studies have shown meaningful correlations between a shortened

pectoralis minor muscle and scapular dyskinesis or altered scapular positioning (Borstad, 2006; Yeşilyaprak et al., 2016). However, short term stretching of the pectoralis minor muscle may not influence scapular kinematics (Williams, Laudner, & McLoda, 2013). One study found pectoralis minor muscle length differed between symptomatic and asymptomatic shoulders (Harrington et al., 2014), while another study found no difference (Rosa et al., 2015).

Two key clinical measures of the pectoralis minor muscle are the Pectoralis Minor Index (PMI) (Borstad, 2008), and the Pectoralis Minor Length Test (PMLT) (Lewis & Valentine, 2007). Borstad (2006) found ‘very low’ correlation between these measures. However, in Borstad’s study participants were positioned in standing for the PMI and supine for the PMLT, potentially biasing the results. More recently, Lee et al. (2015) report that PMI shortness accounted for 78% of the variance in forward shoulder posture in 18 health adults without shoulder pain. The PMI is conceptually similar to the PMLT, but is taken from a different aspect of the acromion. This raises the question of whether the PMI and PMLT may show a stronger correlation if measured in a standardised position.

Because of the interest in scapular dyskinesis and the pectoralis minor muscle, the conflicting evidence base and the inconclusive relationship between the PMI and PMLT, there is a need for greater understanding of the interaction of these factors and how they influence the shoulder complex. Therefore, the primary aims of this study were to: 1) determine the correlation between the PMLT and PMI when measured in a standardised position; and 2) determine the extent to which the PMI or PMLT is associated with the type (6-Type System) or magnitude (SDT) of scapular dyskinesis. The secondary aims of this study were to: 3) investigate the correlation between shoulder pain and scapular dyskinesis, PMI or PMLT measurements; and 4) determine the association between scapular upward rotation and scapular dyskinesis.

METHODS

Design and ethics

A cross-sectional, explorative observational study was undertaken. All participants provided written, informed consent and the study was approved by the Unitec Research Ethics Committee (Approval No.: 2015-1041).

Participant recruitment and eligibility

Participants were recruited by word-of-mouth, notices posted to social media, and through an emailed newsletter to all staff of a tertiary institution. People responding to advertising were informed of the study requirements. Participants were required to fulfil the following eligibility criteria. To maximise sample size, all healthy participants, between the age of 18 and 65 years with or without shoulder pain were recruited. Exclusion criteria were: pregnancy, systemic illness, neurological conditions, history of glenohumeral arthroplasty or any structural abnormality or disability precluding overhead motion of the arms.

Measures

1) '6-Type System' for classification of scapular dyskinesis

Based on the principal investigator's clinical experience, a modified version of the 4-Type System (Kibler et al., 2002) for visual classification of the vector of scapular dyskinesis was undertaken. Types of dyskinesis are displayed in Table 1. To more sensitively identify scapular anterior tilting (Type 1), two additional categories ('Type 5' and 'Type 6') identifying combined movement with or without anterior tilting were added. The vectors of dysfunctional scapular movement from the 4-Type System have been previously validated by 3D computer tomography of scapular position (Park et al., 2013). 'Very high' intra-rater reliability of the 4-Type System has been demonstrated (ICC = 0.8, CI not reported) (Park et al., 2013).

Table 1. Description of the 6-Type System for scapular dyskinesis – modified from Kibler et al. (2002)

Type 1: The inferior angle of the scapula is prominent at rest and with movement the scapula tilts forward about a horizontal axis in the sagittal plane.

Type 2: The medial border of the scapula is prominent at rest and with movement the scapula tilts dorsally about a vertical axis in the frontal plane (external rotation).

Type 3: The superior border of the scapula is elevated and displaced anteriorly at rest and shrugging of the scapula initiates movement with abnormal movement about a sagittal axis. This description is somewhat ambiguous and does not distinguish between excessive upward or downward rotation as ‘abnormal’.

Type 4: Normal symmetrical movement of the scapulae with sufficient upward rotation about a sagittal axis (Kibler et al., 2002).

Type 5: Combination of 2 or more dyskinesis types including Type 1 (anterior tilting).

Type 6: Combination of 2 or more dyskinesis types not including Type 1.

2) ‘Scapular Dyskinesis Test’

Ratings were made according to the magnitude of dyskinesis using the categories of: ‘obvious’, ‘subtle’ or ‘no’ (McClure et al., 2009). Findings of ‘obvious’ dyskinesis have

been validated using electromagnetic motion capture analysis (Tate et al., 2009). The inter-rater reliability of this measure has been shown to be ‘moderate’ ($\kappa_w = 0.54$) (McClure et al., 2009). Scapular Dyskinesis Test ratings were made for flexion, abduction and ‘combined’ planes of movement using the method described by McClure et al. (2009). [See Thesis Appendix E for details of the rating criteria]

3) ‘Pectoralis Minor Index’

The PMI is derived from a direct skin surface measurement of the pectoralis minor muscle, taken from the inferior, medial coracoid process to the caudal aspect of the 4th rib at the sternum (Borstad & Ludewig, 2005). This measure has been validated on fresh cadavers with a ‘nearly perfect’ (ICC = 0.96) comparison with the length of the muscle as determined by dissection and direct measurement (Borstad, 2008). ‘Very high’ to ‘nearly perfect’ intra-rater reliability has been demonstrated with this measure (ICC = 0.76 to 0.93) (Struyf et al., 2014). Technically, this measurement is called the PMI only after it has been normalised against height (Borstad & Ludewig, 2005) or clavicular length (Tate et al., 2012) but for the sake of flow and brevity, ‘Pectoralis Minor Index’ (PMI) will also be used when referring to the raw measurement. Clinically, a ‘shorter’ pectoralis minor muscle is indicated by a ‘shorter’ PMI (Borstad, 2008).

4) ‘Pectoralis Minor Length Test’

The PMLT is a classic clinical test hypothesised to determine pectoralis minor muscle length indirectly, by measuring the distance between the posterior, lateral acromion and plinth (Kendall et al., 1971). Intra-rater reliability of this measure is ‘nearly perfect’ (ICC = 0.92 to 0.96) (Lewis & Valentine, 2007). The correlation between PMLT and the validated PMI was found to be ‘very low’ (Borstad & Ludewig, 2005). Weber, Enzler and Wieser (2016) demonstrated trivial change in PMLT immediately following a surgical release of the pectoralis minor tendon. Despite poor measurement properties, the PMLT was employed here because it is a classic test commonly used in research and clinic practice (Morais & Cruz, 2016). Clinically, a ‘shorter’ pectoralis minor muscle is indicated by a ‘longer’ PMLT (Kendall et al., 1971).

5) 'Kendall Secondary Test'

This adjunct to the PMLT, involves applying moderate downward pressure over the anterior shoulder girdle while gradually introducing passive flexion of the elbow and glenohumeral joint (Kendall et al., 1971). If the shoulder girdle drops towards the table with the introduction of flexion, the upper brachial muscles are thought to contribute to the anterior starting position of the scapula (Kendall et al., 1971). To date, there have been no reports of measurement properties for this test in the literature. The Kendall Secondary Test was included in this study to potentially identify upper brachial muscle shortness or tension as a possible confounding factor in the clinical appraisal of pectoralis minor muscle length.

6) 'Shoulder Pain and Disability Index (SPADI)'

The SPADI is a 13-item questionnaire designed to assess shoulder pain and function (Williams, Holleman, & Simel, 1995). The SPADI has demonstrated acceptable construct validity with medical diagnosis and pain medication usage (MacDermid, Solomon, & Prkachin, 2006). Reproducibility of the SPADI has been demonstrated to be 'high' to 'very high' (ICC = 0.66 to 0.89) across studies (Breckenridge & McAuley, 2011).

7) 'Scapular Upward Rotation'.

Estimates of Scapular Upward Rotation were made from observation of surface landmarks using digital images sampled from video recordings using digital image analysis software. Similar measurements have been conducted by determining the distance from the spine to the inferior angle and root of the spine of the scapula in a horizontal plane with 'nearly perfect' intra-rater reliability of ICC > 0.9 (Lewis & Valentine, 2008).

Procedures

Measures of pectoralis minor muscle length

Participants were positioned supine on a plinth, in a standardised way, to minimise interference by the contours of the plinth or pillow. Similarly, participants' hands were positioned with fingers interlaced and resting on the umbilicus. The skin overlying key bony landmarks was palpated as described by Borstad (2006) and

Lewis and Valentine (2007), and marked using an ink marker. Clavicular length and PMI were measured taken using a flexible tape measure with the examiner blinded to the measurement. Prior to data collection, preliminary PMI and clavicular measurements were taken using electronic calipers and a flexible tape measure as described by Borstad (2008). The flexible tape measure was determined to be the optimal choice, because it allowed for concurrent palpation and measurement, with greater participant comfort. The PMLT was taken using a set square (Lewis & Valentine, 2007). All measurements were repeated three times. The investigator was blinded to the actual measurement during each repetition. This was achieved by using instruments without the unit of measurement visible while in contact with the participant. [Further details of the blinding procedure are displayed in Thesis Appendix F]. To avoid bias, the SPADI and video capture of scapular motion were completed after the measurements.

Video capture of scapular motion

Participants were filmed from behind using a digital camera positioned on a tripod with the field of view such that the posterior thorax and hands were always in frame. Participants less than 65kg were assigned 1kg dumbbells while those above 65kgs used 2kgs (Park et al., 2013). The rate of movement was guided by a metronome to approximately 3 beats, at a rate of 70 beats per minute for both raising and lowering. Participants underwent familiarisation with the movement prior to data collection. Participants performed 5 repetitions each of weighted flexion and abduction.

Assessment of shoulder pain and disability

Participants completed one SPADI questionnaire for each shoulder, regardless of symptoms. The investigator was blinded to the SPADI questionnaire results while the other measures were performed. [see Thesis Appendix G for SPADI questionnaire].

Video analysis

Subsequent to data collection, videos were rated by the primary investigator. Each scapula was assessed independently by viewing each video a minimum of three times

and a rating was determined based on the impression gained across all repetitions. A more complex rating system, consisting of multiple categories was initially piloted. It was determined that the sample size would likely be insufficient and a more simplified modification of the 4-Type system was developed (the 6-Type System).

Digital images were sampled from each video of abduction at the point where the arms achieved parallel overhead and again when they reached the sides on the first repetition. Using digital image analysis software (Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, <http://imagej.nih.gov/ij/>, 1997-2016), an Upward Rotation angle was calculated between the spine of the scapula and the thoracic spine for the overhead images, and from the medial border of the scapula to the thoracic spine for the images with arms at sides, each three times.

Reliability of the 6-Type System, Scapular Dyskinesis Test, and angle measurements

Intra-rater reliability for 6-Type System, Scapular Dyskinesis Test, and Upward Rotation was established for the principal investigator by rating all recordings on two occasions separated by an interval of two weeks. Intra-rater reliability coefficients using Gwet's Agreement Coefficient (AC1) (Wongpakaran, Wongpakaran, Wedding, & Gwet, 2013) for ratings made using the 6-Type System in the directions of flexion, abduction, repeated for left and right ranged between (min-max) AC1 = 0.68 to 0.71, 95% CI 0.55 to 0.84. The Scapular Dyskinesis Test had an inter-rater reliability of AC1 = 0.65 to 0.79, 95% CI of 0.5 to 0.91. For Upward Rotation with the arms at the sides, the intra-rater reliability ranged from ICC of 0.74 to 0.87, 95% CI 0.59 to 0.92. Intra-rater reliability of Upward Rotation in an overhead position ranged from ICC 0.5 to 0.83, 95% CI 0.29 to 0.9.

Data analysis

Extraction

Data from raw scoring sheets were tabulated in spreadsheets. The mean of three repetitions for each of the pectoralis minor muscle length, clavicular length and Upward Rotation measurements were calculated. The PMI and PMLT measurements were divided by clavicular length for normalisation (Tate et al., 2012). Data were

imported into SPSS for statistical analysis (v22.0, IBM SPSS Statistics for Windows, Armonk, NY).

Statistical analysis

The PMI and PMLT were correlated with shoulder pain and Upward Rotation angles using Pearson's correlation coefficients. Correlation between the PMI and the PMLT was also determined using Pearson's correlation. These analyses were also repeated with positive Kendall cases excluded. Binary logistic regression was undertaken with data recoding to isolate individual dyskinesia types from the 6-Type System and 'obvious' dyskinesia from the Scapular Dyskinesia Test. Additionally, Type 1 and Type 5 (a combination of types including Type 1) were combined as a single primary variable to encompass all manifestations of the Type 1 pattern. Multiple regressions were carried out with different combinations of the two pectoralis minor and two upward rotation measurements for each of the dependent variables. Because the SPADI disability scores were low in this sample, only the pain score was included in the analysis. To facilitate interpretation, odds ratios less than 1 were converted to odds ratios greater than 1 using the method described by McHugh (2009). Hopkins' descriptors for magnitudes of effect were used to interpret all effect statistics (Hopkins, 2002). Odds ratios less than 1 remain unchanged in the results tables. Statistical significance was accepted when $p < 0.05$.

Results

Participant descriptive characteristics

A total of 41 females and 29 males were recruited. Sixty-three of the 70 participants were right handed. Descriptive characteristics are displayed in Table 1. Dyskinesia frequencies are displayed in Figures 1 and 2.

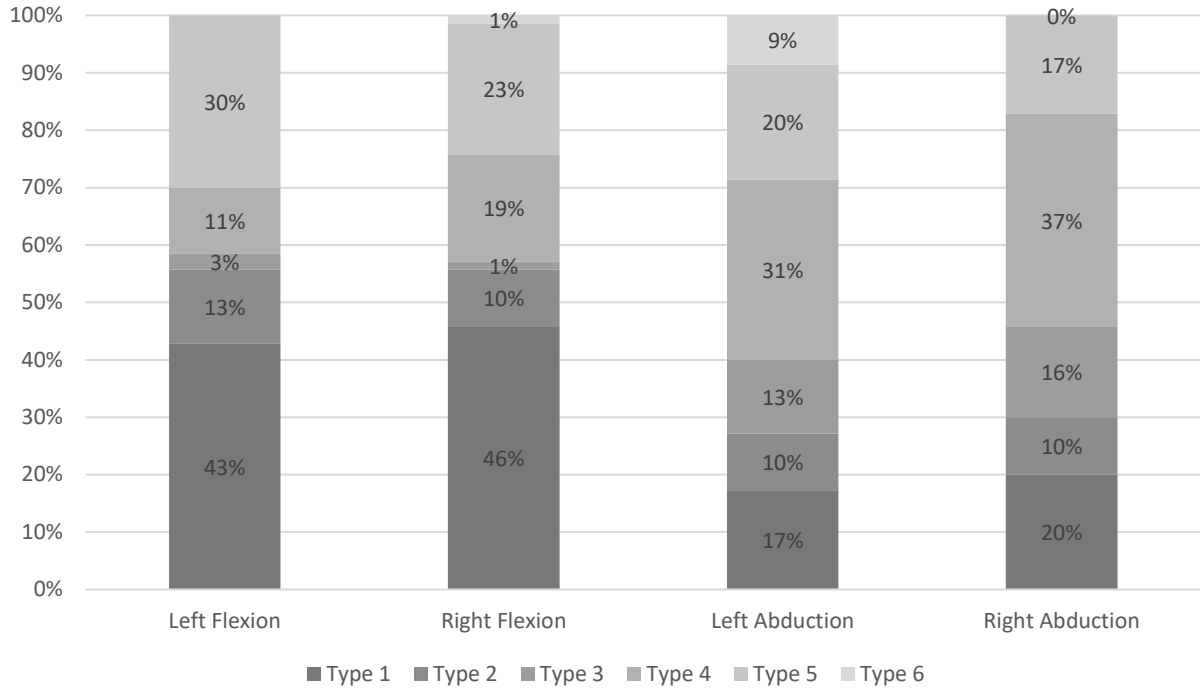


Figure 1) 6-Type System dyskinesia frequencies (n = 70).

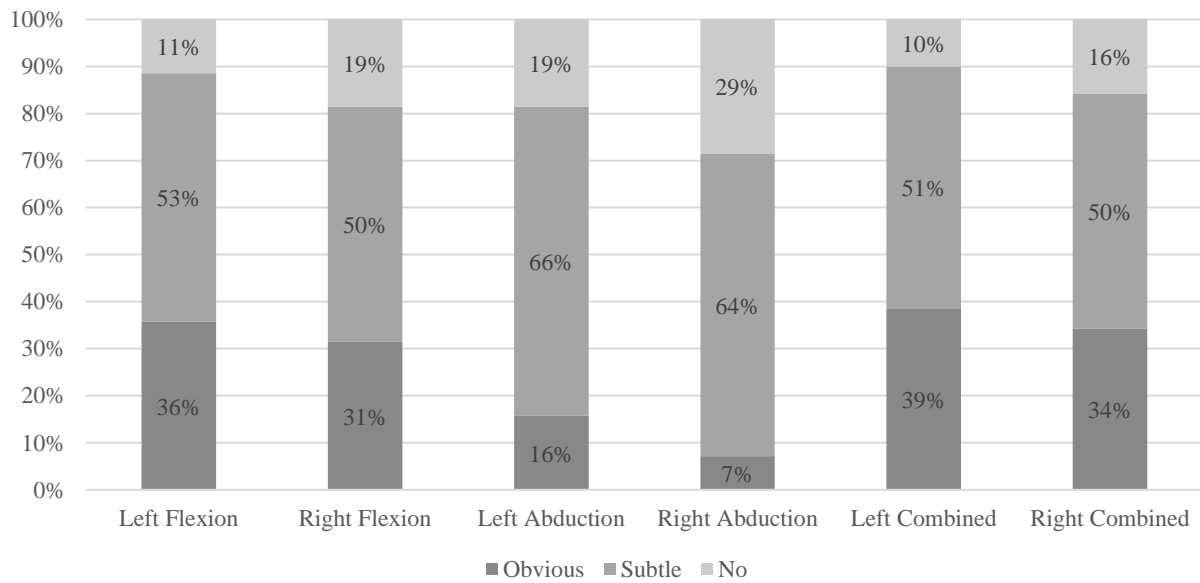


Figure 2) Scapular Dyskinesia Test frequencies (n = 70).

Univariate correlation of pectoralis minor length, shoulder pain and upward rotation

Results from the univariate analysis are displayed in Table 2. There were ‘very low’, non-significant correlations between the PMI and PMLT measurements in the whole sample and with positive Kendall cases excluded. A ‘low’ to ‘moderate’ correlation was found between Overhead Upward Rotation and PMI, but this relationship was only statistically significant on the left. There were ‘low’ correlations between the PMLT with and without Kendall positive cases excluded, and pain with statistical significance in all conditions except for the left side with positive Kendall cases excluded.

Table 1: Descriptive Characteristics (mean \pm SD¹)

Group	General Characteristics				SPADI ²	Pectoralis Minor (cm)		Upward Rotation (°)	
	Age (years)	Height (cm)	Weight (kg)		Pain	PMI	PMLT	Arms At Sides	Arms Overhead
Male (n = 29)	34.1 \pm 11.8	179.5 \pm 8.9	81.4 \pm 13.6	Left	3.7 \pm 7.6	10.5 \pm 7.7	3.3 \pm 5.4	-1.5 \pm 6.7	119.3 \pm 4.3
				Right	4.9 \pm 9.7	10.4 \pm 8.5	3.5 \pm 5.1	0.7 \pm 6.1	116.6 \pm 5
Female (n = 41)	29.7 \pm 7.3	165.5 \pm 5.6	70.8 \pm 17.4	Left	4.8 \pm 10.8	10.7 \pm 8.1	3.4 \pm 7	-5.6 \pm 5.5	121.8 \pm 3.5
				Right	8.5 \pm 15	10.7 \pm 8.2	3.7 \pm 6.4	1 \pm 6.2	119.6 \pm 4.5
Overall (n = 70)	31.5 \pm 9.6	171.3 \pm 10	75.2 \pm 16.6	Left	4.4 \pm 9.6	10.6 \pm 8	3.3 \pm 6.4	-3.8 \pm 6.4	120.8 \pm 4
				Right	7 \pm 13.1	10.6 \pm 8.4	3.6 \pm 5.9	0.8 \pm 6.1	118.3 \pm 4.9

Notes: ¹SD = standard deviation ²SPADI = shoulder pain and disability index

Table 2: Univariate Correlation Analysis For Pectoralis Minor, Upward Rotation And Pain

		PMLT		PMLT-'ve K		UR Arms At Sides		UR Arms Overhead		Pain	
		Pearson's <i>r</i> 95% CI	P Value	Pearson's <i>r</i> 95% CI	P Value	Pearson's <i>r</i> 95% CI	P Value	Pearson's <i>r</i> 95% CI	P Value	Pearson's <i>r</i> 95% CI	P Value
PMI	Left	-0.13 -0.38 to 0.17	0.277	0.11 -0.24 to 0.48	0.623	0.07 -0.18 to 0.30	0.582	0.28 0.06 to 0.5	0.022	-0.06 -0.38 to 0.32	0.605
	Right	-0.04 -0.29 to 0.19	0.723	-0.18 -0.55 to 0.19	0.316	0.07 -0.22 to 0.36	0.621	0.58 -0.18 to 0.27	0.641	0.03 -0.19 to 0.23	0.83
PMLT	Left	-	-	-	-	-0.02 -0.26 to 0.23	0.86	-0.2 -0.24 to 0.18	0.873	0.24 -0.01 to 0.43	0.043
	Right	-	-	-	-	0.01 -0.25 to 0.26	0.967	0.03 -0.23 to 0.27	0.822	0.32 0.06 to 0.53	0.007
PMLT -'ve K	Left	-	-	-	-	-0.01 -0.32 to 0.26	0.964	-0.06 -0.27 to 0.15	0.713	0.31 -0.66 to 0.61	0.135
	Right	-	-	-	-	-0.02 -0.35 to 0.27	0.908	-0.05 -0.37 to 0.31	0.78	0.41 0.09 to 0.67	0.015

Notes: CI = confidence interval, PMLT -'ve K = PMLT with only including cases with negative Kendall, UR = upward rotation

Logistic regression of predictor variables for types and magnitude of dyskinesia

The logistic regression findings are displayed in Tables 3 and 4. The two most notable models were PMI/Pain/At Sides Upward Rotation (PMI model, see Table 3) and PMLT/Pain/Overhead Upward Rotation (PMLT model, see Table 4). The PMI model explained 11.6% to 42.5% of the variance in Type 1, while the PMLT model explained 2.1% to 15.3% of Type 1.

The PMI and PMLT were the only individual predictor variables associated with scapular dyskinesia. ‘Very small’ but significant associations were found between shorter PMI and Type 1 in flexion and abduction bilaterally. Additionally, ‘very small’ associations were also found between longer PMI and Type 5 with significance in bilateral abduction and right flexion. A longer PMLT had a ‘very small’ association with Type 1 in left abduction, while a shorter PMLT had a ‘very small’ association with Type 5 in abduction bilaterally, but was significant on the left side only. A shorter PMLT demonstrated a ‘very small’ association with ‘obvious’ dyskinesia in flexion and abduction, bilaterally with significance in all planes and sides except for left abduction. For Types 2 to 4 from the 6-Type System, ‘very small’ and statistically non-significant associations in both directions were found with all variables (PMI, PMLT, Upward Rotation and shoulder pain). [See Thesis Appendix H]

Table 3: Logistic Regression for PMI, Pain, Upward Rotation At Sides (Types 1, 5 and 1 & 5)

Dependent Variables	Overall Model			Pectoralis Minor Index			
	R ²	χ^2	P Value	Wald	P Value	Odds Ratio	95% CI
Left Abduction							
Type 1	0.267	4.27	0.832	7.33	0.007	0.85	0.75 to 0.96
Type 5	0.293	7.28	0.507	8.07	0.004	1.18	1.05 to 1.32
Types 1 & 5	0.048	6.71	0.569	0.01	0.944	1	0.94 to 1.07
Right Abduction							
Type 1	0.425	6.83	0.555	9.58	0.002	0.8	0.69 to 0.92
Type 5	0.32	7.42	0.492	8.92	0.003	1.19	1.06 to 1.33
Types 1 & 5	0.058	3.79	0.875	0.22	0.64	0.98	0.92 to 1.05
Left Flexion							
Type 1	0.116	3.88	0.868	3.29	0.07	0.93	0.87 to 1.01
Type 5	0.04	10.7	0.22	1.29	0.256	1.04	0.97 to 1.13
Types 1 & 5	0.072	4.41	0.819	0.87	0.351	0.96	0.88 to 1.05
Right Flexion							
Type 1	0.317	4.92	0.766	9.87	0.002	0.86	0.79 to 0.95
Type 5	0.414	3.92	0.865	7.56	0.006	1.17	1.06 to 1.3
Types 1 & 5	0.099	7.46	0.488	1.37	0.242	0.96	0.89 to 1.03
Obvious Dyskinesia							
Abduction Left	0.067	8.59	0.378	0.46	0.499	1.03	0.94 to 1.13
Abduction Right	0.128	10.5	0.231	1.77	0.184	1.09	0.96 to 1.22
Flexion Left	0.042	10.26	0.247	1.15	0.285	1.04	0.97 to 1.11
Flexion Right	0.035	20.15	0.1	0.71	0.401	1.03	0.96 to 1.10
Combined Left	0.055	8.76	0.363	0.38	0.537	1.02	0.96 to 1.09
Combined Right	0.033	8.31	0.404	0.33	0.566	1.02	0.95 to 1.09

Notes: CI = confidence interval

Table 4: Logistic regression for PMLT, Pain and Overhead Upward Rotation (Types 1, 5 and 1 & 5)

Dependent Variables	Overall Model			Pectoralis Minor Length Test			
	R ²	χ^2	P Value	Wald	P Value	Odds Ratio	95% CI
Left Abduction							
Type 1	0.153	3.62	0.89	3.46	0.063	1.11	0.99 to 1.23
Type 5	0.208	9.96	0.268	4.91	0.027	0.87	0.77 to 0.98
Types 1 & 5	0.037	8.98	0.344	0.22	0.64	0.98	0.91 to 1.06
Right Abduction							
Type 1	0.021	7.31	0.503	0.03	0.867	1.01	0.91 to 1.13
Type 5	0.102	3.16	0.924	1.7	0.193	0.92	0.80 to 1.05
Types 1 & 5	0.03	12.28	0.139	0.78	0.378	0.96	0.87 to 1.05
Left Flexion							
Type 1	0.054	6.14	0.632	0.45	0.503	1.03	0.95 to 1.11
Type 5	0.005	8.96	0.346	0.21	0.886	0.99	0.91 to 1.08
Types 1 & 5	0.048	7.04	0.533	0.34	0.56	1.03	0.94 to 1.13
Right Flexion							
Type 1	0.065	3.44	0.904	0.52	0.471	1.03	0.94 to 1.13
Type 5	0.191	7.94	0.439	0.6	0.807	0.99	0.88 to 1.11
Types 1 & 5	0.013	13.78	0.088	0.14	0.708	1.02	0.92 to 1.12
Obvious Dyskinesia							
Abduction Left	0.096	7.07	0.529	2.68	0.102	0.9	0.80 to 1.02
Abduction Right	0.169	12.38	0.135	3.77	0.052	0.8	0.64 to 1.00
Flexion Left	0.213	8.50	0.386	7.85	0.005	0.86	0.78 to 0.96
Flexion Right	0.26	2.78	0.948	8.84	0.003	0.82	0.71 to 0.93
Combined Left	0.217	13.36	0.1	7.83	0.005	0.87	0.78 to 0.96
Combined Right	0.226	2.93	0.939	7.77	0.005	0.84	0.74 to 0.95

Notes: CI = confidence interval

DISCUSSION

Scapular dyskinesis and pectoralis minor muscle length measurements are of clinical interest in relation to shoulder health (Kibler et al., 2013; Tate et al., 2012). However, their roles remain unclear and the relationship between scapular dyskinesis and pectoralis minor muscle length measurements has limited evidence (Yeşilyaprak et al., 2016). The primary aims of this study were to determine: 1) the relationship between PMI and PMLT when measured in a standardised position and 2) the relationship between clinical measures of pectoralis minor muscle length (PMI and PMLT) and observational assessment of scapular dyskinesis (6-Type System and SDT). The secondary aims of this study were to determine: 3) the correlation between shoulder pain and scapular dyskinesis, PMI or PMLT measurements; and 4) the association between scapular upward rotation and scapular dyskinesis. The main findings were that 1) the correlation between the PMI and PMLT in a standardised position was ‘very low’ and not significant, 2) Type 1 dyskinesis had a significant but ‘very small’ association with shorter PMI measurements, 3) ‘obvious’ dyskinesis had a ‘very small’ but significant negative association with longer PMLT measurements, 4) shoulder pain demonstrated ‘low’ to ‘moderate’, significant correlations with longer PMLT measurements; and 5) the 6-Type System and SDT demonstrated ‘very low’ and non-significant correlations with Upward Rotation and shoulder pain.

The PMLT is a classic clinical measure, however the construct validity has not been established (Weber, Enzler, Wieser, & Swanenburg, 2016). The correlation between PMLT measures and pectoralis minor muscle length was also questioned by Borstad (2005) on the basis that their correlation was ‘very small’ and non-significant. Similarly, here the correlation between the PMLT and the validated PMI measure was ‘very small’ and non-significant. However the PMLT was the only variable in this study that related to shoulder pain with ‘low’ to ‘moderate’ and significant correlations. This finding contrasts with the findings reported by Lewis and Valentine (2007) who found trivial differences in mean PMLT length (1-2mm) between symptomatic and asymptomatic participants. The results of this study indicate that the PMLT, while unsuitable for pectoralis minor muscle length measurement, may be of some marginal clinical value and may address a different aspect of shoulder functional than the PMI.

The Kendall secondary test is intended as an adjunct to the PMLT to help interpret findings by identifying shortness in the upper arm muscles including coracobrachialis and biceps brachii which have been reasoned to produce anterior tilting of the scapula independent of

pectoralis minor muscle (Kendall et al., 1971). Here, exclusion of those with a positive Kendall secondary test did not affect the correlation between PMLT and other variables (PMI, Upward Rotation, pain) in a meaningful way. This measure is generally under researched and to date, no reliability or validity data are available for the Kendall secondary test.

In clinical terms, it might be expected that longer PMLT measurements, which are thought to be indicative of a shorter pectoralis minor muscle, would contribute to greater magnitudes of scapular dyskinesia (Morais & Cruz, 2016). In contrast this study found longer PMLT measurements were negatively associated with 'obvious' dyskinesia using the SDT. This may indicate the potential stabilising role of a protracted scapula, related to the serratus anterior muscle, which is the primary protractor and stabiliser of the scapula (Gilroy et al., 2012). In the presence of a longer PMLT measurement, the serratus anterior may be shorter, more active or under greater resting tension which may explain the negative association with 'obvious' dyskinesia. It has been suggested that scapular dyskinesia may occur as a compensatory mechanism in response to shoulder pain (McClure, Greenberg, & Kareha, 2012). In this study, those with a longer PMLT measurement experienced greater shoulder pain, which suggests the possibility of a similar compensatory mechanism. Recent commentary has suggested scapular dyskinesia represents natural and advantageous movement variability and may not be as important to shoulder pain as previously considered (McQuade, Borstad, & de Oliveira, 2016). This raises the question of whether scapular dyskinesia or a longer PMLT is indicative of dysfunction and indicates an unclear and complex relationship between shoulder pain, 'obvious' dyskinesia, and the PMLT.

Notable limitations associated with the 4-Type System include: the forced choice between types, despite the high prevalence of multiplane dyskinesia (Uhl, Kibler, Gecewich, & Tripp, 2009), the low prevalence of symmetry (Morais & Pascoal, 2013) with difficulty in its appraisal (Ellenbecker et al., 2012) and the use of the contralateral scapula for reference (Morais & Pascoal, 2013). These limitations were addressed in here in two ways. Firstly, to address the issue of symmetry, each scapula was assessed independently, and secondly, additional categories were included in the criteria to account for multiplane dyskinesia. To more sensitively identify those with anterior tilting of the scapula (Type 1), the 'Type 5' category was added, which identified multiplane scapular dyskinesia (combination of types) with aspects of Type 1. Type 6 was used to represent multiplane scapular dyskinesia without aspects of Type 1. In the original description of the 4-Type System, Kibler et al. (2002)

required raters to choose one type of dyskinesia most prevalent across both tested planes of movement, which proved to be difficult for the primary investigator in this study. Because a combination of types was already represented in Types 5 and 6, a type prevailing across both planes of movement was not determined. Unfortunately, the additional types did not provide any additional utility. Type 5 was inexplicably correlated with a longer PMI measurement and the combined single variable of 'Type 1 & Type 5' was not significantly correlated with the predictor variables. Type 6 occurred in such low frequency, it was omitted from data analysis (see Figure 1).

Here, scapular upward rotation measurements were taken from screen captures of the videos used to rate dyskinesia. Similar methods of determining scapular position from photographs have been shown to be valid and reliable (Kim, Yun, & Ha, 2013; O'Shea, Kelly, Williams, & McKenna, 2016). In previous studies, scapular and spinal landmarks were palpated and the overlying skin was marked prior to measuring upward rotation (O'Shea et al., 2016), but due to time constraints with participants and because this was not a primary measure, landmarks were not identified prior to obtaining images. Without validity available for this simplified approach, the exact accuracy of upward rotation calculated in the study is not known. Nevertheless, a shorter PMI measurement was correlated with reduced upward rotation in the overhead position.

Limitations

This study was purposefully designed to use measurement methods that are achievable in typical clinical practice for greater ecological validity to clinical practice (George, Batterham, & Sullivan, 2000). The magnitudes of effect identified here were generally small and this may be at least partially attributable to pragmatic decisions related to resource constraints. Compromises in participant homogeneity were made to maximise participant recruitment, which resulted in participants spanning a wide age range, with varied histories of shoulder pain and injury, athletic participation, fitness and body morphology. Thus, the sample was quite heterogeneous, which could have influenced measurement error and diluted effect size. Additionally, because of the numerous variables, a large sample was required for sufficient statistical power. A recent study of similar design but with fewer variables determined that 208 shoulders were required for sufficient statistical power

(Yeşilyaprak et al., 2016). Under ideal conditions, this study would have used a homogeneous sample of at least this size. Because of the heterogeneity of the sample, the incidence of shoulder disability was very low, demonstrated trivial scores and this variable was therefore not included in data analysis.

Because the 6-Type System is a novel adaptation of the 4-Type System, comparison of these findings with the literature is limited. While the 6-Type System addresses some of the issues with the 4-Type System, it was devised to more sensitively identify characteristics of Type 1 scapular dyskinesis, and is not necessarily for clinical use.

Implications and future research

The PMI and PMLT each correlated with different clinical measures. Because reduced PMI length was correlated with Overhead Upward Rotation and associated with Type 1 scapular dyskinesis, while increased PMLT length was correlated with shoulder pain and was negatively associated with the magnitude of scapular dyskinesis, they may offer distinctly differing clinical utility. Clinicians and researchers should consider using the PMI and PMLT together to obtain maximum information. Further research is required to investigate the relationship between shoulder pain and disability, the PMLT, serratus anterior and the SDT. A larger homogeneous sample with less variation in age, activity, body morphology, and shoulder pain and injury among subgroups, may provide more substantial correlations.

Conclusion

Type 1 dyskinesis demonstrated a ‘very small’ association with shorter PMI measurements, while the effect of a longer PMLT measurement was insignificant. Despite a standardised test position and the use of the Kendall secondary test, non-significant correlations were found between the PMI and PMLT. The PMLT was the only measure associated with shoulder pain in this study, however, increased dysfunction with this measure was associated with less ‘obvious’ dyskinesis and more ‘subtle’ or ‘no’ dyskinesis ratings using the SDT. The findings of this study are

indicative of a complex relationship between clinical measures of pectoralis minor muscle length, upward rotation, pain and observed scapular dyskinesis.

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SECTION III: Appendices

Appendix A: Ethics approval letter

Conner Bond
64 Taylors Road
Mount Albert
Auckland 1025



22.7.15

Dear Coner,

Your file number for this application: **2015-1041**

Title: **Comparison of Scapular Dyskinesia and Pectoralis Minor Length.**

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: 21.7.15

Finish date: 21.7.16

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.

You may now commence your research according to the protocols approved by UREC.

We wish you every success with your project.

Yours sincerely,

A handwritten signature in blue ink, appearing to read 'S. Donaghey'.

Sara Donaghey
Deputy Chair, UREC

cc: Rob Moran
Cynthia Almeida

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Appendix B: Ethics application ammendment

Conner Bond
64 Taylors Road
Mount Albert
Auckland 1025

10.12.15

Dear Conner,

Your file number for this application: **2015-1041**

Title: **Comparison of Scapular Dyskinesis and Pectoralis Minor Length.**

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

Start date: 3.12.15

Finish date: 21.7.16

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.

You may now commence your research according to the protocols approved by UREC.

We wish you every success with your project.

Yours sincerely,



Sara Donaghey
Deputy Chair, UREC

cc: Rob Moran
Cynthia Almeida



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Appendix C: Information sheet



Information for participants

COMPARISON OF SCAPULAR DYSKINESIS AND PECTORALIS MINOR LENGTH

My name is Conner Bond. I am currently enrolled in the Masters of Osteopathy degree in the Osteopathy department at Unitec New Zealand and seek your help in meeting the requirements of research for a Thesis course, which forms a substantial part of this degree.

The aim of my project is:

To determine the relationship between the length of a muscle in the upper chest, the different ways the shoulder blades can move and how they relate to shoulder pain (if applicable to you).

What we are doing:

We will be measuring the length of the pectoralis minor muscle in the upper chest, followed by video and photographic recording of your shoulder blades while you perform overhead reaching movements.

I request your participation in the following way:

In this study, you will be asked to attend one session of approximately 15 minutes where the following will take place:

- Answer some medical questions and fill out a shoulder pain and disability questionnaire, which will remain confidential.
- Be weighed in order to allocate appropriate hand weights.
- Uncover your shoulder blades and upper chest from around armpit level. For male participants this will require the shirt to be removed. For female participants, a halterneck top or similar garments are required.
- Be filmed from behind while reaching overhead straight arms and holding 1 or 2kg hand weights.
- Hold both arms overhead while the researcher identifies and marks points on the upper back then takes a photo from behind.
- Lay on your back while three measurements are taken on each side.

1. Length of each collarbone
 2. Distance from the back of your shoulder to the underlying surface. This will be followed by putting light pressure onto the front of your shoulder while fully flexing your elbow and lifting it up about 12cm.
 3. One point on the front of your shoulder and another at the bottom of your 4th rib at the middle of your upper chest will be identified, marked and measured.
- At a later date, the researchers will review the photographs and videos to 'rate' your type of scapular movement.

If you agree to participate, you will be asked to sign a consent form. This does not stop you from changing your mind if you wish to withdraw from the project. However, because of our schedule, any withdrawals must be done within 48 hours after we have collected data from you. Your refusal or withdrawal from the study will not affect the delivery of services from Unitec and you will not incur any penalties.

Your name and information that may identify you will be kept completely confidential. All information collected from you will be stored on a secure computer and any paper documents will be stored in a secure office. Only the researchers and supervisors will have access to this information. Neither you nor any organisation you may be affiliated with will be identified in the Thesis. You can request for a plain language summary of the research findings at the bottom of the consent form. You will be eligible for a \$20 petrol voucher to contribute to your travel related costs if you have traveled to the researcher for the sole purpose of participating.

Please contact us if you need more information about the project. I hope that you will agree to take part and that you will find your involvement interesting. At any time if you have any concerns about the research project you can contact our supervisor:

My supervisor is Rob Moran, phone 815 4321 ext. 8197 or email rmoran@unitec.ac.nz

UREC REGISTRATION NUMBER: 2015-1041

This study has been approved by the UNITEC Research Ethics Committee from 22 July 2015 to 30 December 2016. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (ph: 09 815-4321 ext 8551. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Appendix D: Consent form



Participant Consent Form

COMPARISON OF SCAPULAR DYSKINESIS AND PECTORALIS MINOR LENGTH

I have had the research project explained to me and I have read and understand the information sheet given to me.

I understand that I don't have to be part of this research project should I chose not to participate and may withdraw before, during or within 48 hours after participation.

I understand that everything I say is confidential and none of the information I give will identify me and that the only persons who will know what I have said will be the researchers and their supervisors. I also understand that all the information that I give will be stored securely on a computer and in a locked office at Unitec for a period of 10 years.

I understand that I will be required to uncover my shoulder blades and upper chest. For males this involves removing the shirt. For females this involves wearing a 'halter-neck' or similar garment, which does not obscure the upper chest or shoulder blades.

I understand that bony landmarks on my upper chest and upper back will be touched and marked with a washable pen or marker.

I understand that I will be filmed and photographed from behind.

I understand that I can see the finished research document.

I have had time to consider everything and I give my consent to be a part of this project.

I understand I can email the researcher at shoulderstudy2016@gmail.com for a plain language summary of the outcomes of this study.

Participant Name:

Participant Signature: *Date:*

Project Researcher: *Date:*

UREC REGISTRATION NUMBER: 2015-1041

This study has been approved by the UNITEC Research Ethics Committee from 30 December 2015 to 22 July 2016. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (ph: 09 815-4321 ext 8551. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Appendix E: Scapular Dyskinesia Test rating criteria

The Scapular Dyskinesia Test assigns a rating of 'obvious', 'subtle' or 'no' dyskinesia (McClure et al., 2009). Scapular dyskinesia is described by McClure et al. (2009), as dysrhythmia observed as excessive, premature, stuttering or non-smooth movement, and/or winging, characterised by the features of Type 1 and Type 2 (McClure et al., 2009).

For a rating of 'no' dyskinesia, the scapula must smoothly and continuously rotate upwards on elevation and downwards on return without winging or other abnormality present (McClure et al., 2009). Subtle abnormality is defined as 'mild' or 'uncertain' abnormality and may not be present on every repetition, while obvious abnormality must be seen on at least 3 of 5 repetitions with marked dysrhythmia or winging of greater than "1 inch" (2.54cm) from the thorax (McClure et al., 2009).

'No' dyskinesia is assigned to participants with no abnormality in one movement and either no abnormality or subtle abnormality in the other. 'Subtle' dyskinesia is assigned when subtle abnormality is observed in both movements. 'Obvious' dyskinesia is assigned when obvious abnormality is observed in either movement (McClure et al., 2009).

Appendix F: Measurement blinding

Efforts were made to ensure the primary investigator was blinded to each measurement repetition during data collection. For the clavicular and Pectoralis Minor Index measures, three separate sections of flexible tape measure were used, each with a different unit of measure (metric, imperial and Chinese inches ‘cun’). Measurements were recorded by measuring the flexible tape measure against a hard ruler between each repetition. For the Pectoralis Minor Length Test, the numbers on the set square were obscured with adhesive putty which was marked upon measurement. The set square was measured against a hard ruler and the mark was rubbed off prior to the next measurement repetition. To avoid bias, the SPADI and video capture of scapular motion were completed after the aforementioned measurements were taken.

Appendix G: Shoulder Pain and Disability Index

Shoulder Pain and Disability Index

Please place a mark on the line that best represents your experience during the last week attributable to your shoulder problem.

Pain scale

How severe is your pain?

Circle the number that best describes your pain where: 0 = no pain and 10 = the worst pain imaginable.

At its worst?	0	1	2	3	4	5	6	7	8	9	10
When lying on the involved side?	0	1	2	3	4	5	6	7	8	9	10
Reaching for something on a high shelf?	0	1	2	3	4	5	6	7	8	9	10
Touching the back of your neck?	0	1	2	3	4	5	6	7	8	9	10
Pushing with the involved arm?	0	1	2	3	4	5	6	7	8	9	10

Total pain score _____ / 50 x 100 = _____ %

(Note: If a person does not answer all questions divide by the total possible score, eg. if 1 question missed divide by 40)

Disability scale

How much difficulty do you have?

Circle the number that best describes your experience where: 0 = no difficulty and 10 = so difficult it requires help

Washing your hair?	0	1	2	3	4	5	6	7	8	9	10
Washing your back?	0	1	2	3	4	5	6	7	8	9	10
Putting on an undershirt or jumper?	0	1	2	3	4	5	6	7	8	9	10
Putting on a shirt that buttons down the front?	0	1	2	3	4	5	6	7	8	9	10
Putting on your pants?	0	1	2	3	4	5	6	7	8	9	10
Placing an object on a high shelf?	0	1	2	3	4	5	6	7	8	9	10
Carrying a heavy object of 10 pounds (4.5 kilograms)	0	1	2	3	4	5	6	7	8	9	10
Removing something from your back pocket?	0	1	2	3	4	5	6	7	8	9	10

Total disability score: _____ / 80 x 100 = _____ %

(Note: If a person does not answer all questions divide by the total possible score, eg. if 1 question missed divide by 70)

Total Spadi score: _____ / 130 x 100 = _____ %

(Note: If a person does not answer all questions divide by the total possible score, eg if 1 question missed divide by 120)

Minimum Detectable Change (90% confidence) = 13 points
(Change less than this may be attributable to measurement error)

Source: Roach et al. (1991). Development of a shoulder pain and disability index.

Appendix H: Additional results tables

This appendix contains results tables excluded from the manuscript. There were multiple variations of the regression model and only the two most relevant models were included in the manuscript.

Table A1: Logistic regression for PMI, Pain and Overhead Upward Rotation (Types 1, 5 and 1 & 5)

Dependent Variables	Overall Model			Pectoralis Minor Index			
	R ²	χ^2	P Value	Wald	P Value	Odds Ratio	95% CI
Left Abduction							
Type 1	0.216	9.48	0.303	5.63	0.018	0.89	0.80 to 0.98
Type 5	0.231	8.6	0.377	5.7	0.017	1.14	1.02 to 1.27
Types 1 & 5	0.033	12.26	0.14	0.01	0.953	1	0.94 to 1.07
Right Abduction							
Type 1	0.296	5.30	0.725	9.05	0.003	0.85	0.76 to 0.94
Type 5	0.218	6.89	0.549	5.92	0.015	1.12	1.02 to 1.23
Types 1 & 5	0.027	3.51	0.898	0.64	0.414	0.98	0.92 to 1.04
Left Flexion							
Type 1	0.086	17.56	0.25	2	0.157	0.95	0.88 to 1.02
Type 5	0.012	9.8	0.279	0.33	0.565	1.02	0.95 to 1.01
Types 1 & 5	0.063	10.57	0.227	1.01	0.315	0.96	0.88 to 1.04
Right Flexion							
Type 1	0.317	5.04	0.754	10.80	0.001	0.87	0.8 to 0.94
Type 5	0.295	7.58	0.475	4.84	0.028	1.1	1.01 to 1.2
Types 1 & 5	0.097	4.30	0.829	3.91	0.048	0.93	0.87 to 1
Obvious Dyskinesis							
Abduction Left	0.024	14.97	0.06	0.53	0.817	1.01	0.92 to 1.11
Abduction Right	0.041	9.75	0.283	1.02	0.313	1.06	0.95 to 1.19
Flexion Left	0.035	11.34	0.183	0.15	0.699	1.01	0.95 to 1.09
Flexion Right	0.043	7.35	0.5	0.12	0.734	1.01	0.95 to 1.08
Combined Left	0.041	13.03	0.111	0.03	0.865	0.99	0.93 to 1.07
Combined Right	0.041	8.44	0.392	0.01	0.974	1	0.94 to 1.07

Notes: CI = confidence interval

Table A2: Logistic regression for PMLT, Pain and Upward Rotation At Sides (Types 1, 5 and 1 & 5)

Dependent Variables	Overall Model			Pectoralis Minor Length Test			
	R ²	χ^2	P Value	Wald	P Value	Odds Ratio	95% CI
Left Abduction							
Type 1	0.078	8.42	0.393	2.51	0.113	1.09	0.98 to 1.21
Type 5	0.165	5.03	0.754	4.14	0.042	0.88	0.78 to 1
Types 1 & 5	0.053	7.44	0.49	0.20	0.651	0.98	0.90 to 1.07
Right Abduction							
Type 1	0.42	9.54	0.299	0.36	0.359	0.94	0.83 to 1.07
Type 5	0.056	2.98	0.935	0.01	0.975	1	0.89 to 1.12
Types 1 & 5	0.067	12.39	0.135	0.61	0.434	0.96	0.87 to 1.06
Left Flexion							
Type 1	0.045	7	0.537	0.27	0.603	1.02	0.94 to 1.11
Type 5	0.01	9.38	0.311	0.02	0.881	1.01	0.92 to 1.1
Types 1 & 5	0.067	2.73	0.95	0.65	0.419	1.04	0.94 to 1.16
Right Flexion							
Type 1	0.055	10.72	0.218	0.03	0.856	1.01	0.91 to 1.16
Type 5	0.22	6.02	0.645	0.23	0.635	1.03	0.91 to 1.17
Types 1 & 5	0.069	13.48	0.096	0.09	0.762	1.02	0.91 to 1.14
Obvious Dyskinesis							
Abduction Left	0.126	5.94	0.654	2.47	0.116	0.91	0.80 to 1.02
Abduction Right	0.207	6.73	0.566	3.35	0.067	0.82	0.66 to 1.01
Flexion Left	0.206	8.59	0.378	7.34	0.007	0.86	0.78 to 0.96
Flexion Right	0.247	7.07	0.53	8.42	0.004	0.82	0.71 to 0.94
Combined Left	0.237	9.49	0.302	7.53	0.006	0.86	0.77 to 0.96
Combined Right	0.223	17.46	0.026	7.46	0.006	0.83	0.73 to 0.95

Notes: CI = confidence interval

Table A3: Logistic Regression for PMI, Pain and Upward Rotation At Sides (Types 2-4)

Dependent Variables	Overall Model			Pectoralis Minor Index			
	R ²	χ^2	P Value	Wald	P Value	Odds Ratio	95% CI
Left Abduction							
Type 2	0.009	9.58	0.296	0.14	0.708	1.02	0.92 to 1.13
Type 3	0.049	5.65	0.686	0.3	0.586	1.03	0.93 to 1.14
Type 4	0.249	8.98	0.344	1.26	0.261	0.95	0.88 to 1.04
Right Abduction							
Type 2	0.131	6.7	0.57	0.01	0.956	1	0.90 to 1.11
Type 3	0.014	8.55	0.381	0.2	0.657	1	0.9 to 1.07
Type 4	0.122	7.31	0.504	0.57	0.451	1.03	0.96 to 1.10
Left Flexion							
Type 2	0.089	3.33	0.912	1.77	0.183	1.1	0.97 to 1.18
Type 3	0.137	4.53	0.806	0.65	0.42	0.9	0.71 to 1.16
Type 4	0.079	8	0.434	0	0.996	1	0.86 to 1.16
Right Flexion							
Type 2	0.08	9.91	0.271	0.66	0.415	1.04	0.94 to 1.15
Type 3	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Types 4	0.056	9.45	0.305	0.3	0.581	1.03	0.93 to 1.12

Notes: CI = confidence interval, n/a = not applicable

Table A4: Logistic Regression for PMI, Pain and Overhead Upward Rotation (Types 2-4)

Dependent Variable	Overall Model			Pectoralis Minor Index			
	R ²	χ^2	P Value	Wald	P Value	Odds Ratio	95% CI
Left Abduction							
Type 2	0.031	7.99	0.434	0.01	0.921	0.99	0.89 to 1.11
Type 3	0.048	6.16	0.629	0.21	0.651	1.03	0.92 to 1.14
Type 4	0.09	5.65	0.687	0.27	0.603	0.98	0.91 to 1.06
Right Abduction							
Type 2	0.103	4.52	0.808	0.01	0.951	1	0.90 to 1.1
Type 3	0.039	7.98	0.435	0.93	0.335	0.96	0.88 to 1.04
Type 4	0.096	11.14	0.194	2.6	0.107	1.06	0.99 to 1.13
Left Flexion							
Type 2	0.075	5.51	0.702	0.77	0.381	1.05	0.94 to 1.17
Type 3	0.177	4.81	0.778	1.04	0.309	0.89	0.72 to 1.11
Type 4	0.035	6.28	0.616	0.68	0.409	1.05	0.94 to 1.18
Right Flexion							
Type 2	0.022	6.87	0.551	0.54	0.463	1.04	0.94 to 1.14
Type 3	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Type 4	0.09	7.01	0.536	2.85	0.091	1.07	0.99 to 1.17

Notes: CI = confidence interval, n/a = not applicable

Table A5: Logistic Regression for PMLT, Pain and Upward Rotation At Sides (Types 2-4)

Dependent Variables	Overall Model			Pectoralis Minor Length Test			
	R ²	χ^2	P Value	Wald	P value	Odds Ratio	95% CI
Left Abduction							
Type 2	0.02	8.56	0.381	0.46	0.497	0.96	0.84 to 1.09
Type 3	0.116	9.57	0.297	2.5	0.115	1.1	0.98 to 1.24
Type 4	0.255	3.84	0.871	1.54	0.215	1.07	0.96 to 1.18
Right Abduction							
Type 2	0.138	9.53	0.299	0.2	0.651	0.96	0.82 to 1.13
Type 3	0.019	7.94	0.44	0.35	0.552	1.04	0.91 to 1.19
Type 4	0.127	6.47	0.594	0.81	0.369	1.05	0.94 to 1.17
Left Flexion							
Type 2	0.087	4.31	0.828	1.62	0.203	0.92	0.81 to 1.05
Type 3	0.181	3.64	0.888	0.76	0.383	0.81	0.51 to 1.3
Type 4	0.14	7.25	0.51	1.3	0.254	1.11	0.93 to 1.33
Right Flexion							
Type 2	0.085	14.27	0.075	0.77	0.38	0.93	0.78 to 1.1
Type 3	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Type 4	0.058	10.40	0.238	0.41	0.523	1.05	0.91 to 1.21

Notes: CI = confidence interval, n/a = not applicable

Table A6: Logistic Regression for PMLT, Pain and Overhead Upward Rotation (Types 2-4)

Dependent Variables	Overall Model			Pectoralis Minor Length Test			
	R ²	χ^2	P Value	Wald	P Value	Odds Ratio	95% CI
Left Abduction							
Type 2	0.047	4.36	0.823	0.52	0.472	0.95	0.83 to 1.09
Type 3	0.107	16.34	0.038	2.32	0.127	1.01	0.97 to 1.23
Type 4	0.111	9.19	0.326	1.33	0.249	1.05	0.97 to 1.15
Right Abduction							
Type 2	0.117	4.71	0.788	0.48	0.487	0.95	0.80 to 1.1
Type 3	0.052	4.85	0.773	1.44	0.23	1.08	0.95 to 1.23
Type 4	0.048	12.2	0.142	0.3	0.583	1.03	0.96 to 1.13
Left Flexion							
Type 2	0.111	3.73	0.88	1.99	0.158	0.91	0.8 to 1.04
Type 3	0.191	2.55	0.961	0.8	0.37	0.81	0.51 to 1.29
Type 4	0.05	6.65	0.575	1.23	0.267	1.07	0.95 to 1.22
Right Flexion							
Type 2	0.036	8.91	0.35	0.94	0.334	0.93	0.79 to 1.08
Type 3	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Type 4	0.025	2.82	0.945	0.27	0.602	1.03	0.92 to 1.16

Notes: CI = confidence interval, n/a = not applicable



Full name of author: Conner Bond

Full title of thesis/dissertation/research project ('the work'):
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scapular dyskinesis and pectoralis minor muscle length: An
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