INTEGRATING BIOMECHANICS AND HEALTH PSYCHOLOGY: BIOPHYSICAL AND PSYCHOLOGICAL CONSIDERATIONS FOR SPINE AND SHOULDER MUSCULOSKELETAL DISORDERS

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ABSTRACT

Musculoskeletal disorders of the spine, predominantly the low back, and shoulder are common, costly burdens that impact health, function, occupation, and quality of life. Therefore, the overall goal of this research was to integrate biomechanics with health psychology to explore biophysical and psychological considerations towards understanding the relationship between these two regions for improving ergonomics, clinical biomechanics, and rehabilitation research and practice. The pathways of inquiry were achieved through a description of historical and relevant literature complemented by Canadian work-related lost time injury claims data demonstrating consistent rates of shoulder and low back claims. A question of the functional relationship between the shoulder and spine was answered using a large lab based cross-sectional, on over 160 young adults to determine the ROM and curvature relationship between the shoulder and spine. Although a moderate relationship was found in an asymptomatic sample, there were selected biophysical and psychological modifiers related to previous injury and spine curvature that were suspected considerations. Consequently, previous injuries and current Kinesiophobia and fear-avoidance beliefs were measured in this group of young adults, where most individuals with previous shoulder/low back injury still had Kinesiophobia irrespective of length of time since injury. Concurrently with the lab-based study, body composition was a hypothesized biophysical modifier of interest, however, within a sample of >160 young adults, the range of body composition was small and within established body mass index cut-offs for normal weight. Therefore, a systematic review was conducted to evaluate the relationship between body composition and thoracolumbar spine range of motion and curvature reported in the literature. There was strong evidence to suggest a positive relationship between body mass index and thoracic kyphosis and lumbar lordosis when body mass index was greater than normal cut-offs, that is in overweight and obese ranges. This body of evidence reports that the shoulder and spine share a functional ROM and curvature relationship and that the biophysical consideration of body composition and the psychological consequence of Kinesiophobia after a previous injury are important modifiers in the measurement of the musculoskeletal function of the shoulder and spine.

Dedication

"I have no special talents; I am only passionately curious" – Einstein

To all of those who have fostered my curiosity from,
Thank you for doing so.

Mom & Dad – thank you for supporting me and reminding me that I am good enough and to strive for any dream I have.

Brock – "We're on this boat… and it's about the journey." Thank you for being my partner, the one who holds me through the good and the bad, and most importantly for teaching me that it's not always about the destination, in fact, we must enjoy the journey.

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Chapter 1 Introduction

1.1 Motivation

Musculoskeletal disorders (MSD) are multifactorial burdens that impact many individuals across the lifespan. It is anticipated that 80% of adults will experience an episode of back pain in their lifetime, with degenerative diseases such as arthritis impacting functional joints like the shoulder and spine. The shoulder and spine are two regions major regions for MSD due to their necessity to complete many motions like posture, reaching, lifting, pushing, and pulling. The complement of musculoskeletal connections between these two regions in part contributes to these motions. Fundamentally, both regions are used frequently and consistently throughout activities of daily living and in many occupational tasks. The physical factors of repetitive use, intrinsic and extrinsic loads, and variety of postures exposed to the shoulder and region are established mechanism towards MSD. However, there are also many psychological, occupational, and social factors that contribute to their multifactorial nature.

Biomechanics and ergonomics research has been an integral component of understanding mechanisms of injury and risk factors for MSD. Biomechanical studies have provided established tissue tolerance levels. For example, the spine loads listed in the National Institute for Occupational Health and Safety lifting equations are based on studies of vertebral forces. Likewise, human factors and ergonomics studies have identified the physical ergonomic risk factors related to musculoskeletal function. Risk factors for MSD like repetition, force, and posture are now mitigated through occupational standards and practices. While injury mechanisms and risk factors are important in the prevention of MSD, there has also been much recognition that there are other psychosocial, occupational, and environmental factors that require consideration in the prevention of shoulder and spine MSD.

Characterization of an individual and their shoulder and spine musculoskeletal function is necessary for interpreting both preventative and predisposing musculoskeletal patterns. The variability in musculoskeletal patterns or risk of MSD may be attributed to non-modifiable and modifiable factors. Human behaviour, and as a result musculoskeletal function, is in part related to non-modifiable factors like sex, anthropometry, and age. However, shoulder and spine structural factors may be modified by body composition. Comparably, shoulder and spine movement may be modified by previous experiences, cognition, and resultant behaviour. Though such biophysical and psychological factors are not novel, they are difficult to interpret in shoulder and spine biomechanics and ergonomics due to their multifactorial and intersected relationships. Therefore, characterization of interrelated shoulder and spine musculoskeletal function can be challenging due to gaps in biophysical and psychological factors varying between individuals.

This dissertation is motivated by a need to incorporate interdisciplinary approaches to MSD research to help characterize factors that modify relationships in shoulder and spine related musculoskeletal function. The biophysical and psychological considerations explored in this dissertation influence our understanding of the shoulder and spine and provide tangible outcomes to redefine research protocols, rehabilitation, and practice, and provide modifiers for future prevention and management best practices. Ultimately, this research aims to address the needs of researchers, clinicians, ergonomists, occupational health and safety specialists and the general population by determining factors that impact shoulder/spine relationships.

1.2 Scope of the Dissertation

The global aim of this research was to investigate biophysical and psychological factors and the shoulder and spine to identify modifiers and measurement considerations for improved MSD research and practice. It was hypothesized that from a biophysical perspective the shoulder and spine shared a functional relationship, and that body composition would be an important modifier in spine curvature. From a psychological perspective, it was hypothesized that previous injuries would impact fear-avoidance beliefs. This aim was achieved through integrating research approaches from biomechanics with health psychology to develop cross-sectional and systematic review methodologies. Within Health Psychology, the biopsychosocial model, a common overarching approach, informed the use of The World Health Organization International Classification of Function Model (ICF) a working model commonly used to investigate MSD such as low back pain. The ICF model was used to explore biophysical and psychological factors integrating both Biomechanics and Health Psychology.

This scope of this dissertation demonstrates breadth through incorporating disciplines to encompass research on biophysical and psychological factors towards investigation of two regions of the body. This breadth resulted in many common terms, of which, could be interpreted through multiple definitions. To narrow the definitions of these terms, the common dissertation terms have been operationally defined in Table 1. Where appropriate, other key terms or data considerations are defined in their respective chapters.

Table 1 Operationally defined common terms used throughout this document.

Term	Definition
Age	Chronological time since birth reported in years. Note: Chapter 3 represents age in brackets of 5 years as reported by the Association of Worker's Compensation Board Canada. Chapter 6 used categorical groupings of young adults, middle-age adults, and older adults to synthesize evidence across studies in a systematic review.
Biophysical	Characteristics and factors that comprise anatomical, structural, and biomechanical features
Function	Joint ranges of motion and spine curvature contributions to shoulder and spine musculoskeletal movement.
Gender	Socially constructed roles used to express and reflect identify.
Modifier	A dynamic consideration that changes or impacts the outcomes of interest.
Posture	Positioning of the spine during neutral standing. Specifically for this document, the thoracolumbar regions are in scope.
Psychological	Characteristics and factors that relate to mental and emotional features
Range of Motion (ROM)	The limits of planar joint motion.
Sex	Biological attributes used to categorize humans commonly into the dichotomy of female and male.

1.3 Outline of the Dissertation

Following this general introduction (Chapter 1), this document is comprised of two motivational evidence chapters (Chapter 2: Review of the Literature and Chapter 3: Description of Recent Data), two cross-sectional studies (Chapter 4: Shoulder and Spine Planar Assessment Relationships and Chapter 5: Kinesiophobia and Fear-Avoidance after Previous Injuries), one systematic review (Chapter 6: Body Composition and the Thoracolumbar Spine), and a synthesis of the document (Chapter 7: General Discussion and Conclusions). Capture in Figure 1 are the pathways of inquiry guided by the ICF Model that directed the studies within this research.

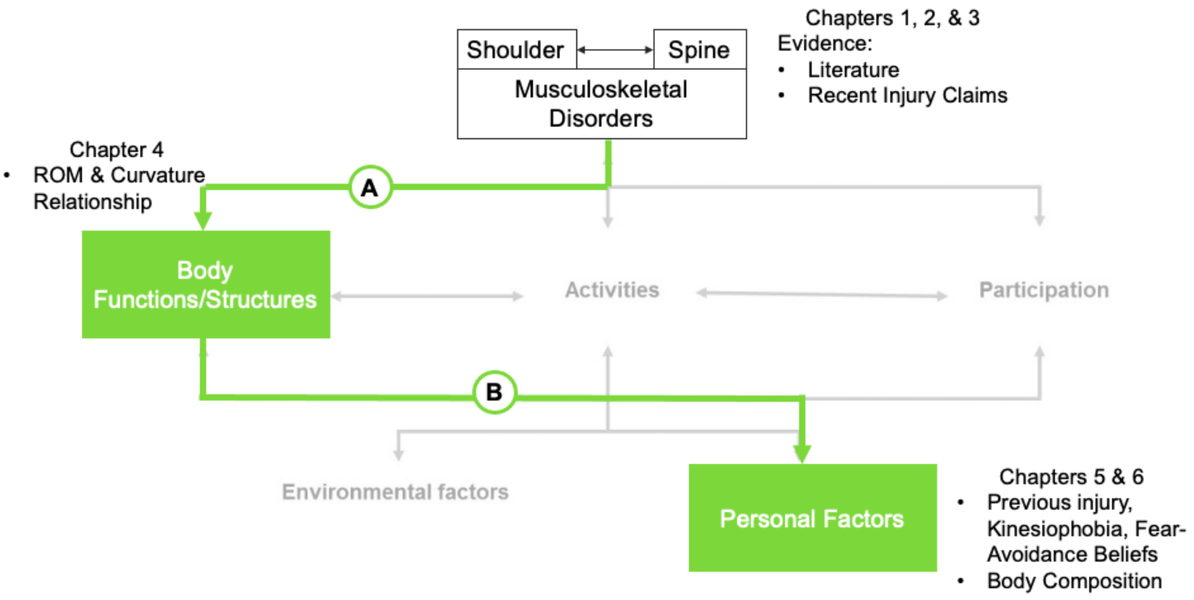

Figure 1. Adapted ICF Model from the World Health Organization (2001) highlighting the key pathways of inquiry (solid green lines) (A): What is the relationship between the shoulder and spine? and (B): What is the role of biophysical and psychological factors in shoulder and spine measurement and assessment, specifically body composition, previous injury, Kinesiophobia, and fear-avoidance?

1.4 Specific Objectives and Hypotheses

The specific objectives addressed by this dissertation to achieve the global aim of investigating biophysical and psychological factors and the shoulder and spine to identify modifiers and measurement considerations for improved MSD research and practice were the following.

Chapter 3: Review of Recent Data

Objectives:

- *To describe lost time injury claims of the shoulder and back in Canada throughout 2010-2018.*
- *To describe the difference in the number of loss time claims and injury rates by age groups and shoulder/back regions.*

Hypotheses: Overall loss time injury claims have decreased over 2010-2018 as reported by previous analyses of compensation claims. The specificity of shoulder and back related claims have not been described and it was hypothesized that lost time injury claims of the shoulder and spine would have an interaction, where a decrease in low back related claims would precede an increase in shoulder claims throughout this time period. It was hypothesized that working middle age and older adults (age groups greater than 30 years of age) would have a greater number of loss time claims due to greater employment in the labour force. For injury rates, it was hypothesized that rates would be similar for these two regions across age groups.

Chapter 4: Multivariate shoulder and spine relationship using planar assessment

Objectives:

- *To determine differences and relationships in bilateral shoulder and spine active planar ROM and spinal curvature in male and female young adults*
- *To investigate the interplay of the shoulder and spine using active planar ROM and spinal curvature assessment.*

Hypotheses: It was hypothesized that there would be no difference in bilateral ROM (Right = Left ROM), however, there would be moderate associations within shoulder ROM, within spine ROM, with low associations between regions. Relationships have previously been established in motion of the thoracic spine and shoulder movements (Barret et al., 2016; Crosbie et al., 2008). Therefore, it was hypothesized that a multivariate analysis would capture ROM and curvature parameters, commonly performed in assessment of these regions, with the highest contribution to the shoulder and spine relationship.

Chapter 5: Kinesiophobia and Fear Avoidance: Connecting previous injuries to the present

Objectives:

- *To report the number of previous shoulder and low back pain injuries in a sample of self-reported asymptomatic young adults.*
- *To measure Kinesiophobia, and fear-avoidance beliefs in asymptomatic young adults self-reporting previous shoulder and low back pain injuries.*
- *To examine the relationships between length of time since previous shoulder and low back injuries and Kinesiophobia and Fear-Avoidance Beliefs.*

Hypotheses: It was hypothesized that there would be a higher prevalence of previous low back injury than shoulder injury in young adults. It was hypothesized that there would be greater proportion of individuals scoring high compared to low on Kinesiophobia and Fear-Avoidance questionnaires in the previously injured groups. It was hypothesized that a negative association would exist where an increase in length of time since injury would result in a decrease in Kinesiophobia and Fear-Avoidance Beliefs.

Chapter 6: Body Composition and its Relationship to the Thoracolumbar Spine: A Systematic Review

Objective:

- *To determine the relationship between body composition and thoracolumbar spine curvature and range of motion in asymptomatic adults as represented in the literature.*

Hypothesis: A body of literature has investigated non-modifiable factors like sex and age on thoracic and lumbar spine curvature and ROM. Therefore, it was hypothesized that this literature would also capture anthropometric data to discern a relationship between body composition and thoracolumbar spine outcomes.

Chapter 2 Review of the Literature

MSD of the spine and shoulder have been consistent global burdens for many decades. This chapter provides a brief review of the literature to capture the following elements: the burden of spine and shoulder MSD, musculoskeletal considerations, and disciplinary models. This review of the literature covers a breadth of topics necessary for integrating biomechanics (clinical and occupational approaches) and health psychology towards understanding biophysical and psychological considerations in MSD research and practice.

2.1 Musculoskeletal Disorders

Musculoskeletal disorders (MSD) are a global burden. According to the Global Burden of Disease study, it was determined that approximately 1.71 billion people live with an MSD (Cieza et al., 2020). It was also acknowledged that MSDs are the biggest contributor to years lived with a disability (Cieza et al., 2020). The individuals who experience MSDs, are not restricted by demographics like age range, socioeconomic status, and geographical location, highlighting the magnitude of this burden across the world. The most-reported MSD is low back pain (LBP), with conditions like fractures (436 million people globally), osteoarthritis (343 million), neck pain (222 million), rheumatoid arthritis (14 million), among many others in the top burdens (Cieza et al., 2020). While MSDs are a most important concern at an individual level through impacts on quality of life and activities of daily living, there are equally occupational and economic burdens that purpurate the burden of MSD throughout society.

Work-related MSD are one of the leading causes of injury across workplaces and represents an example of where the interaction of a person, their activities, and their environment poses many risk factors. Previous estimates before the early 2000s indicated that 40% of the world's occupational and work-related health care costs were attributable to MSD (Takala et al., 1999). Annually across Canada, MSD rates are consistent and sizeable concerns ranging anywhere from 40% and 50% of all work-related claims (AWCBC, 2019). For example, throughout 2019 in Ontario, MSD (sprains and strains) represented 44% of all lost-time claims (WSIB, 2020). The low back region was the number one area reported (16%), with the shoulder region reporting in the top 5 regions at 6% (WSIB, 2020). The impact of spine and shoulder MSD merit the wealth of research focused on investigating biopsychosocial factors like anatomical, neuromuscular, and psychosocial relationships to prevent and manage these disorders.

2.1.1 The Spine and Low Back Pain

Worldwide, low back pain (LBP) is one of the most common and complex MSD. With acute, chronic and/or reoccurring symptomology (Linton, 2000), it is difficult to investigate and isolate the etiology and injury mechanisms. In addition, the lack of definitive diagnostics makes LBP research challenging (McGill, 2015, p.7). Anatomically, the spine displays a common structure of intervertebral discs, vertebrae, ligaments, and surrounding musculature. However, divided by region (cervical, thoracic, and lumbar), unique anatomical characteristics contribute to its regional and whole-body function. Therefore, while it is important to consider the spine movement as a whole, it is equally important to understand the specific trunk components related to LBP.

The spine is typically referred to in four regions, including the cervical, thoracic, lumbar, and sacral regions. The thoracolumbar spine typically refers to the twelve thoracic vertebrae (T1) through the five lumbar vertebrae (L5). This region has the greatest contribution to whole-body stability and trunk motion and posture. The structure of the vertebrae in each region differs both in size (e.g., size of the vertebral endplate) and orientation (e.g., facet joint orientation). An important consideration for trunk motion is that the bony structures of the thoracic and lumbar regions permit different planes and ranges of motion compared to the cervical and sacral regions. The thoracic region is predominantly associated with axial rotation (Lee et al., 2005; Marras & Granata, 1995), whereas the lumbar region is attributed to its contributions of flexion/extension of the trunk (Oxland, Lin, & Panjabi, 1992). As a whole, the thoracolumbar region permits a combination of frontal, sagittal, and transverse plane motion creating trunk lateral bend, flexion/extension, and axial rotation. In addition to bony configurations of the spine, trunk both neural and active components, including spine musculature (e.g., trapezius, rhomboid major and minor, erector spinae muscle group, latissimus dorsi, quadratus lumborum) contribute to posture, regional motion, and whole-body stability (Panjabi, 1992). The relationship of the spine's passive, neural, and active components are important factors when attempting to investigate LBP and other spine-related MSD.

The relationship between spine curvature has been an important consideration in LBP and other MSD, including those of the shoulder. The vertebral column consists of four primary sagittal alignments. Listed cranial to caudal include cervical lordosis, thoracic kyphosis, lumbar lordosis, and sacral kyphosis (Roussouly & Pinheiro-Franco, 2011). In the thoracolumbar region, thoracic kyphosis and lumbar lordosis are the two primarily investigated curves, Chaleat-Valayer and colleagues, reported significant sagittal alignment differences at almost every level of the spine (sacral slope, pelvic incidence, lumbar tilt, lordotic levels, thoracic kyphosis, thoracic tilt and lumbosacral joint angle) between those with and without chronic LBP (Chaleat-Valayer et al., 2011). There was a greater proportion of chronic LBP patients with low sacral slope, low lumbar lordosis and smaller pelvic incidence (Chaleat-Valayer et al., 2011). In a review specific to lumbar lordosis, decreased lumbar lordosis had a strong relationship to LBP, recognizing variability due to factors like age, the severity of LBP, and spinal disease (Chun et al., 2017). However, in paradigms used to elicit LBP, such as the prolonged standing protocol, increased lumbar lordosis during the stand was linked to LBP development and symptom intensity (Sorenson et al., 2015). Similarly, throughout standing, increased thoracic kyphosis has also been associated with increased loading and muscle force (Briggs et al., 2007). Functionally, these natural curves exist to maintain an upright posture and to provide protection through assisting with shock absorption (Briggs et al., 2007; Panjabi, 1992). Yet through observing varying shapes and degrees of curvature there are asymptomatic boundaries that important for understanding risk or development LBP and other spine-related MSD.

2.1.2 The Shoulder Complex and MSD

Shoulder-related MSD and shoulder pain are common conditions in the general and working populations. While the low back receives greater attention due to prevalence, MSDs of the shoulder have substantial socioeconomic consequences across the world (Hamberg-van Reenan et al., 2007). In a study of chronic pain in Canadian adults, the shoulder was within the top 6 reported sites for chronic pain with a prevalence of 6.2% (4.4–8.0) (Schopflocher, Taenzer, & Jovey, 2011). The most common report of pain was arthritic and joint pain (Schopflocher et al., 2011), and examples of common MSD contributing to such pain include rotator cuff tears and impingement. Given the complex anatomy and repetitive use in daily life, the shoulder region is challenging to prevent, manage, and rehabilitate MS.

The large mobility and versatile range of motion shoulder region make it a highly susceptible area for MSDs. The clavicle, scapula, and humerus and associate glenohumeral, sternoclavicular, acromioclavicular, and scapulothoracic joints, connect the upper limb to the axial skeleton (Moore & Dalley, 2006, p.321). The glenohumeral joint consists of a ball and socket design, where the glenoid surface area is typically less than 30% of the humeral head surface area, permitting large mobility and range of motion (Veeger & Van der Helm, 2007). The large mobility of the glenohumeral joint, harmonized with the motions of the adjoining joints, permits combinations of flexion, extension, internal and external rotation, and abduction/adduction (Omoumi et al., 2011). Therefore, the large mobility of this synovial joint is, therefore, at the expense of stability, requiring demand of the surrounding ligaments and muscles (Labriola et al., 2004). In many motion ranges, the rotator cuff muscle group (supraspinatus, infraspinatus, subscapularis, and teres minor) plays the largest role in active stability (Labriola et al., 2004). However, towards the end ranges of motion, the two acromioclavicular, four sternoclavicular, and six glenohumeral ligaments further assist in stability (Labriola et al., 2004). This combination of muscles and ligaments can be used to main stability or generate motion and force. The ability to complete these tasks is impacted by posture, the motion of interest, and external forces applied to the joint (Chopp et al., 2010; Wickham et al., 2010) and highlight the challenge of interpreting shoulder function.

While useful for reaching and other upper extremity motions, the large range of motion and the musculoskeletal arrangement of the shoulder region creates an area for MSD. The lack of skeletal contribution to stability results in increased demands on the other ligamentous and muscular structures such as the rotator cuff muscle group. Therefore, dislocation and instability are common, and with the increased demands, MSD such as impingement syndrome or rotator cuff tears can arise.

Shoulder MSDs impact range of motion, strength, and overall ability to complete an individual’s ability activities of daily living, which can also negatively impact quality of life (MacDermid et al., 2004; Michener et al., 2008; Vidt et al., 2016). While age may play a small role in MSD occurrence, repetitive use, cumulative loading, and overhead postures are required in the workplace and many of the functions performed in daily life. Increased vulnerability and injury severity can be associated with a lack of strength and rest of the shoulder (Kelley et al., 2013). The combination of intrinsic and extrinsic risk factors for injury makes the shoulder a common site for MSDs.

2.1.3 Relationships between the Spine and Shoulder

Concerning occupational and MSD research, many prevention, intervention, and management efforts have targeted the low back because of the substantial portion of reported injuries occurring in this region (Burgess-Limerick, 2003). However, many manual materials handling (MMH) tasks such as repetitive lifting, pushing, pulling, and overexertion also address and raise concern for other regions in the body; Yeung et al. (2002) reported that 85% of lower back symptoms are associated with disorders in other body regions. In MMH tasks, the shoulder is another commonly injured body region (Yang et al., 2020). The fact that large muscle groups in both the shoulders and back contribute to lifting and other MMH tasks, past studies have shown a transfer of loading or risk level from one joint to others during different lifting conditions (Gagnon & Smyth, 1987) and in nurses during patient handling tasks (Belbeck et al., 2013). Therefore, it is reasonable to assume that the low back and shoulder relationships are both structural and functional.

The spine and shoulder are connected anatomically. While the cervical and thoracic regions demonstrate the clear musculoskeletal connection between the spine and the shoulder, the lumbar region has muscular connections as well (Figure 2). Large superficial muscles of the back such as the latissimus dorsi, trapezius, and rhomboid groupings have origins on the thoracic and lumbar spine with insertions into the humerus, clavicle and scapula (Figure 2).

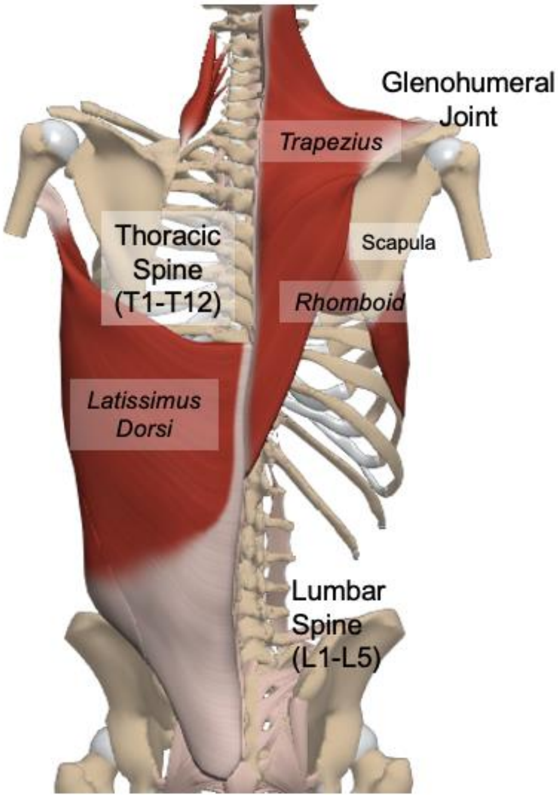

Figure 2. Anatomical depiction of a musculoskeletal relationship between the shoulder and thoracolumbar spine as highlighted by adjoining structures such as the scapula, latissimus dorsi, and trapezius. Image created on January 25th, 2021, using Primal Pictures. Primal Pictures Ltd. (2006). Anatomy.TV. London, UK: Primal Pictures Limited.

A commonly described anatomical relationship between these inferior regions of the spine and shoulder is the scapula-thoracic relationship. The scapula-thoracic relationship functions as a liaison between thoracic spine curvature, scapular motion, and shoulder function (range of motion and strength) (Barrett et al., 2014; Kebaetse et al., 1999). For example, the positioning of the scapula has implications for both thoracic and shoulder motion (Crosbie et al., 2008; Imagama et al., 2014). However, the positioning of the thoracic region is equally related to the lumbar region through the thoracolumbar junction (Bernhardt & Bridwell, 1989). Therefore, the curvature and range of motion of the thoracic region and the lumbar regions are a function of the musculoskeletal anatomical contributions of both regions (Barrett et al., 2014). Likewise, arm positioning and upper extremity motions influence the pattern of trunk muscle activation as described by Siu et al., (2016). Through cross-correlations, it was determined that arm positioning was impacting latissimus dorsi trunk pairings, highlighting the anatomical connections described earlier (Siu et al., 2016). Similarly, arm positioning also impacts kinematic patterns, where maximum spine angles were highest when arms were hanging to the floor (flexion), abducted to 90° (axial twist), and either hanging to the floor or crossed over the chest (lateral bend) during range of motion sequences (Schinkel-Ivy et al., 2014).

Biomechanically, external loads and internal loads are experienced by both regions in many movements and motions. (Marras & Radwin, 2005). Physical ergonomic risk factors performed during work (e.g., lifting, repetitive work, working above shoulder level) are associated with both low back pain (Norman et al. 1998) and shoulder pain (Pope et al. 2001; van Der Molen et al., 2017). Previous attempts to mitigate loads and resultant MSD experienced by these regions have investigated alternate motions to reduce compressive forces. For example, instead of lifting, pushing and pulling can be adopted as well. While such interventions resulted in reduced compressive forces at the low back (De Looze et a1., 1995), there were still marked increases in compressive loads at the shoulder owing to the line of action of the push or pull. In addition to the transfer of forces between these two regions, Nussbaum et al. (1999) reported antagonistic co-contraction of trunk flexor and extensor muscles during such lifting, reaching, pushing and pulling motions. Studies investigating the biomechanical tradeoff between these two regions assist in determining additional mechanisms beyond force, repetition, and posture (Belbeck et al., 2014). These studies' results and the known anatomical connection highlight the potential concern of transferring demands between these two regions, despite efforts to mitigate biomechanical demands in one region.

Research beyond anatomical and biomechanical mechanisms also highlights similarities in the role of psychological, environmental, organizational, and other factors (e.g., pain, fear, and job demands) in LBP, shoulder MSD and other MSD more broadly (van der Windt et al., 2007). In the general population, biophysical factors such as age, limb dominance, previous injury, range of motion and strength, have all been reported as risk factors for both spine MSD (LBP) and shoulder MSD (rotator cuff tear) (Ludewig & Braman, 2011; Yamamoto et al., 2010). In the working population, there are again parallels of physical, psychosocial, and organizational factors between spine and shoulder MSD. For example, the established biomechanical and ergonomic risk factors of load/force, posture, repetition, and rest are considerable for both LBP (Kerr et al., 2001) and shoulder MSD (van de Molen et al., 2017). Likewise, psychosocial factors like job demands, job stress, and job control all contribute to risk of MSD for both regions (Jansen et al., 2004). The overlap in anatomy, structure, function, and risk factors demonstrate a biopsychosocial relationship between the shoulder and the spine.

2.2 Biophysical Factors

MSDs are multifactorial in nature. It is well established that multiple factors under the Biopsychosocial model can play a role in MSD risk and severity. Particularly under a biophysical lens, sex, age, and body composition are examples are potential factors that may modify the risk of shoulder and spine MSD. Through their direct impacts on structure and consequential impacts on function these factors are commonly captured in relation to shoulder and spine musculoskeletal anatomy.

2.2.1 Sex & Age

The biological differences that exist between males and females are non-modifiable factors that assist in understanding outcomes of shoulder and spine related MSD (Tosi et al., 2005). Prevalence studies have highlighted higher prevalence of upper extremity MSD for women (Treaster & Burr, 2004) along with higher amounts of musculoskeletal pain (Rollman, & Lautenbacher, 2001). While there are biopsychosocial mechanisms at play for the prevalence of MSD, there are distinct sex differences in structure and function that can not be overlooked. For example, structurally, the glenoid anatomy differs in size and shape with males having greater dimensions and a rounder shape compared to the smaller oval shape of the female glenoid (Checourn et al., 2002; Churchill et al., 2001; Merrill, Guzman, & Miller, 2008). Similarly, males on average have larger vertebrae at the cervical, thoracic, and lumbar levels (Amores et al., 2013; Bastir et al., 2014; Hou et al., 2012). The anatomical differences between males and females are determinants for musculoskeletal function.

These sex specific structural differences are linked to important measurable outcomes such as anthropometry, posture, and motion. Anthropometry data highlights key differences important for understanding MSD risk along with design and accommodation. On average, females have a shorter length measures such as stature, acromial height, hip height and leg length and wider hips compared to males (Kroemer et al., 2010). Range of motion data has highlighted that on average, female have greater joint range of motion compared to males (Peharec et al., 2007; Roy et al., 2009; Soucie et al., 2011). However, specifically at the lumbar spine level minimal differences in lumbar spine mobility have been demonstrated between males and females in three planes of motion (Flexion/extension, Lateral bending L/R, and axial twist)

(Dvorak et al., 1995). The differences in such anthropometric and functional characteristics also have interactions with chronological changes to the body.

Chronological age is another non-modifiable factor is commonly associated with structural changes. For example, bone mass and bone density typically decrease with an increase in chronological age resulting in decreased structural strength of structures like the vertebral body (Ferguson & Steffen, 2005). Such changes also interact with degenerative conditions like osteoporosis. Likewise, muscle strength and muscle force generation often decrease with age and potential biological mechanisms for this include may include decreases in the pennation angle or muscle atrophy (Singh et al., 2011). These musculoskeletal changes are furthered by changes to accessory structures like loss of elasticity in ligaments (Ferguson & Steffen, 2005), and loss of proteoglycan content in intervertebral discs subsequently impacting joint function and response to stress (Adams, McNally, & Dolan, 1996). Changes to the content of the intervertebral discs, impact overall hydration in turn altering the mechanical responses of the disc and increasing risk of injury (Ferguson & Steffen, 2005). Functional implications of the described age-attributed changes are also demonstrated in posture and function for the shoulder and spine. Where both muscle and skeletal changes can alter the curvature of the spine, such that thoracic kyphosis increases with age (Boyle et al., 2002; Hinman, 2004). In addition, movement patterns in certain ranges of motion like shoulder abduction are altered increasing risk of discomfort and shoulder pain (Overbeek et al., 2020). The structural and functional changes of the shoulder and spine while important considerations for understanding MSD are not necessarily the only mechanisms at play.

While there are many structural changes that may occur that can alter function of the musculoskeletal system of the spine and shoulder, it is important to consider that some of these age-related changes are also related to other biopsychosocial factors. Van Eerd and colleagues reported a scoping review on aging and MSD and found no direct correlation across the literature (Van Eerd et al., 2016). The authors highlighted that mitigating age related stereotypes were important for maintaining the aging work force. Therefore, while important considerations, age related should be interpreted with a holistic view of an individual and what other factors play a role in the risk of MSD. For example, body composition represents a modifiable factors associated with both sex and age that may play a role in understanding musculoskeletal function and associated risks to MSD (Cavuoto & Nussbaum, 2013).

2.2.2 Body Composition & Obesity

The topic of body composition is important for many chronic conditions and in particular for MSD, as obesity is often a reported co-morbidity (WHO, 2016). Obesity and unhealthy body weight have increased in our populations over the years, with a worldwide estimate of over 600 million people being classified as obese in 2016 (Bleich et al., 2008; de Mutsert et al., 2013; WHO 2016). Obesity's associations with LBP (Shiri et al., 2013) and other MSD (Kortt & Baldry, 2002) highlight the importance of considering body composition in its interaction with structure and function of the thoracolumbar spine and importantly for the prevention and management of MSD.

The relationship of obesity and MSD is a function of the additional demands placed on the musculoskeletal system. Work-related studies of LBP and other musculoskeletal disorders (MSD) highlight the consideration of body weight, mass, and obesity in MSD (Cavuoto & Nussbaum, 2013; Janssen, 2011). Individuals with higher body mass index (BMI) have been found to have decreased spine flexibility and increased trunk stiffness (Gilleard & Smith, 2007; Hue et al., 2007). Moreover, their joint profiles of ranges of motion are smaller and there is potential for reduced muscular strength (Xu et al., 2015; Katzmarzyk et al., 2000). Increased mass and regional distributions of mass can also impact functional capacity. For example, at the shoulder, endurance times to complete upper limb tasks have been negatively associated with obesity (Cavuoto & Nussbaum, 2013). Unsurpsingly, this is also resultant in earlier fatigue due to accommodating the increased weight (Cavuoto & Nussbaum, 2013). With the external mass of obesity creates loads, there are resultant increases in internal loading onto body tissues, as reported by higher mass of the torso generating greater moments about the lumbar spine (Xu et al., 2015). These structural considerations may play a role in the strong association between obesity and MSD.

LBP and other MSD associated with obesity ultimately have negative impacts on work capacity (Gilleard & Smith, 2007; Hue et al., 2007) and productivity (Gates et al., 2008; Morris, 2007). The added mass, joint moments, and reduced ranges of motion create biomechanical demands posing a greater risk of MSD, which has been documented in common injuries including those of the spine and shoulder regions (Capodaglio et al., 2010; Hue et al., 2007). As a result of the biomechanical demands posed onto the musculoskeletal system from obesity and larger weight create a perfect interaction for LBP, reflected by the high rates of work absenteeism due to MSD by obese workers (Gu et al., 2016; Lier et al., 2009; Pandalai et al., 2013; Tsai et al., 2009). While a complex factor, body composition may be a factor that is both modifiable and should be accounted for in addition to sex or age when investigating shoulder and spine MSD.

2.3 Psychological Factors

A factor thought to influence long-term morbidities such as chronic pain, MSD, or recurrent injury is fear of movement, reinjury and activity. One of the most influential models to capture this factor is the Fear-Avoidance Model (Figure 3) developed by Lethem et al., and later adapted by Vlaeyen et al. This model has been validated for a variety of experimental and prognostic models of pain and injury (Vlaeyen et al., 2000; Leeuw et al., 2007). This model is a representation of the impact of beliefs on behaviour where cognitive, emotional, and behavioural responses are importantly considered. As a process-oriented approach, pain, a biologically relevant signal, can be linked with an initial cue (even if it is neutral), which in turn elicits protective functions like increased attention and arousal. The cue and the protective functions may result in fear which then would provoke immediate escape or removal from a situation to reduce or prevent the biological signal from reoccurring (Vlaeyen, Crombez, & Linton, 2016). This fear which may include fear of pain, movement, or reinjury, then results in avoidance of activities (Miller, Kori, & Todd, 1991). Since its development as a hypothetical model, it has developed into operational and empirical use in LBP and some shoulder MSD contexts, due to its experimental (Trost et al., 2011) and clinical backings (Eccleston, Williams, & Rogers, 1999). The credibility of this model has enabled it to be adopted by multiple disciplines due to its physical and psychological constructs.

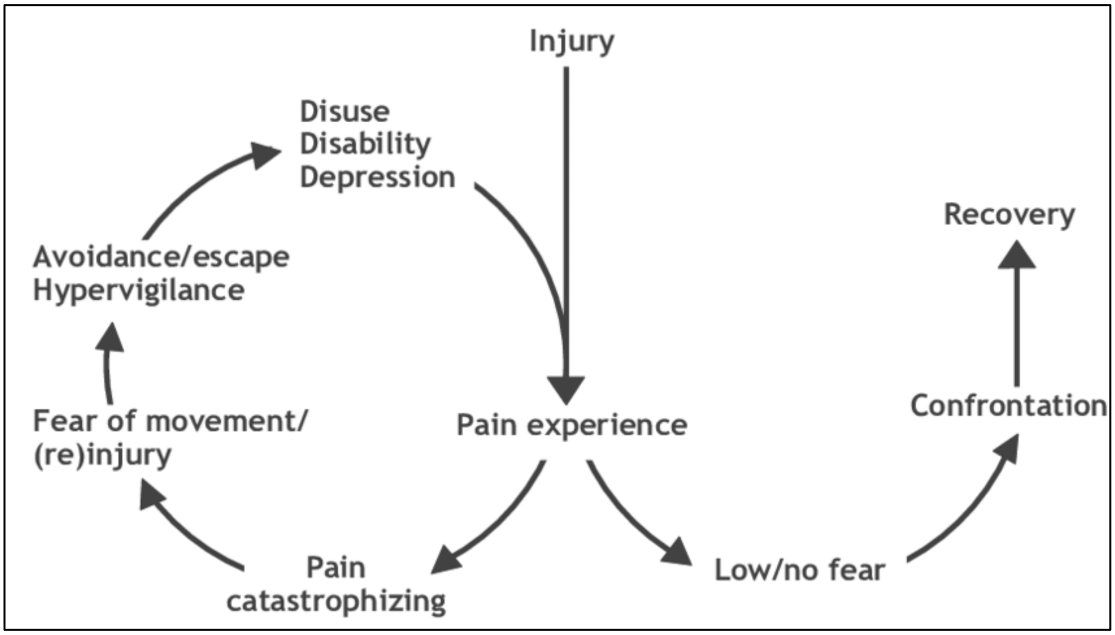

Figure 3. Fear-avoidance model reproduced from Lethem et al. (1983) retrieved from Wideman, T. H., Asmundson, G., Smeets, R., Zautra, A. J., Simmonds, M. J., Sullivan, M., Haythornthwaite, J. A., & Edwards, R. R. (2013). Rethinking the fear avoidance model: toward a multidimensional framework of pain-related disability. Pain, 154(11), 2262–2265. https://doi.org/10.1016/j.pain.2013.06.005 Figure retrieved from IASP with permission for reuse license #: 5087790775895.

The current state of evidence around the fear-avoidance model supports its position in understanding LBP and shoulder MSD. Measurements of fear-avoidance such as the Fear-Avoidance Beliefs (Waddell et al., 1993) questionnaire and Tampa Scale for Kinesiophobia (Miller, Kori, & Todd, 1991) were developed for individuals with varying chronicity of LBP (Fritz et al., 2001; Rainville et al., 2011; Swinkels-Meewisse et al., 2003; Waddell et al., 1993) and since further explored in shoulder pain patients (Kromer et al., 2014; Riley et al., 2019; Sindhu et al., 2012). Many studies have determined moderate to high test-retest reliability and strong relationships to activity avoidance and disability (Kromer et al., 2014; Mintken et al., 2010), and therefore fear-avoidance has strong relationships with the presentation of symptomology and disability (Pincus et al., 2006; Wertili et al., 2014). For example, individuals with high fear-avoidance more often report higher intensity of pain during assessment (Crombez et al., 1996; Martinez-Calderon et al., 2017; Nordstoga et al., 2019; Trost et al., 2011). Some studies report fear-avoidance individuals have performed poorer than low fear-avoidance individuals on physical assessments like raising the arm or performing trunk flexion and extension (Trost et al., 2011). Osumi and colleagues (2019) have reported that Kinesiophobia modulates the forward and return of lumbar bending movements in individuals with chronic low back pain and Nordstoga et al (2019) have reported an association with FABQ and velocity of trunk flexion. In a more recent study by Knetchle et al. (2021) fear-avoidance was related to lifting patterns (e.g., simulated MMH tasks) in a cohort of pain-free adults. Therefore, the relationships between fear-avoidance and disability highlight that there are multiple pathways to be understood in MSD and can be interpreted with asymptomatic individuals as well as symptomatic individuals.

Important in bridging this model with biophysical studies of spine and shoulder MSD is the consideration of interpretation and attention around pain (de Baets et al., 2019; Melzer et al., 2019). The interpretation of pain or MSD recovery in daily life can be non-impactful or catastrophic (Sullivan, Bishop, & Pivik, 1995), which explains why some individuals will resume activities, while others may determine the pain to be a serious pathology with little control over the outcome (Sullivan et al., 1995; Seminowicz & Davis, 2006). The attention and interpretation given to pain can further perpetuate the fear responses and expand the fears to more activities (Vlaeyen et al., 2000). Moreover, some individuals may develop misinterpretations or myths about pain, such as specious beliefs like pain are always linked to signal tissue damage or that pain can only be treated medically (Sullivan et al., 1995). While common biopsychosocial approaches to pain, disability, and MSD disaffirm these myths, they can still be underlying assumptions for many individuals experiencing pain, MSD, and resulting disability which are important considerations in the prevention, rehabilitation, and management of MSD.

2.4 Measurement and Assessment

There are various tools and techniques for measuring shoulder and spine function and psychological factors for MSD. These tools range in cost, complexity, and invasiveness in practice, all of which contribute to their use and applicability for understanding musculoskeletal function and dysfunction. Some of the most common field techniques include anthropometry, goniometry, inclinometer, dynamometry, and assessment of spinal curvature, which can provide measurements of body proportions, ranges of motions, strength. The benefits of cost, ease of use, interrater reliability, and ability to use in the field are among the reasons these techniques continue to be at the forefront for assessing, diagnosing, and measuring musculoskeletal disorders. Recognizably, there are benefits and limitations to each of these techniques as they apply to the shoulder and spine.

2.4.1 Range of Motion

The measure of joint range of motion is a common assessment of function for both the spine and the shoulder. ROM measures the extent of movement of a joint, about a set axis (joint centre of rotation) and is typically measured in degrees (Norkin & White, 2016). About the glenohumeral joint, typically, the motions captured in the frontal, sagittal, and transverse plan are captured, yielding measurements of abduction, flexion/extension, and internal/external rotation, respectively. About the spine, typically, ROM can be assessed at each region, cervical, thoracic, and lumbar. Owing to the relationship between the thoracic and lumbar region, measurements of the thoracolumbar spine are also often captured, especially for LBP and other clinical populations. ROM measurements provide a baseline of joint function, which can be useful in predicting disability and pain development (Michel et al., 1997), assisting in injury prevention or rehabilitation protocols and the evaluation of intervention and recovery (Gajdosik & Bohannon, 1987). While common to practice in manual and clinical therapies such as physiotherapy, orthopedic medicine, and chiropractic medicine, these measures are also found in applied sport settings, e.g., athletic therapy (Borsa, Laudner, & Sauers, 2008) and fitness assessment (ACSM, 2013; Frost et al., 2013); and applied occupational settings, e.g., ergonomics (David, 2005; Lowe, Dempsey, & Jones, 2019)., functional capacity evaluations (Parks et al., 2003) and return to work protocols (Faber et al., 2006; Staal et al., 2002). These measures are widely practiced and are important measurements in spine and shoulder MSD.

Primarily, ROM measures are performed by two methods with a variety of tools and devices for measurement. First, passive measurements are assisted movements completed with an external force applied by the observer (Gajdosik & Bohannon, 1987). While passive ROM references structural joint limits, literature has highlighted that it can be difficult to obtain high inter-rater reliability due to the variation in external forces applied (Boone et al., 1978; Gajdosik & Bohannon, 1987). Therefore, the second method of active ROM is often preferred, where active measures are movement performed solely by the individual without any assistance (Gajdosik & Bohannon, 1987). While there are various tools to capture ROM, some common tools include goniometers and inclinometers (Fitzgerald et al., 1983; Hayes et al., 2001; Johnson et al., 2012), among more novel tools such as smartphone-based applications (Milani et al., 2014). The most common, cost-effective, and feasible methods still widely used are goniometry and inclinometer. Norkin and White (2016) provide reference text to capture shoulder and spine ROM using the universal goniometer and inclinometer. The measurement properties of these methods and tools provide them as valid and reliable assessments for both the spine and the shoulder.

Boone et al., 1978 and Riddle et al., 1987 were some of the initial authors to describe the measurement properties of active and passive shoulder goniometry. The authors reported good inter-and intra-rater reliability for shoulder measurements compared to lower extremity motions (Boone et al., 1978; Riddle et al., 1987). Riddle et al. reported on the measurement properties of passive measurements and found high ICC for inter-rater reliability for shoulder flexion and abduction, but poor reliability for extension (Riddle et al., 1987). While these methods continue to be used in practice, approaches have been adopted to cater to clinical populations. For example, supine and sitting positions in comparison to upright standing. Sabari et al., highlighted that while both sitting and supine measurements have high inter-rater reliability, they could not be reliably compared to one another (Sabari et al., 1998). Even though goniometry has been determined to be reliable, consistency and transparency in reporting of ROM measurements is necessary for shoulder measurement.

Measurement of the thoracolumbar spine ROM is typically measured as functional ROM rather than individual joint ROMs. Inclinometry assists in measuring regional (thoracic versus lumbar) and collective (thoracolumbar) ROM. In the sagittal and frontal planes of motion, inclinometry placed at palpable levels of the vertebrae, measure angles of ROM with respect to gravity’s direction. Inclinometry validation began in the 1970s, where the correlations between measures were assessed using thoracic and lumbar radiographs (Mayer et al., 1984; Portek et al., 1983; Reynolds 1975). It has since been determined to be a for spine reliable and valid measure for spine flexion and spine extension for ROM (Saur et al., 1996). Similar to goniometry, the appropriate and consistent placement and calibrations are important considerations towards its use for the thoracolumbar region (Norkin & White, 2016).

Despite the portability and feasibility of the aforementioned tools, there are limitations of goniometry and inclinometry that should be considered in the assessment. The measurement properties of both tools vary based on factors of time, instruction and experience, and the joint being observed (Kolber et al., 2012). Goniometry requires an observer to have accurate palpation, landmarking, and estimation of a joint center while concurrently using both hands to maneuver the goniometer. As such, stabilization to the appropriate joint center can be difficult, resulting in an increased error (Bovens et al., 1990; Gajdosik & Bohannon, 1987; Kolber et al., 2012). Inclinometry, while both hands are still required to affix the device to the individual, the use of gravity serves as a reference point. However, the determination of this reference point requires reliable calibration, which can be easily affected based on the positioning of the device (de Winter et al., 2004; Kolber et al., 2011). Consideration of these factors is critical for determining valid and reliable measurements of any joint range of motion.

2.4.2 Spine Curvature

Quantitative assessment of spine curvature is a useful clinical tool for determining posture and pathology, monitoring progression and rehabilitation, and for orthopedic intervention. Thoracic and lumbar spine curvature can be assessed non-invasively through measurement of the natural curves of the body. Two-dimensional (2D) analyses are commonly used in practice and clinical assessment due to their feasibility, low cost, and measurement properties between professionals (Vrtovec et al., 2009). These 2D methods have limitations in their validity to the morphological, anatomical, and structural characteristics and, like any manual assessment, also have considerations for use within and between practitioners (Willner, 1981). Historically, X-ray imaging or other three-dimensional (3D) assessments such as computed tomography and magnetic resonance imaging have been considered as gold standards (Salisbury & Porter, 1987; Vrtovec et al., 2009). However, concerns such as radiographic exposure, costs, and feasibility limit their use in day-to-day practice. Therefore, a variety of devices have been developed for the 2D assessment of thoracic kyphosis and lumbar lordosis (Fortin et al., 2011). Examples include the acrometer (D'Osualdo et al., 1996), Debrunner's Kyphometer (Ohlen et al., 1989), the flexi-curve (Milne & Lauder, 1974), Moiré topography (Goldberg et al., 1981), the spinal pantograph (Willner, 1981), the inclinometer (Mellin, 1986), and the spinal mouse (Mannion et al., 2004). The flexi-curve is a tool that captures indices of curvature for both the thoracic and lumbar region and is widely used in current practice and research (de Oliveira et al., 2012).

The flexi-curve ruler is a pliable metal ruler outfitted with plastic that can be moulded along the skin surface of the spine of an individual producing the shape of the region. The design of this tool renders it portable and applicable to many populations. Previous studies have reported the flexi-curve to be valid based on clinical imagine gold standards. Hart and Rose determined that the flexi-curve was a valid clinical assessment of lumbar spine curvature, reporting high agreement with X-ray images of the angles created from the vertebral bodies and high interrater reliability (ICC= 0.97) (Hart & Rose, 1986). The flexi-curve also had good validity in an assessment of both thoracic and lumbar regions when compared to X-rays with correlations of (r = 0.72; r = 0.60) for the thoracic and lumbar curvatures, respectively (de Oliveira et al., 2012). In a systematic review of tools to measure kyphosis, the flexi-curve had strong levels of evidence to support its validity (Barrett et al., 2014). However, a more recent study by the same authors also highlighted that despite the strong relationship between the flexi-curve and X-ray images, there was lower agreement, and therefore findings should always be interpreted with caution (Barrett et al., 2018). As with many assessment techniques, the validity of this tool is highly dependent on the observer.

Given the importance of the observer in spinal curvature assessment, both intra- and inter-rater reliability have been studied for the flexi-curve. With respect to intra-rater reliability, Lovell et al. reported higher ICC values ranging from 0.73 through 0.94 compared to inter-rater reliability, where ICC ranged from 0.41 to 0.54 (Lovell et al., 1989). However, in a study on inter- and intra-rater reliability for the measurement of kyphosis in women with normal and rounded backs, the reported intra- ICC ranged from 0.65 to 0.93, and inter- ICC was 0.87 (Ludon et al., 1998). Barrett et al. also found a strong level of evidence in a review of tools that supported very high inter-rater reliability for the flexi-curve (Barrett et al., 2014). In a study on novice users, Hinman determined good reliability between trained graduate student observers, with higher validity for the index of kyphosis compared to lordosis (Hinman, 2004). Despite strong evidence of reliability, the importance of proper landmarking and the use of at least three trials for each measurement are important considerations in the use of the flexi-curve for spinal curvature assessment (Ludon et al., 1998).

2.5 Models and Frameworks

Throughout the literature, there are a variety of models, frameworks, and theories for understanding the complexity and factors that impact MSD. While each model, framework and theory support specific research domains or research questions, this current body of research emphasizes integrating research disciplines for understanding considerations in MSD. Therefore, two models that have a strong overlap in definitions and are widely used in spine and shoulder

MSD research include the Biopsychosocial Model and the International Classification of Functioning Model.

2.5.1 The Biopsychosocial Model

Health psychology has been described as an intersection of biology, psychology and sociology to understand health elements and illness (APA, 1999). While this discipline seeks to understand a multitude of factors relating to the person and their environment, similar to some of the models discussed above; Health Psychology as it relates to MSD research excels in understanding the personal or psychological factors that influence a given health outcome. With great recognition for the relationship between health, behaviour, and work, there have been branches of Health Psychology that directly address understanding musculoskeletal disorders, one example being the field of Occupational Health Psychology, which emphasizes understanding how a worker's experience affects their overall health (APA, 1999; Ganster & Rosen, 2013). According to the American Psychological Association, a healthy workplace can emerge from health promotion, employee assistance, flexibility, prevention of work stress, and health and safety (APA, 1999). Therefore, it is understandable that the approaches used in occupational health psychology and health psychology more broadly would improve the ability to research, prevent, and understand shoulder and spine musculoskeletal disorders.

The biopsychosocial model depicts the integration of the biological, psychological, and social processes that affect health or illness (George & Engel, 1980). It captures a holistic approach which is in contrast to traditional biomedical models that suggest disease, illness, or disorders are rooted in biological or physiological processes. The biopsychosocial model is important as it broadens the scope in which MSD can be examined in research, clinical, and occupational practice, and it adopts both circular and structural causality, which best characterizes the influence of function as it relates to health. For example, the fear-avoidance model is a feedback loop that demonstrates how a response to pain can result in behaviour change and health outcomes which could, in turn, may impact movement and function. Much of the knowledge around the biomechanics of human motion may be interpreted as structural causality where an event such as a large amount of force (trauma) results in the deformation of tissue (injury). However, the experience of injury, the personal response, and the environment all play a role in highlighting the importance of both circular and structural causality in interpreting human function.

2.5.2 International Classification of Functioning (ICF) Model

The interaction of function, health, and disability is critical for understanding MSDs, specifically risk factors and mechanisms. The World Health Organization highlighted that many models of health and illness were polarized to medical or social models lacking integration of multiple factors (World Health Organization, 2001). To integrate these factors, the WHO proposed a model, called the International Classification of Functioning (Figure 4). This model since become a standardized tool for understanding regarding function, health, and disability (Ustun et al., 2013). Depicted in Figure 4 is the ICF Model, which highlights the outcomes of function, activity, and participation as an interaction of a health condition with contextual factors. The definition for each of the model constructs as described by WHO are: "*Body Functions are physiological functions of body systems (including psychological functions). Body Structures are anatomical parts of the body such as organs, limbs and their components. Impairments are problems in body function or structure, such as a significant deviation or loss. Activity is the execution of a task or action by an individual. Participation is involvement in a life situation. Activity Limitations are difficulties an individual may have in executing activities.*

Participation Restrictions are problems an individual may experience in involvement in life situations. Environmental Factors make up the physical, social and attitudinal environment in which people live and conduct their lives." (World Health Organization, 2001).

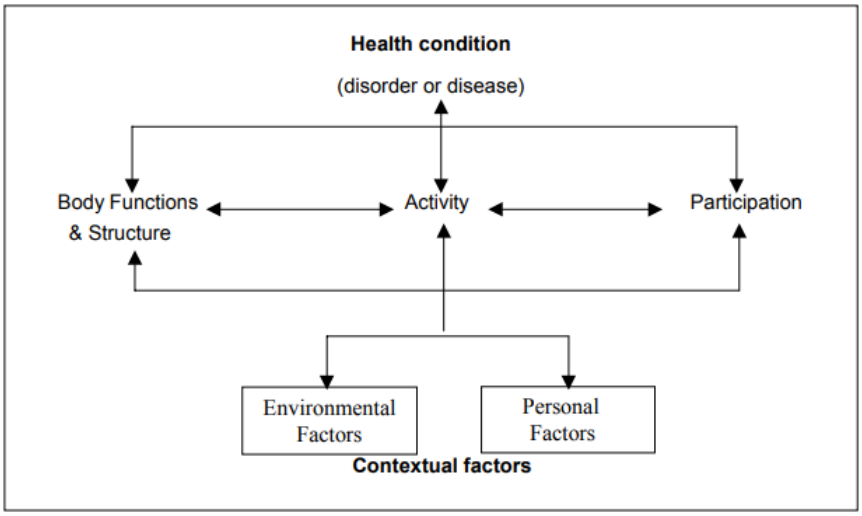

Figure 4. International Classification of Function (ICF) Model Conceptual Framework, highlighting the multifactorial biopsychosocial components of health condition or disease. In this document shoulder and spine MSD would be the health condition of interest. Reproduced from the World Health Organization (2001).

Specific applications of this model have been used for a variety of health conditions, including MSD of the shoulder (Roe et al., 2013) and spine (Bombardier 2000). For example, an relevant application of this model to the MSD of interest in this dissertation is the ICF Core Set for Low Back Pain. Within this core set, the dimensions of symptoms, function, general well-being, work disability and satisfaction with care were suggested (Bombardier 2000; Ciezo et al., 2004; Deyo et al., 1998). As such, components of body function and structures, such as the previously described spinal range of motion and curvature techniques, and psychological factors have been included to understand function and dysfunction (Bombardier 2000). These components and categories are consistent with many cross-sectional and longitudinal studies that have raised the variety of risk factors associated with MSD. In a systematic review of measures used for shoulder pain, more concepts related to activities and participation were used compared to concepts of body function and structures (Roe et al., 2013).

The WHO ICF model is largely formed upon the biopsychosocial model. Using a multisystem approach such as one of these adapted models allows research to recognize the influence that multiple factors have within and between one another to affect human function. Merging the disciplines of Health Psychology and traditional human movement science such as Biomechanics and Ergonomics is, therefore, a logical integration. A foundational value of this model is that it appreciates the interconnectivity and correlation of the three core facets (biological, psychological and, social), recognizing the complexity in capturing human behaviour (Suls & Rothman, 2004). By virtue of this complexity, it is necessary that robust human movement research must be conducted with multiple methods and indicators.

2.6 Summary

The reviewed literature and founding theoretical models lend useful perspectives and approaches to understanding musculoskeletal function and MSD. Each model and approach provide the potential for a diverse and interdisciplinary approach to answering questions like *why* or *how* an MSD occurs. The field of clinical biomechanics lends strengths in interpreting anatomical, biological, and physical modifiers of MSD. Occupational Biomechanics and Ergonomics blend these physical modifiers with the addition of human factors and encompassing the surrounding environment like the workplace. Finally, health psychology provides the intersection of the biological, psychological, and social factors towards understanding an MSD. Acknowledging expertise from each discipline, the research questions, methods, and tools developed in this dissertation address prevention, assessment, rehabilitation, and management of spine and shoulder MSD through an interdisciplinary lens of multiple methods.

This review of the literature positions shoulder and spine MSD as leading health-related burdens and demonstrate anatomical and biomechanical relationships between these two regions. There is a gap, however, in detailed reports of work-related lost time injuries of the specific shoulder and spine regions which could identify whether these regions are decreasing in rates over time and if there are priority sex/age groups that should be targeted. From the anatomical and biomechanical perspective, there is little evidence of the relationships from a range of motion and postural perspective. Equally, few studies demonstrated effective analyses to capture relationships between and within continuous outcome measurements of these regions. Investigating the shoulder-spine relationship through applied dataset (injury rate) and functional (ROM and posture) research can improve measurement and assessment of these two regions. Further, a biopsychosocial approach highlights that measurement must also consider biophysical and psychological factors for appropriate measurement of the musculoskeletal system. While the known ramifications of injury, fear-avoidance, and obesity are established with clinical populations. Such parameters are often negated in asymptomatic adults who participate in biomechanical research. As such interpreting shoulder-spine function rather than dysfunction requires the following studies to establish considerations of measurement and modifiers.

Chapter 3 Review of Recent Data: Shoulder and Spine Loss Time Injury Claims in Canada

3.1 Overview

As highlighted in the review of the literature the structural integration of the spine and shoulder, through musculoskeletal anatomy, poses a rationale for understanding relationships between these two regions and the factors that may be related to an MSD of either region. Practical evidence including common risk factors and injury rates additionally highlight that there may be basis to interpret relationships and factors between these two regions. In Canada, the low back continues to remain one of the number one sites of pain (LBP), and the number one region for injury, specifically in the workplace. The shoulder, however, commonly appears in the top five regions for injuries in the workplace. While this is unsurprising given many shared occupational/ergonomic risk factors, there is a sparsity in the reporting of injury claims at a detailed body region level. Supported by the review of the literature, the purpose of this chapter is to further the motivation of investigating relationships between the shoulder and the spine by describing Canadian loss time injury claims of the shoulder and spine regions.

3.2 Introduction

Work-related injuries are large societal burdens both from the societal lens of economics and the individual lens of quality of life. According to 2019 highlights from the Association of Canadian Worker's Compensation Boards (AWCBC) there were 271, 806 lost time claims from work-related injuries (AWCBC, 2020). It has been estimated that a work-related injury can equate to an average loss of 7.9 workdays per month (WSIB, 2019) and an economic burden of over two million dollars depending on the jurisdiction (example Ontario) (WSIB, 2019). Individuals who sustain work-related injury are at risk for complications in activities of daily living, return to work, and other ramifications of disability and lost time in the workplace. As highlighted by Takala (2014), fostering safe work is imperative to prevent work-related injury where workers can maintain their function and health.

Across many jurisdictions, there are similarities in the nature of injury and region of the body in work-related lost time claims. Over the past decade, the most common region of the body reported for work related injuries is the back, accounting for over 20% of all lost time claims in 2019 (AWCBC, 2020). The shoulder was reported within the top three body regions representing approximately 7.5% of all lost time claims (AWCBC, 2020). The high amount of lost time claims attributed to the back and the shoulder are likely due to the necessity of these two regions to complete occupational tasks across sectors and industries and are challenging to prevent given their complex etiology. Respective to these two regions, the highest reported nature of injury includes injuries and disorders to muscles, tendons, ligaments and joints. Signifying the continued global burden of MSDs (Cieza et al., 2020), the back and the shoulder remain two important areas for prevention and management of injury. Given that low back injuries dominate the loss time claims across many jurisdictions in Canada and that the shoulder region is often within the top 5 regions of claims (WSIB, 2019; WorkSafeBC 2019) it is important to understand if there have been any annual changes in these lost time claims and to determine the role of non-modifiable factors like sex and age.

There are mixed trends with respect to frequency of lost time claims when accounting for age and sex, where co-morbidities, disease progression and proportion of the labour force are important confounders (Laflamme & Menckel, 1995; Salminen, 2004). Breslin and colleagues reported a smaller proportion of adolescent lost-time claims compared to adults (Breslin et al., 2003). Where, older workers (age 35+) were reported to have more musculoskeletal injuries, compared to younger workers (Breslin & Smith, 2005) and when the older age groups were further stratified in a later study, Smith et al. found that middle-aged workers (35 – 44 years old) were at greatest risk for MSDs compared to both older and younger workers (2013). Despite the increasing proportion of lost time claims with older workers, a systematic review found that age is not an independent risk factor for MSDs; rather there is stronger evidence that the increased prevalence of MSD lost-time claims in this cohort may be due to the demands of work exceeding the capabilities of older workers (Okunribido et al., 2011). In reference to sex differences, work related injury rates for males are reported to be three times higher than for females (Salminen, 2004) and for some occupations males also experience a higher rate of MSD lost time claims (Macpherson et al., 2018). Sex differences in injury risk may be due to differences in anthropometry, strength, fatigue, motor control and perceived pain and stress between men and women (Côté, 2012). However, much like the factor of age, the opposing perspectives on whether work injuries are sex/gender differences are also likely due to various confounding work-related factors including the differences in job type, associated work environments, and organizational structure (Breslin & Smith, 2005). Nonetheless, understanding the sex and age-related differences and similarities in work related injury claims are important for tailoring injury prevention and management in the workplace.

For the last three decades, there has been an overall decrease of annual lost time claims across Canada, yet the number of reported musculoskeletal lost time claims has been consistent and are the largest contributor to lost time claims in Canada (AWCBC, 2020). Of the workplace musculoskeletal injuries, both shoulder and low back are some of the most commonly reported (Punnet & Wegman, 2004) and they accounted for some of the most costly accepted lost time claims across Canada between 2017-2019 (AWCBC, 2020). Previous reports and analyses on lost-time injury rates emphasize comparisons between age, sex, occupations, sectors, and nature of injury. The analyses of this data often are portrayed by jurisdiction (e.g., WSIB, WorkSafeBC, WorkplaceNL) or as a compilation presented by AWCBC compensation boards. In these data compilations, a common finding is the large percentage of claims for males and for older adult groups (workers aged 50-60 years) (AWCBC, 2020; WSIB, 2019; Macpherson et al., 2018). Tucker and Keefe provide annual reports using AWCBC data on work fatality and injury rates (Tucker & Keefe, 2020). In the most recent 2020 report, Ontario, New Brunswick, and Alberta saw some of the greatest increases in lost-time injuries compared to previous years (2014-2015) (Tucker & Keefe, 2020). While the average decline in overall work-related injuries is promising, it unknown if this decline holds across each region of injury, and for this line of research, the shoulder and low back.

3.3 Objectives

1. Describe lost time injury claims of the shoulder and back in Canada throughout 2010-2018.
2. Describe the difference in the number of loss time claims and injury rates by age groups and shoulder/back regions.

3.4 Methods

Study Design and Data Collection

This study presented descriptive data and an analysis of data from the National Work Injury/Disease Statistics Program (NWISP) produced by the Association of Workers' Compensation Boards of Canada (AWCBC). NWISP source data originates from data submitted to the AWCBC by the twelve Canadian Workers' Compensation Boards/Commissions (WCBs). The data includes lost time claims which are defined as "An injury where a worker is compensated for wage loss following a work-related injury or exposure to a noxious substance, or receives compensation for a permanent disability whether or not any time has been lost on the job". The NSWIP data is presented using the following standard: Injury/Disease: Canadian Standards Association (CSA-Z795) and covers lost time claims and fatalities accepted for compensation by WCBs. This does not include all workers' compensation claims received by WCBs as claims with no time loss are not included. Certain industries, occupations or types of injuries/diseases may not be compulsorily covered in a jurisdiction, and therefore may not be included in NWISP data. NSWIP data covers the percentage of workers covered by jurisdictional workers' compensation boards and will include both full and part time employment in some provinces/territories. Therefore, if a jurisdiction does not cover 100% of the workforce, it is possible that certain industries, occupations, or types of injuries/diseases may not compulsorily be covered in that jurisdiction and therefore would not be included in NWISP data. For more information about the NWISP data please refer to the online resources provided by AWCBC (2020).

To compliment the data presented by AWCBC on loss time claims, descriptive data was retrieved from the Labour Force Survey produced by Statistics Canada. The Labour Force Survey is a monthly survey aimed at measuring the current state of the Canadian labour market. The data collected by the Labour Force Survey provides national, provincial, territorial, and regional employment (full-time, part-time) and unemployment (seeking employment, and unemployed) rates. The data is collected through telephone and survey methods and is mandatory under the Statistics Act.

Specific Data

Upon request, the AWCBC provided aggregated data for the number of “Lost time claims” and accepted by the boards/commissions sectioned by age, sex, and part of the body for any claims related to the shoulder or back between the years 2010 and 2018. The data did not contain any groupings by industry (SIC) or occupation (NOC) but instead presented an aggregate of all shoulder/back related claims. In total there were 14 classifications of shoulder or back injury as described by the following National Work Injury/Disease Statistics Program (NWISP) codes:

- 21000 – Shoulder, including clavicle, scapula, and trapezius muscle if shoulder is mentioned
- 23000 – Back, including spine, spinal cord, unspecified
- 23100 – Lumbar region
- 23200 – Thoracic region, unspecified
- 23201 – Cervico-dorsal region
- 23202 – Thoraco-lumbar region
- 23290 – Thoracic region, not elsewhere classified
- 23300 – Sacral region, unspecified
- 23301 – Lumbo-sacral region
- 23390 – Sacral region, not elsewhere classified
- 23400 – Coccygeal region
- 23800 – Multiple back regions,
- 23900 – Back, including spine, spinal cord, not elsewhere classified
- 23901 – Low(er) back, unspecified location.

The top three regions of interest in this descriptive analysis included the shoulder (classified as the region where the arm(s) join the trunk and includes the armpit and rotator cuff, includes: clavicle, collar bone, proximal humerus, scapula/shoulder blade, shoulder girdle, armpit, underarm, rotator cuff, excludes: mid-shaft humerus); lumbar (classified as the region of the back that includes the five vertebrae (L1 – L5) on the spinal column located in the lower portion of the back includes: cartilage, muscles, vertebra (backbone) and discs); and low(er) back (classified as low back pain or lumbago as the nature of injury or illness or when the part of body is unspecified to the exact location of the lower back) (AWCBC, 2020).

Data Considerations

NWISP source data originates from data submitted to the AWCBC by the twelve Canadian Workers' Compensation Boards/Commissions (WCBs). All variables are coded by the WCBs, not AWCBC. Coding practices may vary between jurisdictions. Jurisdictions code at different points in time throughout the adjudication process and this may affect the categorization of data.

Analyses

Descriptive analyses including average loss time claims by sex, age group, and region of the body were reported. The loss time claims were also calculated as a proportion of employed Canadian's for each year 2010-2018 (denominator retrieved by each sex from the Labour Force Survey – Statistics Canada Appendix A) to provide injury rates. To calculate the lost-time injury rate, the number of lost-time claims was divided bt the total number of people employed (by sex and age group each year) and multiplied by 100 to show the number of lost-time claims per 100 employed persons.

Statistical analyses were completed in SPSS (IBM 2020) to compare the number of claims by sex, shoulder/spine region, age, and time using factorial analyses of variance (ANOVA). The first three-way model determined the shoulder and back main regions of interest by comparing all 14 possible shoulder and back region average lost time claims over the years 2010-2018. The results of this model, described below, determined 3 main regions of interest (the shoulder, lumbar, and low(er) back region), and no differences over time. Therefore, the subsequent models aimed to determine differences in the average annual lost time claims and the average annual lost time injury rate (per 100 employed persons) using the shoulder, lumbar, and low(er) back claims data. The final model for the average lost time claims was stratified by sex and had two main factors of shoulder/spine region: 3 levels (shoulder, lumbar region, low(er) back of a possible 14 different NSWIP codes listed previously), age group: 11 levels (age groups in 5 year brackets from 15 years through 65+ years) and their interaction. The final model for the average lost time injury rate consisted of three main factors sex: 2 levels (female, male), shoulder/spine region: 3 levels (shoulder, lumbar region, low(er) back of a possible 14 different NSWIP codes listed previously), age group: 11 levels (age groups in 5 year brackets from 15 years through 65+ years) and their interactions.

3.5 Results

Lost time claims for the shoulder and spine regions

Claims attributed to the lumbar region, low(er) back region, and shoulder consistently were the highest shoulder/back related claims over 2010 to 2018 when compared to all other shoulder/spine regions for both females (Figure 5: $F_{(13,1260)} = 215.5$, $p<0.001$) and males (Figure 6: $F_{(13,1260)} = 298.7$, $p<0.001$). The average number of claims were approximately three times greater compared to all other back related regions and on average comprised 76.7% and 80.1% of all shoulder and back related injury claims for females and males respectively. Average lost time claims for females (Lumbar = 757±410; Shoulder = 692±375; Low(er) Back uns.= 581±302) were lower than males (Lumbar = 1308±637; Shoulder = 943±385; Low(er) Back uns.= 943±442) across these top three regions. There was no signifcant difference in the number of claims or injury rate between any year from 2010-2018 for females ($F_{(8,1260)} = 0.230$, $p=0.985$) or males ($F_{(8,1260)} = 0.845$, $p=0.563$)**.** This held for all shoulder and spine regions as there was no significant interaction with time ($p=1.00$ for both females and males).

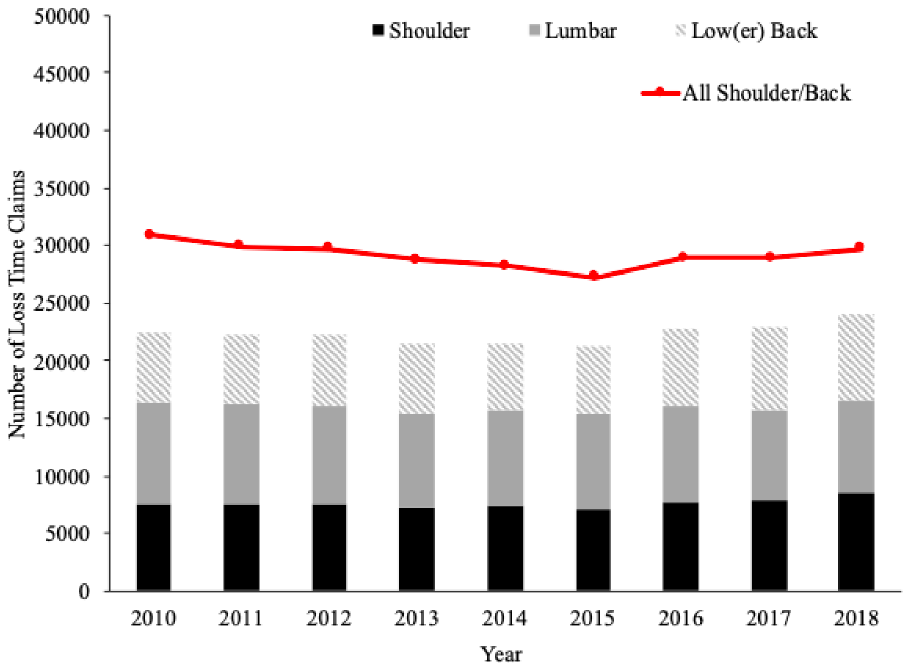

Figure 5. Shoulder and spine related loss time injury claims for all females from 2010 through 2018 highlighting the greatest amounts attributed to the shoulder, lumbar, and low(er) back and consistent amounts of claims.

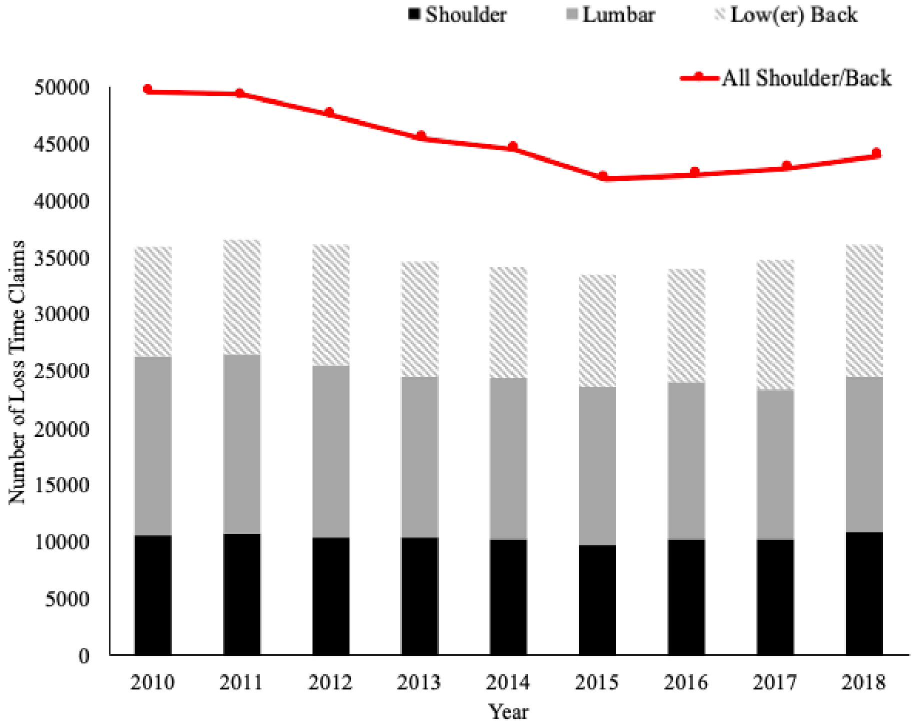

Figure 6. Shoulder and spine related loss time injury claims for all males highlighting the greatest amounts attributed to the shoulder, lumbar, and low(er) back, decline in total number of claims with minimal changes in the shoulder, lumbar, and low(er) back.

Shoulder, lumbar, and low(er) back average lost time claims by sex and age group

There was a signficant three way interaction between sex, age, and shoulder/back region ($F_{(130,2464)}$ = 11.02, p<0.001) when including all of the potential regions listed by AWCBC. Given the substanital proportion of claims related to the shoulder, lumbar, and low(er) back regions and there stastically significant differences to the other regions, these three regions were further analyzed with sex stratified two-way models for age group and body region (shoulder, lumbar, and low(er) back). Sex-stratified models were included as males reported more annual lost time claims of all shoulder and back regions compared to females ($F_{(1,2464)}$ = 2467.04, p<0.001). Age and region of the shoulder/back had significant main effects on the average number of annual lost time claims between 2010-2018 for both females (Age: $F_{(10,264)}$ = 707.2, p<0.001; Region: $F_{(2,264)}$ =152.4, p<0.001) and males (Age: $F_{(10,264)}$ = 502.3, p<0.001; Region: ($F_{(2,264)}$ = 348.3, p<0.001). However, age also held a significant interaction with the three injury regions for both females ($F_{(20,264)}$ = 13.4, p<0.001) and males ($F_{(20,264)}$ = 26.7, p<0.001) average annual lost time claims.

Presented in Figure 7 are the proportional representations of the shoulder, lumbar, and low(er) back region by age group and sex. Two-way ANOVA models examining the interaction of age group with injury region for the top three shoulder/back related claims (shoulder, lumbar, and low(er) back) were performed. Due to the difference in annual injury claims and number of employed individuals for males versus females these models were stratified by sex to account for the differences in claims and further interpret the age related differences. Main effects and interactions were analyzed, where significant interactions were determined the respective results are reported below.

For female lost time claims data, the average annual number of shoulder, lumbar, and low(er) back claims were lowest for, and did not differ between, the two boundaries of working age groupings (15-19 years and 65+ years) ($p=0.999$). For claims related to those under the age of 29 and above the age of 60, there were no differences in the amount of shoulder, lumbar and low(er) back claims ($p=0.131$). For female claims between the ages of 30 and 39 years, the lumbar region had a greater number of claims than the shoulder or low(er) back regions ($p<0.001$). For the 40 – 44-year range, there was no difference between the shoulder claims and the lumbar or low(er) back regions ($p=0.112$), however, the lumbar region was significantly greater than the low(er) back ($p<0.05$). The highest number of claims for these three regions occurred for the 45-49 and 50-59 year age groups, with the lumbar and shoulder regions claims being statistically greater than the low(er) back claims ($p<0.001$).

For male lost time claims, the average annual number of shoulder, lumbar, and low(er) back claims were lowest for, and did not differ between, the two boundaries of working age groups (15-19 years and 65+ years) ($p=0.999$). Between the age groups of 25 to 54 years, the lumbar region had the highest number of claims, the average number of claims was lower for the 25–29-year age group ($p = 0.035$) but similar between all other age groups in this bracket ($p = 0. 082$). For low(er) back claims, there were no significant differences between age groups from 25-54 years, with statistically lower average claims in the 20-24-, 55-59-, and 60–64-year groups ($p<0.05$). For lost time claims related to the shoulder region, the average number of claims was lowest compared to average lumbar and low back claims for all age groups less than 44 years and there was no difference in the average number of claims between age groups from 20-44 years ($p = 0.338$). Notably, there was an increase in the number of claims for the 45-49, 50-54, and 55–59-year age groups ($p = 0.033$, $p < 0.001$ respectively), bringing the average number of shoulder claims greater than the low(er) back claims for all age groups over the age of 50.

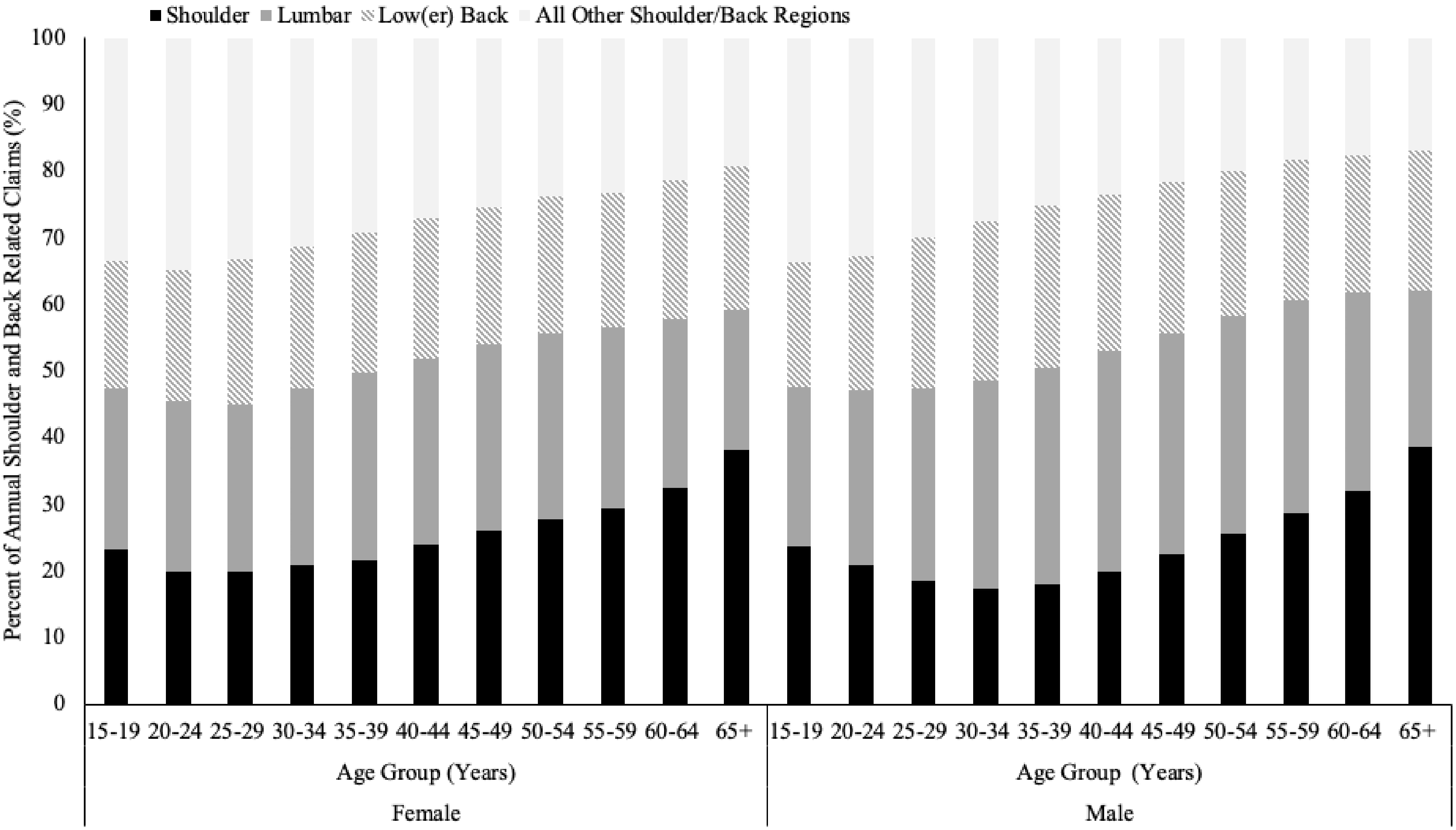

Figure 7. Average annual lost time claims by region (shoulder, lumbar, and low(er) back) for female (left) and male (right) lost time claims by age group. On average males had greater overall amounts of claims than females, however proportionally displayed similar trends.

Lost-time injury rate (per 100 employees) for the shoulder and spine regions

The average difference in annual lost-time injury rate was compared by sex, age group, and region. There was a main effect of region on injury rate ($F_{(2,528)} = 9.49$, $p<0.001$), which was interpreted by its further interactions with sex ($F_{(2,528)} = 6.29$, $p=0.002$) and age group ($F_{(20,528)} = 2.60$, $p<0.001$). Upon analysis of simple effects the sex by region interaction, female lost time injury rates were significantly different between the three regions ($F_{2,294)} = 9.00$, $p<0.001$) (Figure 8). Games-Howell post hoc comparisons for unequal variances noted that the female injury rate for the shoulder region was less than that of the lumbar (mean difference = 0.014, $p<0.001$), and low(er) back regions (mean difference = 0.017, $p<0.001$). Male lost time injury rates were also significantly different between the three regions ($F_{2,294)} = 6.14$, $p=0.002$) (Figure 8). Upon post hoc analysis, the lumbar region had a significantly higher injury rate than the shoulder (mean difference = 0.011, $p=0.027$) and low(er) back (mean difference = 0.013, $p = 0.010$).

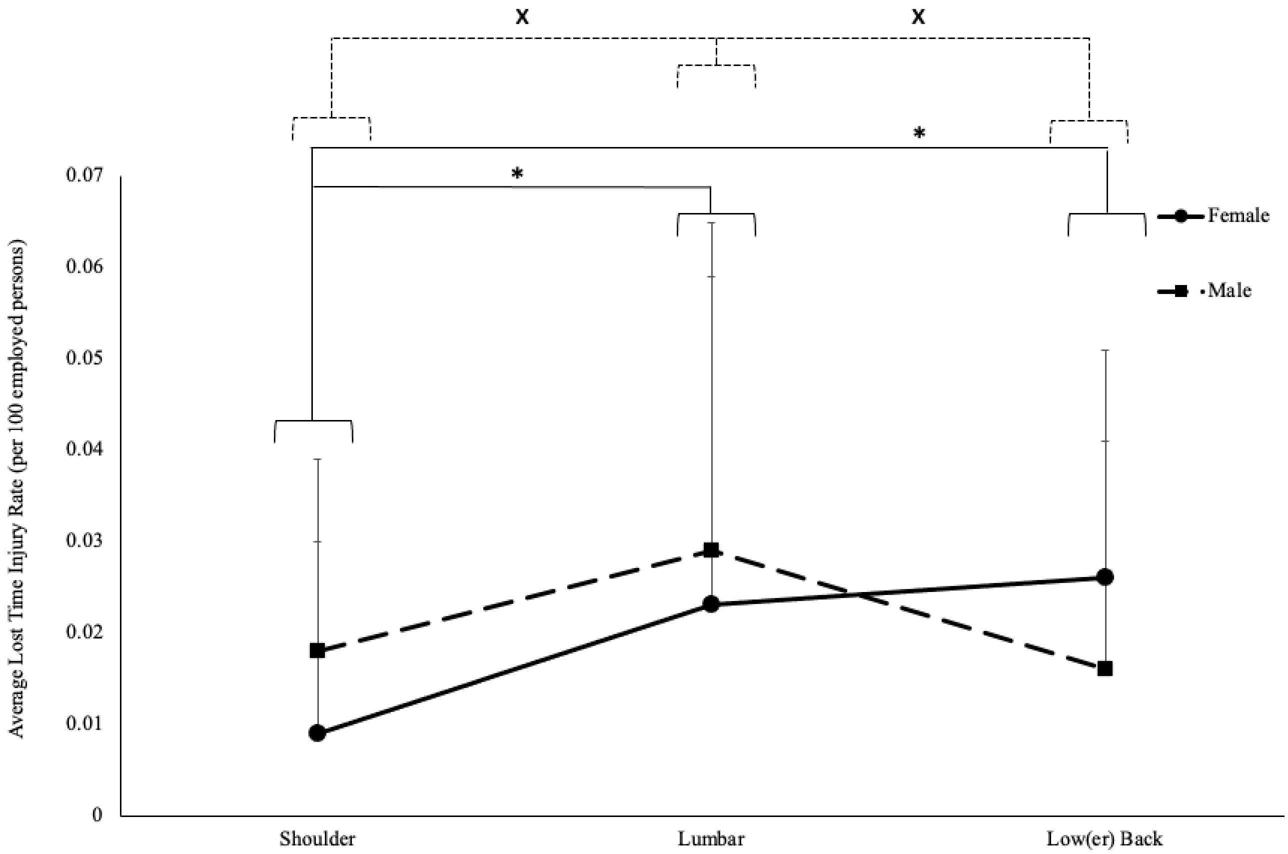

Figure 8. Average annual lost time injury rate for females (solid line), and males (dashed line) for the shoulder, lumbar, and low(er) back regions. *denotes post hoc significant difference P<0.001, x denotes post hoc significant difference P<0.05

With respect to the significant age group by region interaction, when the simple effects were analyzed few differences were found. For the age group between 40-44 years, the shoulder region lost time injury rate was lower than the lumbar region rate (difference = 0.02, p=0.006). For the two peripheral age groups, 15-19 years and 65 years and older the lumbar region had the highest injury rate at 0.04 +/- 0.01 per 100 workers, compared to both the shoulder (0.01 +/- 0.01 per 100 workers, p=0.031), and the low(er) back (0.005 +/- 0.01 per 100 workers, p=0.006). Figure 9 reports the average injury rate for each region by age group.

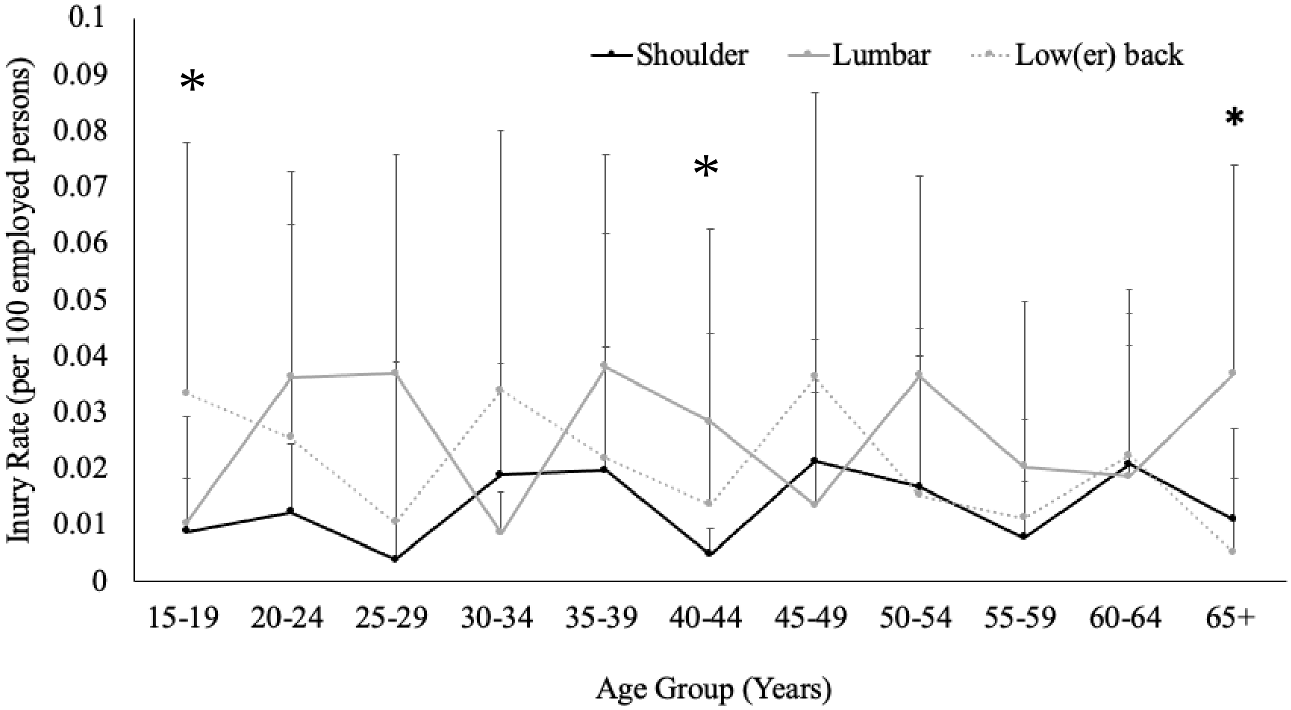

Figure 9. Average annual injury rate and standard deviation (per 100 employed persons). Regional similarities by age group.

* significant difference between regions.

3.6 Discussion

The objective of this description of current lost time claims data was to portray shoulder and back region lost time claims in Canada over 2010-2018, specifically exploring age group and regional differences in the highest claimed regions. Over the recent 9-year period (2010-2018), rates of annual lost time claims related to the shoulder and back regions have remained consistent across Canadian workplaces. Males, on average, had greater numbers of shoulder and back related injury claims than females which is consistent with published statistics across Canadian jurisdictions. Injuries related to the shoulders), lumbar region (including any injury between L1 and L5 vertebrae), and low(er) back (including low back pain, and an injury not specified to a vertebral level of this region accounted for the greatest percentage of any injury claims reported to either the shoulder or back, and average annual claims were almost three-fold compared to any other back region (e.g., cervical, thoracic, sacral).

Historically, the amendment to the 2007 Workplace Hazard Prevention Program in the federal Occupational Health and Safety Legislation resulted in a pronounced decrease in work-related injuries and claims in subsequent years (ESDC, 2019). Current work-related injuries are substantially less than prior to 2007, however, what is notable about the work-related injuries of the shoulder, lumbar, and low(er) back region, is the consistency in lost time claims over the past nine years. According to a report by Tucker and Keefe in 2019, overall changes in lost time injury rates between 2012-2014 and 2015-2017, have on average decreased across Canadian jurisdictions with varied percent decreases of 1-19% change. Their report also highlighted that in jurisdictions with the largest workforce (>100,000 workers), New Brunswick showed the greatest increase in lost-time injury rate (14%). Saskatchewan showed the greatest decrease (-19%), followed by Manitoba (-10%), and Newfoundland and Labrador (-6%) (Tucker & Keefe, 2019). The stable injury statistics of shoulder, lumbar and low(er) back regions over the past few years, are unsurprising given the concerns of low back pain and musculoskeletal injuries manifesting as the costliest contributors to time off work across many jurisdictions (WorkplaceNL, 2019; WorkSafeBC, 2019; WSIB, 2019). Therefore, despite efforts to reduce work-related injury, these regions warrant further understanding of what factors are implicated in their injury risk to improve prevention and management solutions.

While it is unsurprising that these three body region claims were the highest of all shoulder/back related claims, what is interesting is the similarities and subtle differences in the injury rates between males and females and age groups. Previous studies have highlighted sex differences in occupations, occupational hazards, and injury outcomes (Macpherson et al., 2018), and although the number of claims these three regions were higher for males than females, the number of employed males in the labour force is also higher (Statistics Canada, 2019). Consequently, the injury rate data for the shoulder, lumbar, and low(er) back regions, describe an important story as average rates for each region were not significantly different between males and females (ranging from 0.002 through 0.043 lost time injury per 100 workers) but there were differences between regions within each sex.

Unique to females, the injury rate for the lumbar and low(er) back regions were higher than the shoulder. Some of the previously mentioned occupational characteristics such as sector and job type (Hooftman et al., 2004), resulting occupational exposures (Park et al., 2017), along with other biopsychosocial factors (Cote, 2012). For male data, the injury rate of the lumbar region was higher than the shoulder or low(er) back. Recalling that lumbar region represents injuries specified to the L1-L5, it is hypothesized that these are primarily reflective of localized, specific, discogenic injuries compared to the low(er) back region which could encompass any non-specific low back pain (de Schepper et al., 2010). Bergmann and colleagues, who reported a positive dose-response relationship between cumulative lumbar load and LBP among men, but not among women (Bergmann et al., 2017). The authors also highlighted that there was a large variety of potential different etiological pathways in non specific low back pain for men which were necessarily attributed to occupational factors, whereas identified physical occupational risks for specific lumbar disc diseases were higher than for LBP (Bergmann et al., 2017).

When analyzing the lost time claims as a proportion of the employed labour force, there was no clear difference between age groups for males or females. In the literature there are mixed findings related to age, sex, and injury risk. One perspective is that younger age is associated with higher risk of all-cause work injury, while older age is associated with elevated risk of MSD (Okunribido et al., 2011). Prevalence of co-morbidities, biological changes over the lifecourse, and disease progression are suspected mechanisms in work-related injury (Okunribido et al., 2011). However, aligned with the current findings, a study by Smith and colleagues did not find an association between age and injury rates and instead found further evidence to substantiate that the relationship depends on the nature of injury under investigation and impacted by the occupational sector (Smith et al., 2013). A self-report study on 1032 workers with lost time claims, reported that although older workers had more co-morbidities, there were no age-related differences in self-report physical work limitations after injury (Pransky et al., 2005). These authors additionally highlighted those other biopsychosocial factors, such as physical inactivity, were more important determinants that age itself (Pransky et al., 2005).

The lack of age-related differences in proportion of shoulder, lumbar, and low(er) back claims support a recent position paper, informed by a scoping review conducted by Van Eerd and colleagues, as part of an MSD Prevention effort lead by the Centre for Research on Musculoskeletal Disorders (CRE-MSD). The authors identified that the link between aging and

MSD is not clear and warrant caution of ageism in the workplace (Van Eerd et al., 2016). It is therefore important to have equal concern for shoulder, lumbar, low back work-related injury across all ages and to ensure that prevention and management strategies incorporate principles of universal design (Lagace, Nahon-Serfaty, & Laplante, 2015).

Limitations

This descriptive analysis while highlighting a continued need for prevention of shoulder and lumbar/low(er) back work related injuries, should be considered in light of the following limitations. Previous research has identified several factors that affect the accuracy, reliability, and jurisdictional comparability of occupational fatality and injury rates in Canada (Barnetson, Foster & Matsunaga-Turnbull, 2018). For example, lost time claims do not necessarily reflect all injuries and illnesses and this aggregate data did not provide the itemization of type of injury by region. Previous reports have highlighted that the extremes of injury etiology such as less severe injuries and highly complex injuries can be challenging in the filing process (Shannon & Lowe, 2002; Smith, Kosny, & Mustard, 2009) and noted challenges in reporting for precarious employment situations. While an accepted Canadian coding standard (NWISP) was used to identify the regions of interest, there is insufficient detail in this aggregate data to determine the accurate reflection of the clinical diagnosis or the nature of injury related to these work-related lost time claims. Finally, the data source (AWCBC) did not provide a set denominator for estimation into more advanced statistical analyses.

3.7 Conclusions

The shoulders and the spine, specifically the low(er) back and lumbar region, have similarities in consistent, high amounts and rates of injuries in Canadian workplaces over the past nine years. Males on average had greater numbers of claims than females, and comprised a larger percentage of the working population, however, there were no differences in the lost time injury rates for the shoulder, lumbar, and low(er) back regions. While there were differences in number of claims by age group, there no differences in injury rate between age groups. Across all age groups, the shoulder and low back work related injury remain consistent problems in Canadian workplaces. Prevention and management of work-related injury should identify what factors contribute to the higher rate of discogenic and nonspecific low back pain higher injury rate than shoulder for females, and the higher rate of discogenic related injury for males. The similarity in overall claims and injury rates warrant further exploration into what else these the shoulder and back regions share.

Chapter 4 Shoulder and Spine Planar Assessment Relationships

4.1 Overview

The review of the literature and the review of current data positioned an interest and motivation to explore a relationship between the shoulder and spine. Anatomically, the musculoskeletal relationships of these two regions are directly related to the reported biomechanical relationships like muscular synergies and loading tradeoffs. Interestingly, despite the wealth of MSD prevention that has been implemented towards the prevention of low back pain, the rates of loss time claim of the low back regions have remained consisted with little changes over 2010 to 2018. Likewise, the shoulder rates have remained consistent. Initially, it was hypothesized that low back MSD prevention efforts may have created an uptick in shoulder claims. This hypothesis was suspected due to cited biomechanical tradeoffs between the two regions and anecdotal clinical evidence from the author’s years in orthopaedic rehabilitation. However, given this was not found in the description of loss time claims, it raised the question of what further relationships are unknown for the shoulder and spine. Therefore, this chapter sought to answer this line of inquiry by starting with range of motion and spine curvature relationships as commonly measured in clinical and research practice. The specific research objectives created to address this research question, the first positioned an asymptomatic young adult cohort (free of current shoulder/spine injury) within established ROM and curvature norms through a univariate analysis and the second incorporating a multivariate approach to explore the shoulder-spine relationship.

Notes to the reader:

- This study was collected in tandem with another PhD Candidate who focused on hip and spine measures (G. Mayberry). The author would like to note and acknowledge G. Mayberry’s time, knowledge, and contributions to the tandem data collections and acknowledge our team of competent research assistants: J Chow, V Ereqi, P. Ilunga, N. Kareer.
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Johnston, H. A., & Drake, J. D. M. (2021). Multivariate shoulder and spine relationship using planar range of motion assessment. *Musculoskeletal Science and Practice*, *54*, 102398. https://doi.org/10.1016/j.msksp.2021.102398

4.2 Introduction

Anatomically and functionally, the shoulder and spine complement one another for completion of variety of upper limb motions, posture, activities of daily living, and occupational tasks. The large mobility of the shoulder, owing to the multiple structures of the glenohumeral joint, is complemented by adjacent structures like the clavicle and the scapula (Halder, Itoi, & An, 2000; Terry & Chopp, 2000). The spine, while described in terms of its three regions (cervical, thoracic, and lumbar), contributes its mobility to the overall motion of the shoulder and in addition is one of the central stability mechanisms for overall posture (Panjabi, 1992). Together these structures generate some of the greatest ROM in the body for the upper limb, however, they are two of the most common regions for musculoskeletal disorders. Their musculoskeletal relationship is therefore a major contributor to function, which in turn requires robust methods of ROM measurement and assessment.

Measurement and assessment of these two regions has been established through a variety of techniques in the literature. ROM and spine curvature are two components of assessment that are commonly captured for the shoulder and spine, respectively. The interest of ROM assessment has been long established for its ability to diagnosis and monitor pathology and joint dysfunction (Lea & Gerdhart, 1995). Clinically, ROM has become an outcome for many established protocols (Norkin & White, 2016), however the ways in ROM can be captured are quite diverse. For example, the contributions of multi-dimensional movements of the shoulder complex and the postural curvature of the spine can be difficult to quantify. Establishing valid, intrinsic measures of skeletal ROM and spine curvature can be accomplished through imaging such as X-Ray and ultrasound or at the skin level through kinematics including three-dimensional motion capture (Vrtovec, Pernus, & Likar, 2009). While these ROM methods have been instrumental in establishing anatomical shoulder and spine movement relationships (i.e., Theodoridis & Ruston, 2002), they are often more time consuming, cumbersome, and costly in comparison to some clinical assessment techniques. Functional assessments of planar ROM, such as goniometry and inclinometry in turn, present more feasible, non-invasive outcomes that can establish the limits of joint motion (Gerhardt & Rondinelli, 2001; Norkin & White, 2016). While both methods are essential in uncovering shoulder and spine musculoskeletal relationships, functional planar range of motion can be more feasibly captured on a larger sample determine parameters that might influence ROM relationships and can be more quickly captured for individual assessment, diagnosis, and comparison.

For measuring individual planar ROM, techniques such as goniometry, inclinometry, and spinal curvature are well adopted by researchers and practitioners in clinical and occupational settings. Goniometry and inclinometry are planar angular measurements that are both quick and valid, along with providing high internal and external validity for both shoulder (Hayes et al., 2001; Mullaney et al., 2010; Riddle et al., 1987) and spine movement (Burdett, Brown, & Fall, 1986; Norkin & White, 2016; Saur et al., 1996). Spinal curvature has been captured in a few non-invasive ways through devices such as the flexi-curve, which is a pliable ruler that is molded on the spine and then used to calculate the angles of kyphosis and lordosis (Barrett, McCreesh, & Lewis, 2014; de Oliveira et al., 2012; Hart & Rose, 1986). When measured in large samples and specific groups, these measures have been established as normative data for clinical comparison (Soucie et al., 2011). These measures each capture single planes of motion or present a measure curvature for the shoulder and spine and collectively can be used to interpret the limits of joint motion and infer resulting pathology. Their portability and ease of use complements their measurement properties to enable clinicians and other health or safety professionals to use these in daily practice.

Although previous literature and current anatomical knowledge demonstrate the direct connection between the shoulder and spine, many of the previously mentioned ROM and posture assessments continue to be measured, reported, and compared independently for joint segments. Using professional experience and best practices, many practitioners may subjectively account for relationships between outcomes of shoulder and spine ROM and posture or relate the interpretation to normative data available for the shoulder and spine (Roy et al., 2009; Soucie et al., 2011). While current studies highlight shoulder and spine relationships of posture (Singla & Veqar, 2017), mobility (Heneghan et al., 2019), and injury (Hunter et al., 2020), there are still few studies that look at the relationships through planar ROM and posture assessment techniques. The normative databases are established (i.e., Roy et al., 2009; Soucie et al., 2011), without any direction as to how to interpret relationships between the shoulder and spine regions. With the lack of multivariate analyses for interpreting the relationships between and within ROM measures the aim of this component of the dissertation was to answer the research question highlighted at the beginning of this chapter: *In what way can human movement relationships between the shoulder and the spine be measured using common assessment techniques?* This question was addressed by the following objectives.

4.3 Objectives

1. Determine differences and relationships in bilateral shoulder and spine active planar ROM and spinal curvature in male and female young adults
2. Investigate the interplay of the shoulder and spine using active planar ROM and spinal curvature assessment.

4.4 Methods

Participants

A cross-sectional, in-laboratory study was completed over the months of September 2019 through February 2020. Participants were recruited from a sample of convenience through York University's undergraduate and graduate student population. Specific recruitment methods included snowball sampling, advertisements, social media, classroom presentations, and research participant pools (Kinesiology Undergraduate Research Experience – KURE; Undergraduate Research Participant Pool- URPP). Participant eligibility included: young adults (aged 18-35 years), had no prior injury to their shoulder, hip, and/or low back requiring medical care or time off occupation within the last 12 months. Participants were excluded if they had current/unresolved low-back, hip, or shoulder injuries or pain, or if a previous injury that required change to the anatomical arrangement of their joint (i.e., orthopaedic implants; tissue reconstruction, spinal fusion). The eligibility criteria were intended to recruit a young adult asymptomatic population. Written informed consent was sought at the beginning of each individual's collection period. Participants were informed of the study protocol, given responses to any questions, and informed that they were welcome stop the collection protocol at any point in time. Research Ethics approval was provided by the Office of Research Ethics at York University certificate #: e2019-240.

Anthropometry

Gender and sex were self-reported, with gender reflecting the participant's current identity and sex as that which was assigned at birth. All anthropometric measures were collected in an upright standing posture, reported as an average across three repeated trials. Length and circumferential measurements were collected using a standard tape measure and reported to the nearest millimeter (mm) as displayed in Figure 10. For chest circumference, participants were instructed on the following steps for collection: without shirt or undergarments such as a bra and were to be taken upon full exhalation. Height was recorded using a stadiometer. Weight was collected using a standard balance scale and reported to the nearest 0.1 kilogram (kg). Body fat percentage was collected using a hand-held bio-electrical impedance device (BIA, % body fat). Spinal curvature was collected using a flexi-curve, a validated flexible ruler outlining the natural curve, in degrees, of the spine. Limb dominance was recorded as handedness: right-handed, left-handed, or ambidextrous.

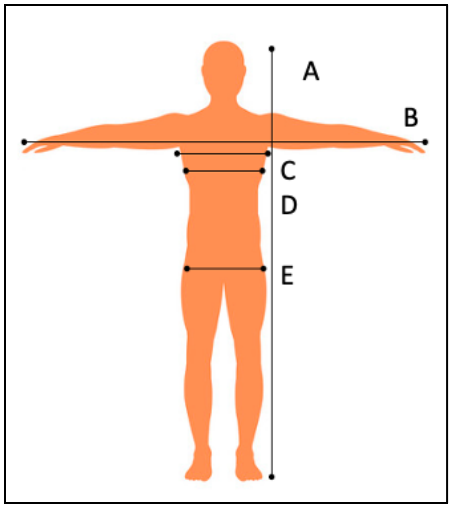


Figure 10. Representation of anthropometric measures (length and circumferential). A: Height, B: Wingspan, C: Over breast chest circumference, D: Under breast chest circumference, E: Waist circumference.

Range of Motion Measures

Upper body and spine range of motion were collected using a variety of validated clinical techniques (Norkin & White, 2016). The principal investigator had previous clinical training (Nova Scotia Health Authority, Dr. Ivan Wong Sports Medicine, Dalhousie University) and trained a team of research assistants for this project. Active shoulder ROM (flexion, abduction) and spine ROM (all) were completed in an upright standing posture. Shoulder internal and external rotation ROM, and all shoulder strength measures were performed in a supine position. All measures were reported as an average across three repeated trials. Measures were collected bilaterally, where appropriate. ROM was an active measure, in that no assistance was given to the participant and they produced the limits of their range of motion. ROM was collected using a goniometer and reported in degrees.

Shoulder ROM was collected using a transparent 360°, 20 cm goniometer. All measurements were performed as stated by Norkin and White (2016) and the instructions were stated verbatim for each participant. For shoulder flexion and abduction participants were asked to raise their arm straight over-head or straight out to the side with their palm remaining parallel to the side of the body as far as possible (Norkin & White, 2016). With participant's arm placed in 90° of abduction and the elbow flexed at 90°, shoulder internal rotation was performed by asking the participant, with their palm towards the floor, to rotate their arm forwards as far as possible (Norkin & White, 2016). Shoulder external rotation was measured by asking the participant to rotate their arm backward with their palm open towards the ceiling as far as possible (Norkin & White, 2016). Thoracolumbar rotation was measured with the participant was seated with legs at 90 degrees, feet completely on the floor for pelvic stabilization, and asked to rotate to one side maintaining a consistent upright trunk as far as possible. Thoracolumbar flexion, extension, and lateral bend using double digital inclinometers placed at T1 and S2 vertebral levels as described by Norkin and White (2016).

Spine Curvature

Thoracolumbar spine curvature was collected using a flexi-curve ruler molded into the spine from C7 through S1 (Figure 11), noting the locations of those two landmarks and T12 when traced onto paper to calculate the indices of kyphosis and lordosis (Hinman, 2004; Milne & Williamson, 1983). Participants stood in a comfortable standing position with standardized instructions to minimize variability in the measurement (Barrett, McCreesh, & Lewis, 2013). Thoracic kyphosis was measured using the C7 spinous process as the remainder of the ruler was moulded to the contour of the thoracic spine through to T12 spinous process. The indices of kyphosis and lordosis were measured using techniques adapted from the original equations by Milne & Williamson (1983) Figure 11.

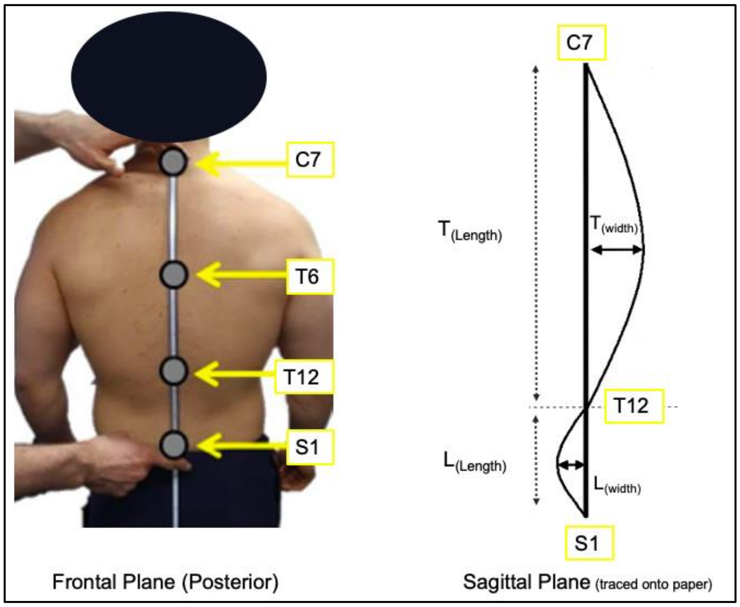


Figure 11. Flexi-curve positioning (Left) and measurement (Right) where thoracic kyphosis index = $T_{(width)}/T_{(length)}*100$ and the lumbar lordosis index = $L_{(width)}/L_{(length)}*100$ as described first by (Milne & Williamson 1983)

Reliability of Measurements

The research team consisted of two primary investigators and four research assistants collected participant data. The principal investigator (Johnston) was trained by the Nova Scotia Health Authority Orthopaedic Department and Dalhousie University's School of Health and Human Performance. Together the primary assessors had over 7 years of experience and performed the pilot measurements on 10 participants with the research assistants (inter-rater agreement range of a lowest for shoulder external rotation ICC=0.94 95%CI (0.90 – 0.96) through a highest for shoulder flexion ICC=0.97 95% CI (0.95 – 0.98).

Statistical Analysis

Raw data was visually inspected for outliers prior to data analysis. Univariate tests for normality were completed on each individual parameter using Q-Q plots and the Shapiro-Wilk test for normality, factor level of sex.

Univariate

For comparison of bilateral differences between sides of the body and sex, a mixed analysis of variance (ANOVA) with between factor of sex (2 levels: male, female), and within factor or repeated measure of side of the body (2 levels: right, left) was performed. The mixed ANOVA was completed individually for all bilateral measures with main effects of sex or side of the body and interaction between these two measures where applicable. Effect sizes were calculated and reported as partial eta squared. Where measures were not applicable to both sides of the body (i.e., thoracolumbar flexion, extension, spinal curvature), an independent samples t-test was performed, treating each measure independently. Cohen's d for effect size was calculated for these interpretations.

For relationships with and between ROM variables and spinal curvature, bivariate correlations were performed for all measures by sex. Pearson's r was calculated along with a significance level of alpha = 0.05, adjusted for multiple comparisons. To determine if there was a significant difference in the bivariate correlations between males and females, the difference was tested between two independent correlations through the extension of z-score testing those two correlations values were the same. Fisher's r to z transformation converted the correlations into r' values, to present a corresponding z-score, and p-value.

Multivariate

A power calculation was performed a priori using G*Power under the F-Test statistical family with the following parameters: effect size $f^2 = 0.33$, alpha = 0.05, power = 0.95, 16 predictors with a final calculation of n = 100 sample size (Faul et al., 2007). Additionally, statistical references surrounding the canonical correlation analysis (Thompson, 2011) highlight that for every predictor there must be at least 5 to 10 observations, providing a sample size range of 80 to 160.

A canonical correlation (CCA) was performed by creating two synthetic variables: a) shoulder and b) spine (Hotelling, 1936). The goal of CCA is to measure the linear relationship between two multidimensional variables (in this case shoulder and spine measures) through determining the optimal two bases where the correlation matrix between the variables is maximized diagonally (Thompson, 2011). For the synthetic shoulder variable eight ROM measures were included (bilateral flexion, abduction, internal, and external rotation). For the synthetic spine variable, the four ROM variables (bilateral axial rotation, lateral bend), two thoracolumbar ROM measures (flexion and extension), and two indices of spinal curvature (kyphosis, lordosis) were included. In a CCA, when the synthetic variables are created and analyzed, the dimensionality of the new bases is always equal or less than the smallest number of variables comprising the overall multidimensional variables. Since both shoulder and spine had eight parameters representing each synthetic variable, the new dimension was equal to eight. CCA takes into account each individual dataset (or individual person in this analysis) by initially collapsing each person's scores on the variables in each variable set into a single composite variable. Each ROM or spinal curvature parameter is then interpreted using derived composite scores that maximize or optimize the relationship between the two sets of data, by weighting each person's individual parameter set and summating the weight scores in each set. These are calculated as function coefficients, and therefore in this analysis 16 function coefficients were calculated, one for each ROM or curvature parameter. These coefficients are analogous to beta weights in a regression analysis or pattern coefficients in a factor analysis. The squared value of these coefficients was also calculated which represents the shared proportion of variance of the linear relationship of the two data sets. Key assumptions of this multivariate analysis that were met prior to calculation included low measurement error, homogeneity of variance, normality, linear relationships between the synthetic variables and the parameters, and a large enough sample size. To test for differences between sex, two separate canonical correlations were performed by sex and the individual canonical scores for each person were tested using independent samples t-tests.

Software

All statistical analyses were performed using IBM SPSS Statistics version 26 (IBM Corp, Armonk, New York).

4.5 Results

The following results section are reported by a general overview of preliminary data analyses and descriptive results of the participant characteristics, followed by sequential reporting of the specific research objectives. With a large sample of 160+ participants, tests of normality, including Q-Q plots and the Shapiro-Wilk tests confirmed that all anthropometrics, ROM and posture data were normally distributed.

Participant Characteristics

Reported in Table 2 are the anthropometrics collected to characterize the asymptomatic young adult asymptomatic study sample. A total sample of 170 participants were eligible and completed the study with a mean age of 21 years and 96.8% of the sample were right-hand dominant. To minimize variability by handedness, only right-handed individuals were included in the univariate and multivariate analyses and results. All individuals self-reported biological sex, male or female and there was a lack of diversity in participant gender identity. Females comprised 63.8% of the group, and on average had smaller anthropometrics but greater ranges of motion. The largest variation in participant anthropometric characteristics were discernible for weight (range of 94 kg) and body fat percentage (range of 35.5 % BIA). Participants also completed the Modifiable Activity Questionnaire (MAQ) (Kriska & Caspersen, 1997). Leisure time and occupational physical activity between participants was similar and comparable to similar Canadian cohorts (Deneau et al., 2018).

Table 2. Descriptive statistics of the participant sample by sex and all participants.

	Female n= 104		Male n=59		Sex Difference	All n=163	
	Mean	SD	Mean	SD	P-Val	Mean	SD
Age (years)	21	6	21	6	0.965	21	6
Height (cm)	163.6	7	177	7.5	**<0.001***	168.5	9.6
Weight (kg)	61.2	13.9	76.7	13	**<0.001***	66.8	15.5
BMI (kg/m^2)	22.5	4.2	24.2	3.5	**<0.010***	23.1	4.2
BIA (%)	21.3	6.8	14.1	5.8	**<0.001***	18.9	7.3
Waist (cm)	84	9.1	87.3	9.6	**0.032***	88.3	10.7
Chest (cm)	11.2	5	5.2	3	**<0.001***	79.3	11.2
Kyphosis Index	9	3	9.5	2.7	0.279	9.2	2.9
Lordosis Index	11.4	3.5	10.9	2.9	0.332	11.2	3.3
Wingspan (cm)	165	8.3	179.9	11.9	**<0.001***	170.4	12.1
Flexion Right	170	10	168	10	0.024	169	10
Flexion Left	170	11	167	12	0.024	169	11
Abduction Right	177	7	173	6	**<0.001***	176	7
Abduction Left	167	6	172	6	**<0.001***	175	6
Internal Rotation Right	54	9	52	9	**<0.001***	53	9
Internal Rotation Left	57	10	51	9	**<0.001***	55	10
External Rotation Right	72	11	70	12	**<0.001***	71	11
External Rotation Left	72	11	65	11	**<0.001***	69	11
Axial Rotation Right	54	10	53	9	0.852	54	9
Axial Rotation Left	54	7	54	9	0.852	54	8
Lateral Bend Right	51	11	46	12	**<0.001***	49	11
Lateral Bend Left	50	11	44	11	**<0.001***	48	12
Thoracolumbar Flexion	54	18	52	16	0.025	53	20
Thoracolumbar Extension	26	16	20	15	<**0.001***	22	16

BMI: Body Mass Index
BIA: Bio-electrical Impedance Analysis

Range of Motion

For bilateral shoulder range of motion, a variety of differences emerged based on the plane of motion (Figure 12). No difference between sex or within side was determined for shoulder flexion. Significant main effects of sex ($F_{(1,161)} = 16.2$, $p < 0.001$) and side ($F_{(1,161)} = 7.41$, $p = 0.007$) were determined for shoulder abduction. For the difference in left and right abduction, both females and males had greater right abduction. Significant interactions between sex and side were reported for both internal ($F_{(1,161)} = 5.25$, $p = 0.023$) and external rotation ($F_{(1,161)} = 5.31$, $p = 0.022$). For males, both internal and external rotation was greater on the right side. Whereas for females, internal rotation was greater on the left side and there was no difference in average external rotation between left or right. For bilateral thoracolumbar ROM measures, axial rotation had no significant effects of sex or side. However, lateral bend had a significant main effect of sex ($F_{(1,161)} = 9.32$, $p < 0.001$). Only the independent variable of sex was tested on thoracolumbar flexion and extension, where extension demonstrated no difference between sex, and thoracolumbar flexion was significantly greater for females compared to males ($t_{(1,161)} = 2.94$, $p < 0.001$, Cohen's $d = 0.502$). For all ROM values where sex had a main effect, average ROM values were greater for females compared to males.

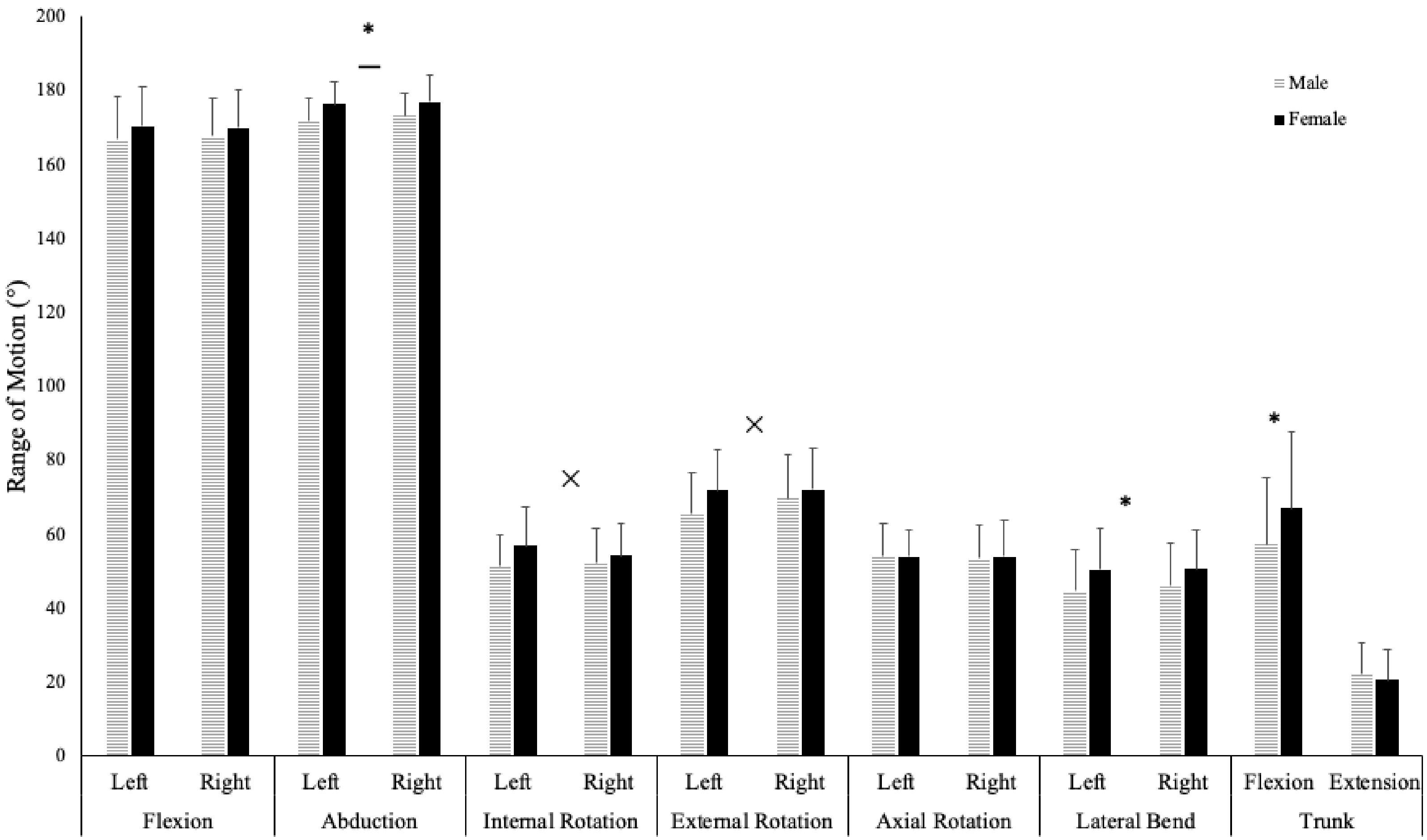


Figure 12. Average and standard deviation of ROM values for males and females by left and right side, where applicable. *denotes main effect of sex; — denotes main effect of side; × denotes interaction between sex and side.

Individual correlations between all collected shoulder and spine range of motion calculated by Pearson's R displayed 22 significant correlations for all participants (Table 3). Differences in correlations by sex were calculated and calculated as z-score and p-values, corrected for multiple comparisons, where only one significant sex difference was determined on the magnitude for the relationship between thoracic kyphosis and lumbar lordosis, where the magnitude of the correlation was 0.355 for females and 0.222 for males (z=2.596, p=0.002). Statistically significant bilateral correlations were moderate to strong (Hemphill, 2003), for example shoulder flexion and abduction and spine axial rotation and lateral bend (Table 3). Bilateral shoulder internal and external rotation were moderately correlated. Bivariate relationships between shoulder and spine parameters, were weak to moderate for example lateral bend held weak correlations with shoulder abduction.

Table 3. Bivariate correlations between shoulder and spine ROM and curvature parameters for all participants. Significant correlations bolded with p<0.003 as adjusted for multiple comparisons.

	Flex L	Flex R	Abd L	Abd R	IR L	IR R	ER L	ER R	AxR L	AxR R	LB L	LB R	KI	LI	T Ext	T Flex
Flex L	1.000	**0.809***	**0.425***	**0.445***	0.064	0.212	0.059	0.005	0.161	0.143	0.133	0.154	-0.118	-0.069	0.077	0.159
Flex R		1.000	**0.411***	0.421	0.115	**0.248***	0.082	0.015	0.046	0.036	0.092	0.152	-0.159	-0.049	0.077	**0.221***
Abd L			1.000	**0.770***	**0.283***	0.178	0.197	0.097	0.028	-0.003	0.158	0.209	0.086	0.030	0.066	0.211
Abd R				1.000	0.200	**0.170***	0.114	0.052	0.068	0.052	0.182	**0.232***	0.151	-0.037	0.084	**0.238***
IR L					1.000	**0.548***	**0.379***	**0.250***	-0.055	-0.047	**0.223***	0.154	-0.081	0.010	0.163	0.079
IR R						1.000	**0.380***	**0.400***	0.010	0.012	0.106	0.079	-0.065	-0.045	-0.023	-0.039
ER L							1.000	**0.579***	0.010	-0.075	0.186	0.168	-0.028	0.075	**0.232***	0.002
ER R								1.000	-0.002	0.000	0.012	0.091	-0.014	-0.152	0.180	-0.165
AxR L									1.000	**0.609***	0.123	0.195	-0.048	0.070	0.169	0.164
AxR R										1.000	0.068	0.197	-0.128	-0.102	0.157	0.196
LB L											1.000	**0.697***	0.066	0.101	**0.506***	0.138
LB R												1.000	0.070	0.092	**0.455***	0.189
KI													1.000	**0.283***	-0.035	-0.111
LI														1.000	0.028	-0.055
T Ext															1.000	0.058
T Flex																1.000

* P-value < 0.0003, adj. for multiple comparisons

Abbreviations: R, Right; L, Left; Flex: Flexion; Abd, Abduction; IR, Internal Rotation; ER, External Rotation; AxR, Axial Rotation; LB, Lateral Bend; KI, Index of Kyphosis; LI, Index of Lordosis; T Ext, Thoracolumbar Extension; T Flex, Thoracolumbar Flexion.

Multivariate Shoulder-Spine

A canonical correlation analysis was conducted using the eight bilateral shoulder ROM variables as one data set [shoulder] and the six spine ROM + the 2 indices for kyphosis and lordosis as the second data set [spine] (Figure 13). The multivariate analysis provided a statistically significant model, with one function $R_{\text{canonical}} = 0.449$, $R_{\text{canonical}}^2 = 0.202$, reported by the Wilks's $\lambda = 0.502$ criterion, $F_{(64,\ 750.5)} = 1.490$, $p = 0.010$. Wilks's λ criterion represents the variance unexplained by the model, $1 - \lambda$ yields the full model effect size in an r^2 metric, therefore the modelled shoulder-spine relationship had an effect size was $r^2 = 0.498$, which indicates that the full model explained a moderate proportion (Thompson, 2011) approximately 50% of the variance shared between the variable sets. The redundancy coefficients were calculated to determine the variance explained by the opposite synthetic variable; 2.7% of the shoulder variance was explained by spine and the shoulder set explained 3.1% of the variance of the spine variable demonstrating that that neither set was a good predictor of the other. However, since there was no difference between indices of shared variance, both sets could be considered independent or dependent variables.

To test for differences between sex, two separate canonical correlations were performed by sex and the individual canonical scores for each group were tested using independent samples t-tests. The overall multivariate relationship of the shoulder and spine for females ($R_{\text{canonical}} = 0.562$, $R_{\text{canonical}}^2 = 0.315$, reported by the Wilks's $\lambda = 0.368$ criterion, $F_{(64,\ 439.1)} = 1.298$, $p = 0.071$) was not significantly difference from males ($R_{\text{canonical}} = 0.526$, $R_{\text{canonical}}^2 = 0.276$, reported by the Wilks's $\lambda = 0.334$ criterion, $F_{(64,\ 225.7)} = 0.739$, $p = 0.923$). It is equally important to note that the sample sizes for two separate analyses would not sufficient for a full canonical correlation analysis, as such these findings are taken in consideration with this limitation.

However, the patterns of the parameter scores were useful in determining if there was a need for a stratified sex analysis for the shoulder-spine relationship. No parameter scores were significantly different between sex as interpreted by independent t-tests, and therefore in consultation with the bivariate associations it was concluded that the full analysis would contain both male and female data together.

As the canonical correlation considers each individual set of data. Given that there were few bivariate differences in correlations between males and females, all participants were entered into the analysis. However, to test for differences between sex, two separate canonical correlations were performed by sex and the individual canonical scores for each person were tested using independent samples t-tests. The overall multivariate relationship of the shoulder and spine for females ($R_{canonical} = 0.562$) was not significantly difference from males ($R_{canonical} = 0.526$) (Zscore=0.307, p=0.379). Moreover, no individual ROM or curvature parameter scores were significantly different between sexs as interpreted by independent t-tests. Therefore, Tte shoulder-spine multivariate relationship was presented and analyzed as a full model across all participants (Figure 13).

Figure 13 presents the multivariate shoulder-spine relationship which displayed a significant moderate relationship between the shoulder - spine variables (R_c=0.449). Depicted as the main circles in the figure are the two synthetic variables, shoulder and spine. The individually measured ROM variables are depicted by the rectangles and report the standardized canonical coefficients. Similar to the beta weights in regression, these standardized canonical coefficients create the linear equation between the individual parameters and synthetic variables. For example, for every one standard deviation increase in right shoulder flexion, there is a 0.690 standard deviation increase in the overall shoulder-spine relationship. Reported on the lines connecting the individual ROM parameters and the synthetic variables are the structure coefficients or canonical loadings which are similar to a factor loading. The grey text presents the squared structure coefficients, which indicate effect size though the percentage of variance the observed variable shares with synthetic variable.

A cutoff was determined as 0.400 for variable structure coefficients to determined based on previous literature for the relevant variables and their relative contribution to the multivariate shoulder-spine ROM relationship (Thompson, 2011). This cutoff was also interpreted with respect to the structure coefficients and squared structure coefficients (Sherry & Henson, 2005; Thompson, 2011), representing the proportion and percentage of shared variance between the observed and synthetic variables. In observing the shoulder variables, the largest meaningful coefficients were determined for bilateral flexion, internal and external rotation, however right shoulder flexion (coef = 0.690, r_s^2=20.7%, $p<0.01$), and left internal (coef = 0.466, r_s^2=21.3%, $p<0.05$), and left external rotation (coef = 0.668, r_s^2=15.1%, $p<0.01$), accounted for the greatest percentage of variance. All three of these ROM parameters had a positive association with the shoulder-spine relationship. Relevant spine variables included lumbar lordosis index (coef = 0.416, r_s^2=14.4%, $p <0.01$), and thoracolumbar flexion (coef = 0.700, r_s^2=45.8%, $p<0.01$). Both had positive associations with the shoulder-spine relationship.

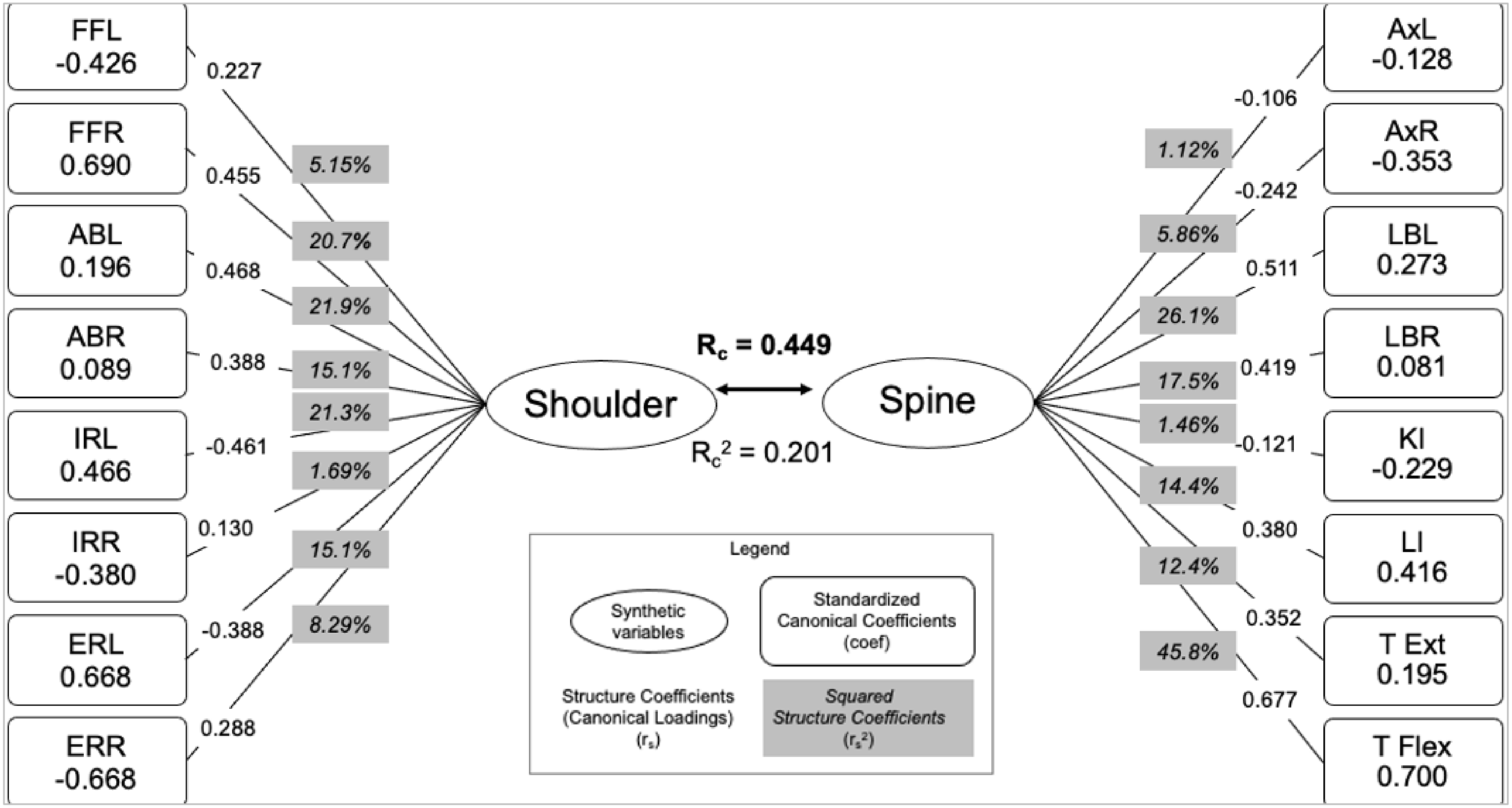


Figure 13. Canonical correlation multivariate shoulder spine relationship as measured by ROM and spinal curvature parameters significant contributions inferred by moderate to high canonical coefficients and moderate structure coefficients (Thompson, 2011).

4.6 Discussion

A multivariate relationship between the shoulder and the spine as measured through planar assessments of ROM and spinal curvature existed for right-handed asymptomatic young adults. Univariate results provided few differences between bilateral ROM with some moderate associations between ROM measures. Sex played a role in univariate ROM differences, however there was only one significant difference in ROM associations by sex. There were no significant differences in ROM relationships by sex as analyzed by the multivariate analysis. The multivariate results presented a significant shoulder spine relationship accounting for 16 shoulder and spine ROM and posture measures. Interpreted together, the findings demonstrated the importance of describing multivariate associations, rather than simply univariate single region assessment for shoulder and spine ROM. This section will discuss these findings positioned within similar literature, answering the question of objective measurement of shoulder spine relationships using common assessment techniques. This study highlights that the interpretation and assessment of regional ROM should be interpreted with respect to adjoining regions as displayed by the relationship of the shoulder and spine for improvement of overall diagnosis, assessment, measurement, and rehabilitation of shoulder and spine musculoskeletal disorders.

Bivariate interpretation of shoulder spine relationship

Bivariate relationships and differences between all ROM variables revealed a subset of significant within shoulder and within spine ROM relationships, respectively. Range of motion was not significantly different bilaterally or between sex for flexion. Females had greater shoulder abduction values (Females: Right 177°, Left 176°; Males: Right 173°, Left 172°) which were significantly greater on the right side for both sexes. Statistically these values were different between males and females, however from a clinical difference standpoint, this equated to only 1 degree difference between sides. Previous datasets of normative ROM values such as those provided by Soucie et al. in 2011, demonstrated non-clinical differences (less than 1 degree difference between limbs) in a cohort of 674 healthy participants (Soucie et al., 2011). As the collected data coincides with established, it was confirmed that in this asymptomatic young adult sample of convenience, females on average had greater ROM than males (Roy et al., 2009; Soucie et al., 2011). The mechanisms contributing to joint ROM are primarily biologically founded through differences in joint laxity that occur with puberty for females (Quatman et al., 2008). With the current findings and previous literature suggesting consideration of sex and supporting bilateral symmetry in asymptomatic populations, it is understandable that common interpretation assumes ROM can be compared to the non-dominant or unaffected limb when diagnosing and assessing an injury. While this method of interpretation may be current clinical, rehabilitative, and occupational practice, the results of this study's multivariate relationship suggest that the underlying shoulder spine patterns contributing to function, mobility, and posture may not be accounted for in simple bilateral comparison.

With at least one significant correlation for all ROM and spinal curvature measures and few between set correlations, there was support to position these parameters, under the assumption of low multicollinearity, within a larger multivariate analysis to understand the shoulder and spine relationship. In comparison to lack of differences previously described for bilateral ROM comparisons, the bivariate associations demonstrated where some patterns of shoulder and spine ROM and posture relationships may occur. The bivariate correlations between ROM parameters, presented relationships of ROM that were common to both males and females. Most associations were positive, when one ROM parameter increased so did the other, with the exception of ROM relationships with the index of kyphosis. The significant associations with kyphosis were primarily negative. This finding however is unsurprising, given that a greater kyphotic index is indicative of increased curvature of the thoracic spine region. With an increase in thoracic curvature, there are known reductions in shoulder ROM, which can be attributed to structural arrangement of the glenohumeral joint with the adjacent scapular contributions (Barrett et al., 2016). When accounting for sex and multiple comparisons, the only bivariate relationship that was close to being significantly different between females and males was the association between index of kyphosis and right shoulder flexion, which demonstrated a negative relationship for women (r=-0.325, p<0.001). This could be interpreted as an increase in either kyphosis or right shoulder flexion corresponding with a decrease in the opposite variable. Functionally and anatomically speaking, increased kyphosis could reasonably decrease shoulder flexion as demonstrated in a previous systematic review on the association of the shoulder and thoracic spine (Barrett et al., 2016). Given the finding only occurred on the right side is likely due to the right-hand dominant sample. However, as the finding is specific for women presents further opportunity for modifiers of this relationship specifically as it relates to clinical considerations, such as anthropometric differences like chest size (Schinkel-Ivy & Drake, 2016).

Multivariate interpretation of shoulder spine relationship

The bivariate relationships in this asymptomatic sample suggest that determining a multivariate relationship would be both attainable and beneficial. Given the small differences, mere degrees, of ROM and modest correlations, assessing all of these parameters was potentially more useful especially where stark differences in ROM are not present (i.e., asymptomatic or populations who have lived with a limitation for a number of years).

As CCA is an overall dimension reduction analysis, there could have been up to eight (number of parameters in each data set) correlations to be interpreted, however it was established that only one canonical correlation existed as interpreted through Wilk's criterion. Therefore, the overall shoulder spine multivariate relationship, was described as moderate relationship ($R_{canonical}$=0.449) comprising the 16 assessment parameters that were inputted in the analysis. Out of the 16 parameters, the most considerable contributions to this relationship included shoulder flexion (right side), internal (right) and external (left) rotation, lumbar lordosis, and thoracolumbar flexion. The interpretations of these ROM and posture variables are discussed in relation to this asymptomatic, right-handed, young adult population and warrant greater attention to shoulder and spine relationships in functional assessments.

An interesting finding of the shoulder-spine relationship was the bilateral considerations demonstrated by directional canonical coefficients (rounded rectangles in Figure 13) compared between left and right side ROM. For bilateral measures of ROM, the left and right side parameters did not always share the same directional coefficients with respect to the interaction between the shoulder and spine. As an example, right shoulder flexion had a strong positive and significant relationship (Coef = 0.690, 20.7%) whereas left shoulder flexion held a negative non-significant relationship. It is hypothesized that this is an indication that this analysis was sensitive to the right-hand dominant sample, recognizing a greater contribution of flexion on the dominant side when considering all the other parameters as well. Moreover, for rotational motions, right external rotation was a significant contribution with left internal rotation also contributing to the spine-shoulder relationship. Functionally speaking, this could be extrapolated to three-dimensional movements requiring performance movement (i.e., overhead activities) on a dominant right side, with there is an increased external rotational demand on dominant side perhaps supported by the internal rotation on the non-dominant side. In previous research on overhead athletes, increased external rotation was typically associated with the throwing arm compared to internal rotation (Borsa, Laudner & Sauers, 2008). Although this sample was not characterized as athletes, it supports the extrapolation of these findings acknowledging the rotational capabilities needed to perform many activities required in daily life. While directionality of these relationships cannot be assumed and would require a left-hand dominant sample as a comparison, these findings do highlight that a simple bilateral comparison of ROM might not translate to more complex relationships which would ultimately influence rehabilitation or functional outcomes.

As highlighted in previous literature the spine has a meaningful relationship to shoulder function (Heneghan et al., 2019; Hunter et al., 2020; Singla & Veqar, 2017), which were demonstrated in this study by the contribution of thoracolumbar flexion and lumbar lordosis along with the aforementioned parameters of shoulder flexion, internal, external rotation to the multivariate shoulder and spine relationship. The substantial contribution of the thoracic region of the spine was highlighted through thoracolumbar flexion (coef = 0.700). This parameter highlighted the known contribution of the thoracic spine in overall shoulder mobility and function (Barrett et al., 2016; Hunter et al., 2020). Given the direct anatomical connection between these two regions (i.e., muscle origins and insertions, and bones such as the scapula), it is reasonable that much of the established shoulder spine relationship research has focused on thoracic contributions (Barrett et al., 2016, Kebaetse et al., 1999; Singla & Veqar, 2017). While this study supports thoracic contributions through the association with thoracolumbar flexion, there was not strong relationship with thoracic kyphosis as previously described. Given the asymptomatic young adult sample, it is unsurprising that kyphosis played a role in this group, given that greater kyphosis and associated detriments in physical function are commonly attributed to physical inactivity and age-related changes in the structural components of the spine

(Kado et al., 2004; Kado et al., 2005). For this cohort, it appears attention to ROM, specifically thoracolumbar flexion, as opposed to thoracic posture (kyphosis) may be more beneficial for assessing the relationship between shoulder and spine function.

Despite kyphosis not playing a large role in the shoulder spine relationship, lumbar lordosis was a significant posture parameter. With more emphasis placed on capturing thoracic posture, this finding is clinically important for interpreting shoulder spine relationships. The lumbar spine is known as a large component of postural control and stability in many upper and lower extremity motions (Been & Kalichman, 2014; Granata & Wilson, 2001). Lumbar lordosis has also been measured and described for its role in understanding the low back pain burden (Sorensen et al., 2015). Given the necessity of postural stability for shoulder function, and the prevalence of low back pain, these results highlight the importance of capturing low back contributions in addition to thoracic contributions to shoulder function (Imagama et al., 2014). The reciprocal relationship, ROM changes at the shoulder impacting lumbar posture, is also an important consideration as the known impacts of scapulohumeral rhythm have an impact on thoracic region motion (Crosbie et al., 2008) and shoulder-pelvic relationships in axial movement (Park et al., 2012). Ensuring appropriate shoulder-spine interaction during ROM assessments may assist in acute regional injury detriments but also prevent consequential and future ROM, pain or injury from a regional injury.

Functional and anatomical understandings of the shoulder and upper body complexes recognize that the glenohumeral joint, scapulothoracic, cervicothoracic, among many other joint articulations, all contribute to movement and require the role of many muscles that cross both regions (Halder, Itoi, & An, 2000; Moromizato et al., 2016; Roy et al., 2009). It is common for health professionals or those who complete assessments of function to account for these multiple contributions through batteries of ROM, posture, and strength parameters and diagnostic tests (Namdari et al., 2012; Norkin & White, 2016). Often the kinetic chain is described, representing the body as a series of links and segments to be activated in coordinated sequences (Heneghan et al., 2019; Rubin & Kibler 2002). As such clinical assessment does take into consideration both shoulder and spine regions when interpreting dysfunction of either region (Rubin & Kibler, 2002) yet predominantly the analyses are univariate and regionally independent in nature. Even rehabilitation protocols, such as those prescribed post-surgical treatment of shoulder injury (Bullock et al., 2019; Sgroi & Cilenti, 2018) often focus in solely on the region of interest without accounting for the potential implications on another region like the spine. While kinetic chain rehabilitation programs and the latter stages of many rehabilitation programs do present exercises incorporating multiple joint segments (McMullen & Uhl, 2000), it is important that the assessment and measurement to monitor progress accounts for regional relationships. Therefore, this multivariate analysis has the potential to not only serve in the diagnosis of injury and dysfunction but in the monitoring and follow-up of rehabilitation by identifying relationships between the shoulder and spine regions.

The multivariate approach had an advantage over typical univariate analyses in determining how all these clinical measures related to one another. As CCA comprises both univariate and multivariate methods it was more respectful of human movement data. Namely, this multivariate method reduced the risk of Type I error and respected the reality of human movement relationships where multiple cause and effects can occur which makes it difficult to apply directional statistical hypothesis and analyses (Sherry & Henson, 2005; Thompson, 2011) The redundancy analysis highlighted little variance explained by the opposite shoulder and spine sets, highlighting that both sets could be modelled as independent or dependent variables.

Clinically, this can be interpreted that both shoulder and spine sets are equally important, share a reciprocal relationship, and that collection of assessments of both regions and their interaction are needed for interpreting ROM in either region.

Limitations

Given this study's cross-sectional nature, the results are applicable to a young adult population, asymptomatic from shoulder and spine injury, and right hand dominant. While this research can be extended into clinical populations in the future, it was necessary to establish these analyses with an asymptomatic sample as both proof-in-principle and as normative data for potential future clinical reference. There are a variety of additional measures and techniques for collecting function and ROM (i.e., diagnostic tests, passive measures, supine measurement) that could be incorporated into such analysis of the shoulder-spine regions and these results demonstrate just one measure of function. The coefficients and loadings are sample specific, and the loadings are subject to considerable variability from one sample to another. Finally, due to the planar assessments of ROM and unidimensional nature some of the previously established coupling patterns (i.e., ipsilateral coupling of spine extension, lateral flexion, and rotation to the right side during arm elevation – Theodoridis & Ruston, 2002) were not described in this study. It is understandable that underling patterns are better detected through three-dimensional analyses, however these methods are not always feasible in practice. Although this study presents that the multivariate relationship between the shoulder and spine can be determined through planar assessments, a larger normative sample for comparison with clinical populations is necessary for external validity of this approach for interpreting dysfunction. Future directions using these findings could investigate additional populations such as left-handed individuals, a larger age range, and clinical populations.

4.7 Conclusions

The multivariate shoulder-spine relationship determined on this asymptomatic young adult sample demonstrates a method for physical assessment analysis of the shoulder and spine that accounts for both regions. While many practitioners and clinicians may already engage in best practices that account for these regions, particular attention to rehabilitation of the additional significant parameters determined here may improve patient outcomes. Future work will be required for diverse populations to determine normative patterns and resultant implications to clinical populations; however, the use of an unaffected population does provide a subset of normative data that warrants particular attention to shoulder flexion, internal and external rotation and thoracolumbar flexion and lumbar posture (lordosis) when performing active planar ROM assessment for the shoulder or thoracolumbar regions.

Chapter 5 Kinesiophobia and Fear Avoidance: Connecting previous injuries to the present

5.1 Overview

In young adults, shoulder injury rates are typically high and pose concerns as potentially recurrent, recovery, implicated in activities of daily life, and potential future pain (Enger et al., 2018; Enger et al., 2019). Likewise, the low back pain remains one of the most common musculoskeletal reports across middle and older aged adults, and it is reported that at least 80% of the adult population will experience acute low back pain at some point in their life and 40-60% of individuals with acute bouts of low back pain will carry on developing chronic pain (Cieza et al., 2020). The participant cohort in Chapter 4 self-reported as asymptomatic, as common in controls for ergonomic and biomechanical studies. Previous injuries prior to the last 12 months are rarely characterized in participant populations unless such injuries result in structural changes anatomical arrangements of the joints. It is known that previous injuries play an important measurement consideration for shoulder and low back biomechanical studies due to changes in movement patterns. However, there are also psychological considerations because of injury that are important indicators of behaviour. The psychological consequences of injury are often described during rehabilitation and recovery but sparsely collected in asymptomatic cohorts. Therefore, the fear-avoidance model presents a pathway in which movement patterns and biomechanical behaviours may be influenced. Through categorizing previous injury in otherwise asymptomatic young adults this chapter answers the question of what proportion of young adults have experienced a previous injury and reports on the impact of a previous injury on Kinesiophobia and Fear-Avoidance Beliefs.

Permissions required & reported in APPENDIX B.
Johnston H., Drake J. (2021) Previous Shoulder and Low Back Injury, Kinesiophobia, and Fear-Avoidance in Young Adult Asymptomatic Participant Groups. Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021). IEA 2021. vol 222. https://doi.org/10.1007/978-3-030-74611-7_106

5.2 Introduction

The spine and shoulder are some of the most affected regions for MSD in the adult population (AWCBC, 2019). Low back pain (LBP) is the number one contributor to the global burden of MSD with an estimated 80% of adults experiencing an acute or chronic episode (Cieza et al., 2020). Shoulder pain from MSD such as rotator cuff tears, has been estimated to impact at least 20% of adults, with at least 25% of individuals having a recurrent episode or continuous pain (Luime et al., 2004). Under the ICF model, both shoulder and spine MSDs are integrated with an individual's body (functions and structures), their activities (limitations in mobility, activities of daily life), and their participation (social engagement, work, physical activity) (World Health Organization, 2001). Further, a biopsychosocial approach, highlights how each of the aforementioned ICF constructs are additionally confounded by individual and situational factors such as attentional processes and behaviour (George & Engel, 1980). MSD of these shoulder and spine are therefore multidimensional, complex disorders to investigate and measure.

Often credited in the rehabilitation and recovery process of MSD, psychological factors such as fear-avoidance are important considerations in the development of chronic MSD such as shoulder and low back pain. Fear is a construct commonly associated with pain and MSD, as it has implications for rehabilitation, recovery, and engagement with behaviours such as physical activity, work, or other activities. The fear-avoidance model (Vlaeyen et al., 2000) describes how an anticipatory emotional response (fear) can be attributed to cues such as pain, or movement, which leads to behavioural responses such as activity avoidance. This model also postulates that chronic pain can develop even if physical healing has occurred, as these protective responses continue to perpetuate even in new situations or environments (Vlaeyen et al., 2000). Fear-avoidance is commonly measured during recovery and rehabilitation phases due to its strong relationships with prognosis (Pincus et al., 2006; Wertli et al., 2014). There are a variety of measures that have been adapted from the fear-avoidance model that aim to capture components of the model.

Two measures derived from the fear-avoidance model include fear of movement and reinjury (Kinesiophobia) as measured by Tampa Scale for Kinesiophobia (TSK) (Miller et al., 1991) and fear-avoidance of activities as measured by the Fear-Avoidance Beliefs Questionnaire for work (FABQw) and physical activity (FABQpa) (Waddell et al., 1993). Kinesiophobia is defined as "*an excessive, irrational, and debilitating fear of physical movement and activity resulting from a feeling of vulnerability to painful injury or reinjury"* (Miller et al., 1991). Fear-Avoidance Beliefs refer to cognitions which result in adapted behavior and limitations in participation in activities (Waddell et al., 1993). These measures have been demonstrated to be reliable and valid measures related of fear-avoidance in populations with spine and shoulder MSD such as LBP (Cleland et al., 2008; Cook et al., 2006; Grotle et al., 2006;) and shoulder pain (Inrig et al., 2012; Kromer et al., 2014; Mintken et al., 2010). From a rehabilitative perspective, these measures provide considerations for recovery and potential difficulties in regaining function or reengagement with activities.

Given that young asymptomatic adults are typically recruited as the control or comparison groups for understanding mechanisms of shoulder and low back dysfunction, many research institutions rely on the convenient samples of young adults based with within the university setting. While it is assumed that university aged comparison groups may mitigate participant variability due to age and physical symptomology (i.e., injury or pain), typically collected descriptive characteristics may not account for previous injuries or psychological constructs such as current fears related to activity. Negating these important characteristics may impact the understanding of musculoskeletal patterns and participation warranting considerations for their applicability as asymptomatic controls. Therefore, the purpose of this chapter was to measure self-report of previous injuries of the shoulder and spine, measure Kinesiophobia and Fear-Avoidance in young adults and to determine if there were any relationships between previous injuries and current Kinesiophobia and Fear-Avoidance Beliefs.

5.3 Objectives

1. Report the number of previous shoulder and low back pain injuries in a sample of self-reported asymptomatic young adults.
2. Measure Kinesiophobia, and fear-avoidance beliefs in asymptomatic young adults self-reporting previous shoulder and low back pain injuries.
3. Examine the relationships between length of time since previous shoulder and low back injuries and Kinesiophobia and Fear-Avoidance Beliefs.

5.4 Methods

A cross-sectional study was completed following approval through the institutional ethics board at York University. The study was collected over the period of September 2019 through February 2020. The protocol consisted of measurement of a small subset of anthropometrics, completion of one week monitoring of PA using a physical activity monitor, followed by completion of surveys regarding their previous injuries and current fear-avoidance beliefs.

Participants

Participants were recruited from a sample of convenience through a university student population previously recruited in Chapter 4. All participants agreed to be contacted for future research and gave permission for secondary analysis of their data. Participants were eligible for the study if they were a current York University undergraduate student, aged 18-35 years, had no prior injury to their shoulder, hip, and/or low back that required any medical care or loss time at work within the last 12 months. Participants were excluded if they had current or unresolved low-back, hip, or shoulder injuries or pain, or if any previous injury, disease, or contraindication had required change to the anatomical arrangement of any joint (i.e., orthopaedic implants; tissue reconstruction, spinal fusion). Participants were informed of the study protocol, given responses to any questions, and informed that they were welcome stop the collection protocol at any point in time. Research Ethics approval was provided by the Office of Research Ethics at York University certificate #: e2019-240.

Fear-Avoidance Model & Questionnaire

The fear-avoidance model of pain was developed to expand beyond typical biomedical and mechanical understandings of chronic pain (Vlaeyen & Linton, 2000; Vlaeyen & Linton, 2012). Under this model, fear-avoidance refers to the behavioral response of avoidance of movements or specific activities based upon pain-related fear. The cascade in which pain-related fear can result in such behavioral responses and potential disability or limitations may include negative appraisals about pain and resultant consequences (pain-catastrophizing), a fear which results in escape and avoidance of activities, avoidance in anticipation of pain, and longstanding avoidance resulting in physical inactivity (Vlaeyen & Linton, 2000). Two questionnaires that have been created from this model were included in this study. The first questionnaire included the measure of fear of movement and fear of reinjury using the Tampa scale of Kinesiophobia (TSK) [3]. The TSK is a 17-item self-report checklist using a 4-point Likert scale with a total score range of 17 through 68, where each question has an answer of “strongly disagree” to “strongly agree”. High values on the TSK indicate higher degrees of fear of movement where a high scoring individual would have a cutoff score of 37 (Miller et al., 1991). The avoidance of activity for physical activity and work was captured using the Fear-Avoidance Beliefs Questionnaire, using both subscales of physical activity (FABQpa) and work (FABQw) (Waddell et al., 1993). The FABQpa assesses fears, avoidance attitudes and beliefs related to general physical activities (4 items, range 0–24), and the FABQw assesses fears, avoidance attitudes and beliefs related to occupational activities (7 items, range 0–42). Each item is scored from 0, “do not agree at all,” to 6, “completely agree”. For both subscales, a low score indicates low fears, avoidance attitudes and beliefs. Both scales have been demonstrated to be reliable in young adults, including shoulder injury and LBP populations (Cook et al., 2006). The Chronbach alphas for these specific populations are: FABQ as a whole 0.93, the FABQw 0.71 to 0.88, and the FABQpa 0.70 to 0.88 (George, Fritz, & Child, 2008). These two questionnaires were chosen as they both report extensive literature on their psychometric properties (Lundberg et al., 2011).

In addition to these scales, the participants were asked the following questions were asked regarding previous injury and pain:

1) Have you ever experienced a previous [insert shoulder or low back] injury?

   Response [Yes/No] If Yes,

      a) Did you seek medical care?
      b) Was this caused by a work activity?
      c) Currently, after exercising or work, have you ever experienced [insert shoulder or low back] pain that impacted your activities of daily living for the following day/s?
      d) When did this injury occur? [DD/MM/YYYY]

The average total time of completion of the questionnaires was 5.5 minutes.

Analyses

Questionnaire data was collected using Qualtrics software and analyses were performed using (version 24.0; IBM Corp., Armonk, NY, USA). The descriptive statistics of the questionnaires were calculated individually for each question where correlations between items and the total questionnaire score were calculated (Appendix C). To report the number of previous injuries in the university asymptomatic young adult sample, the sample size calculation, computed by G*Power, resulted in 114 participants, with an assumed prevalence of 0.05, and precision of 0.04 (Faul et al., 2007). This calculation was based on current data of shoulder pain and low back pain in Canadian young adults (Schopflocher et al., 2011). A descriptive analysis of this data yielded counts and percentages of previous shoulder and low back injuries that required medical care.

The FABQ consists of two subscales, a four-item physical activity subscale (FABQpa), and a seven-item work subscale (FABQw) (Waddell et al., 1993). Each item was scored from 0 to 6 and summed to produce the subscale score. Possible scores range from 0–24 to 0–42 for the

FABQ-PA and FABQ-W, respectively. A participant was considered as having current high Kinesiophobia (>37) and FABQw (>34), FABQpa (> 15) if their scores were greater than the established cutoffs scores (dichotomized into high and low).

Descriptive statistics including counts, means and standard deviations were recorded for previous shoulder and low back pain, TSK, and FABQ scores. To determine if the proportions of previous injuries and dichotomized high/low scorers on the two scales of fear-avoidance were different between males and females, chi-square tests for proportions were performed. To examine the difference in average scores between sex and injury type, a two-way factorial ANOVA was completed with the factors of sex (M/F) and injury type (none, shoulder, back, both). Finally, the relationship between length of time since injury and score was reported using a Pearson correlation coefficient.

5.5 Results

Participant characteristics

In total, 170 participants were recruited for this study, 153 were eligible based on the inclusion and exclusion criteria. The response rate of the questionnaires was 87.6%, with a total of 134 participants completing the questionnaires. The average age of participants, not significantly different between males and females, was 21±6 years. The proportions of participants by sex and questionnaire classification are displayed in Table 4. Where, proportions of previous injury, Kinesiophobia and Fear-Avoidance classification were not significantly different between males and females.

Table 4. Count (percentages) of previous injuries, high versus low scores on the TSK and FABQ with tests of difference on the proportions between sex

		Female (n =87)		Male (n=47)		Difference	
		n	%	n	%	x^2	p-val
Previous back or shoulder injury	Yes	32	36.8	22	46.8		
	No	55	63.2	25	53.2	1.28	0.259
		Female *previous injury* (n=32)		Male *previous injury* (n=22)			
TSK	High	25	78.1	15	68.1		
	Low	7	21.9	7	31.8	0.671	0.412
FABQw	High	9	28.1	2	9.1		
	Low	23	71.8	20	90.9	2.91	0.088
FABQpa	High	0	0.00	0	0.00		
	Low	30	100	21	100	-	-

Previous injuries

Out of the 134 participants, 40.3% (n = 54) of participants reported having either previous low back pain or shoulder pain that required time off occupation and medical care due to an injury (Figure 14). Most previously injured participants reported previous low back pain (n = 35), followed by both having both shoulder and low back pain (n=10), and those with only previous shoulder pain (n=9) (Figure 14). There were no differences in the proportions of the injury type between females and males (Table 4, x^2= 1.28, p =0.259). Of those who had experienced a previous injury, 20.3% (n = 11 out of 54) reported this previous injury was due to work. These 11 individuals had reported a back injury only. The average length of time since injury occurrence ranged from 13 months to 94 months, with an average length of time since injury of 24 months.

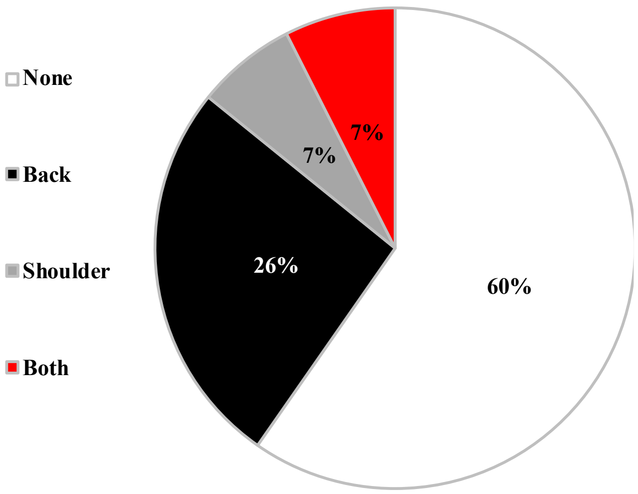


Figure 14. Proportion of injury type for all participants.

Kinesiophobia

There was no difference in TSK scores between males and females ($F_{(1,132)}$=0.001, p = 0.993). The average TSK score was statistically significantly different between previous injury and no injury groups ($F_{(3,132)}$=2.71, p = 0.049), where participants who had experienced a previous back injury, a previous shoulder injury, or both a previous back and shoulder injury had significantly greater TSK scores than those who did not report any previous injury (Figure 16). Using the Tukey-Kramer method for unequal sample sizes, it was determined that there were no significant differences in TSK scores between injury type (shoulder, low back, or both) (p = 0.993). There was no relationship between length of time since injury and TSK score (Figure 15, r = -0.229, p=0.125).

A sub-analysis was performed to determine if the injured groups had higher scores than those with no previous injury when only accounting items that did not directly ask about current pain/injury. Items 1-3,7,9,13-17 were scored and compared between groups. The difference in adjusted score between the three previous injury groups and no injury group approached significance at ($F_{(3,132)}$=5.53, p = 0.052).

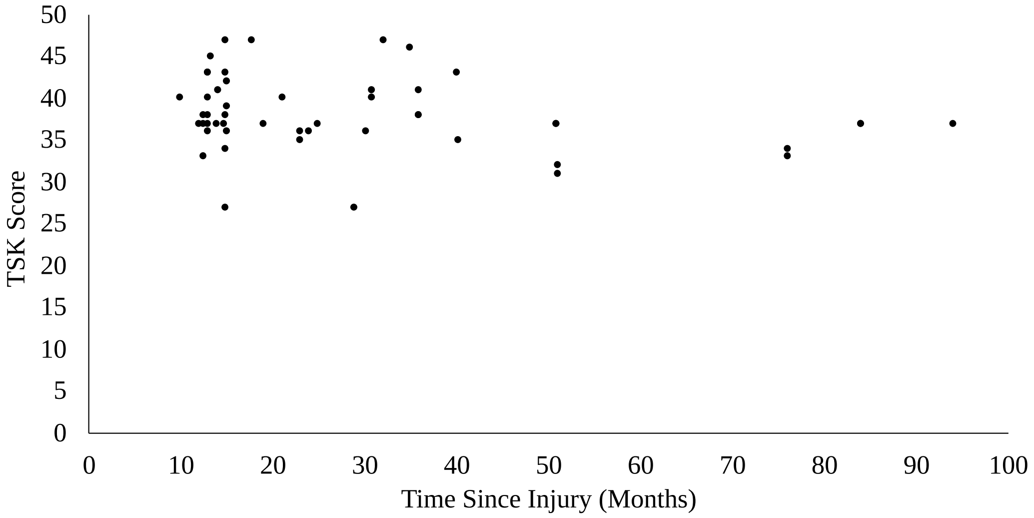


Figure 15. No significant correlation (r = -0.229, p=0.125) between length of time since injury and TSK score (n = 50 of 54 total participants reporting length of time since injury).

Fear-Avoidance Beliefs (FABQpa & FABQw)

Based on the subscale for physical activity, none of the individuals scored high on the FABQpa. FABQpa scores were not significantly different between males and females ($F_{(1,132)}$=0.635, p = 0.427). Additionally, there was no difference between the average FABQpa score between injury groups ($F_{(3,132)}$=0.333, p = 0.801). Scores on the FABQw, were not significantly different between males and females ($F_{(1,113)}$=0.001, p = 0.970), however, there was a statistically significant difference between injury groups. Upon post hoc analysis using Tukey-Kramer method for unequal sample sizes, individuals who had previously experienced both a shoulder and low back injury (FABQw= 30.6 ± 12.0, n=10) had higher FABQw scores than participants who reported only a previous shoulder injury (p=0.010), only a previous low back injury (p=0.019), or no previous injury (p=0.006) (Figure 16). The individuals with higher FABQw scores, comprised 10 of the 11 individuals reporting previous injury due to work. There was no relationship between length of time since injury and FABQw score (n = 10, r = 0.001, p=0.987).

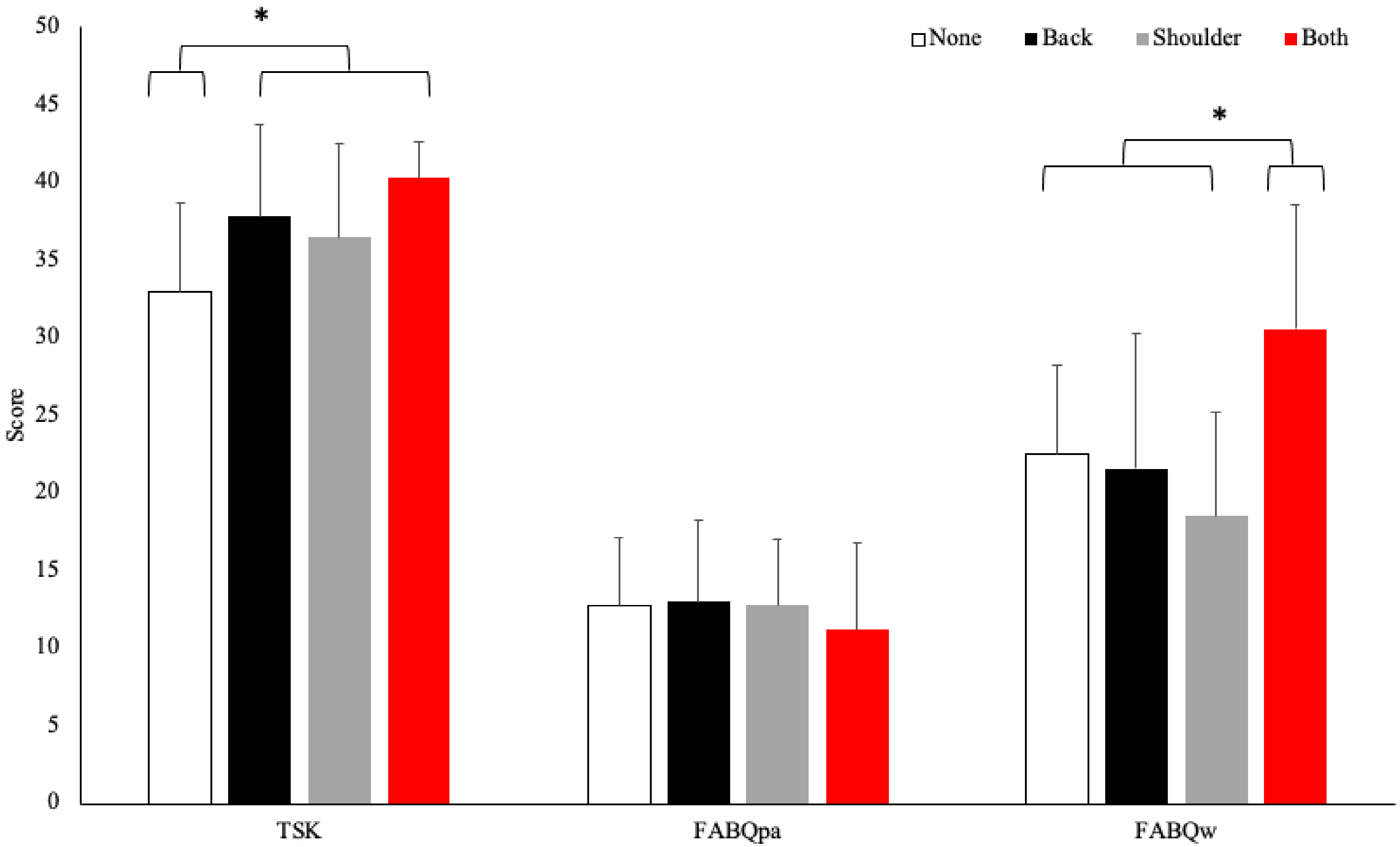


Figure 16. Average scores on the TSK, FABQpa, and FABQw by injury type. *Statistically significant differences highlighted between injury groups as calculated by unequal sample size post-hoc comparisons ($p<0.05$) .

5.6 Discussion

In this study of 134 self-reported asymptomatic young adults between the ages of 18 and 35 years, approximately 40%, had sustained a previous injury of the shoulder or back prior to the last 12 months. Of those who sustained an injury to these two regions, one fifth reported this to be work-related. To the best of the authors' knowledge this was one of the first studies to measure these scales in self-reported asymptomatic adults who reported no injury in the past 12 months. The age, sex, and anthropometrics of this cohort is similar to cohorts of Canadian young adults used in biomechanical investigations (Deneau et al., 2018). These findings demonstrate a continued concern over MSDs of the shoulder and back region in young adults, highlight the importance of characterizing previous injury information to benefit participant characterization or classification, and present underestimated psychotherapeutic considerations of previous injury.

The measurement of Kinesiophobia, suggested that the fear of movement/reinjury may be an important consideration for classifying asymptomatic participants, as 74.0% of young adults who were currently asymptomatic but had a previous shoulder or low back injury prior to the last 12 months scored high on the TSK. The result of previous injuries and potential psychological consequences may impact the way in which participants are categorized for human movement studies (Swinkels-Meewisse et al., 2003). The TSK has previously provided a unidimensional construct of fear of movement in working adult populations across pain levels, ages, and sex (Jorgensen et al., 2015). This scale has also shown associations with three-dimensional kinematics in clinical populations such as those with knee and chronic low back pain (de Oliveira et al., 2019; Osumi et al., 2019). In these studies, Kinesiophobia has been associated with altered movement and lumbar bending (de Oliveira et al., 2019; Osumi et al., 2019) which is infrequently accounted for in common kinematic analyses for the study of normal/healthy movement. Aligning with this previous research, it comprehensible that the addition of screening for previous injury and using psychological questionnaires, such as the TSK, could add value to participant recruitment and classification. Specifically, human movement and biomechanical research, could benefit from such important potential confounders or covariables that could account for movement variability and patterns.

Fear-Avoidance Beliefs were less notable in the current study. However, fear-avoidance relating to work were noted as all 11 participants who reported a previous injury due to work recorded high FABQw. As the FABQw has been validated for work-related low back pain (Iles et al., 2008), it is unsurprising that this content of the FABQ was applicable to those individuals who reported a previous low back injury due to work. Although the FABQ has been used in shoulder populations, a study by Inrig and colleagues demonstrated that it has potential limitations in workers with upper extremity injuries due to high ceiling effects, lower reliability, and poor correlations to clinical outcomes (Inrig et al., 2012). Conversely, a study investigating fear-avoidance in athletes with a history of ankle sprain reported on the FABQ by replacing the word “work” with “sports” and determined that those who had a history of ankle sprain exhibited higher levels of fear than healthy controls (Houston et al., 2018). The findings reported by Houston et al. might suggest that FABQpa and FABQw could be important for distinguishing previous injury and potential ramifications in young adults (Housten et al., 2018). For this sample of young adults, it could be inferred that the scale did potentially identify long-lasting psychosocial concerns for work-related injury, however more participants reporting previous work-related injury would be necessary to explore this inference.

There was no relationship between fear of movement/reinjury (TSK) and fear-avoidance beliefs (FABQ) in this study. Though both questionnaires are derived from the conceptual fear-avoidance model they do attempt to capture different constructs (Lundberg et al., 2011). Contrasting early work by Crombez et al., (1999), Swinkels-Meewise and colleagues (2003) reported the lack of association between the two as an indication that the theoretical constructs may not be the same. Kinesiophobia likely is more related to behavioural responses to reinjury versus activity specific behavioural responses captured in the FABQ (Swinkels-Meewise et al., 2003). It is equally important to acknowledge this young adult cohort, who were relatively active and mostly university students. Fears related to physical activity and work may not be pertinent at this timepoint in their life course but could have temporal considerations with chronological age. The distinction between these constructs and potential implications of the age group require further evidence.

Psychological factors like Kinesiophobia impact many individuals regardless of age or injury type and these findings are also important clinically. Despite a currently asymptomatic sample (all within normative ranges of motion as described in Chapter 4), many of these young adults who sustained injuries within the last 3-4 years experienced Kinesiophobia. Fortunately, Kinesiophobia can be successfully targeted during rehabilitation and stages of recovery as previous reviews have reported a moderate level of evidence that multidisciplinary and psychological interventions along with exercise can reduce Kinesiophobia (Martinez-Cauldron et al., 2018; 2020). Young adults may often be overlooked with such factors due to biophysical characteristics (e.g., physiological health) that lend themselves to timely recoveries. Further clinical studies may wish to emphasize where psychological factors like Kinesiophobia are overlooked in rehabilitation for younger adults (Nicholas et al., 2011; Sullivan et al., 2005).

Limitations

The descriptive analyses presented here are not surprising from a clinical standpoint, as rehabilitation, pain, and return to work research highlights the impact of acute injury and pain beliefs (Vlaeyen & Linton, 2000). However, these findings do warrant attention to participant recruitment when investigating shoulder and low back MSD with the following limitations considered. This study did not follow up this cohort of young adults and therefore longitudinal associations could not be determined. Likewise, without following up on a sub-sample this study was unable to evaluate the test-retest reliability and further evaluate its measurement properties for use in asymptomatic populations. There are a variety of methods in screening and classifying groups of participants and the surveys presented here may not be applicable to all populations. Their measurement properties are debated in the literature and warrant attention to validity and reliability in specific samples. Additionally, as a cross-sectional descriptive study, potential associations, or relationships with respect to shoulder and low back MSD risk are not demonstrated and it is recognized that previous injury, Kinesiophobia, and fear-avoidance on their own may not be sufficient for classification of a group as there is no knowledge of beliefs or behaviour prior to the injury.

5.7 Conclusions

The shoulder and low back remain common areas of interest in human factors and ergonomics MSD research. Previous shoulder and low back injuries, Kinesiophobia, and fear-avoidance beliefs relating to work, collected in young adult university asymptomatic controls emphasized that individuals may have previous experiences like injury and pain that may impact their classification as asymptomatic participants or control groups. The Tampa Scale for Kinesiophobia might be a useful starting point to motivate researchers to investigate ways of better classifying research control groups and participant populations to account for potential variability, especially in ergonomics and occupational biomechanics protocols where research questions focus on potential musculoskeletal pattern differences for the prevention of shoulder and low back MSD.

Chapter 6 Body Composition and its Relationship to the Thoracolumbar Spine: A Systematic Review

6.1 Overview

Chapter 4 presented that trunk flexion and lumbar lordosis were key parameters in a multivariate shoulder-spine relationship. Barrett et al., also demonstrated the strong relationship between shoulder function and thoracic kyphosis. It is equally recognized that the thoracolumbar spine is an important region for whole body stability (Panjabi, 1992) and postural stability while completing upper limb motions. Thoracolumbar curvature (thoracic kyphosis and lumbar lordosis) and associated ranges of motion (flexion, extension, rotation, lateral bending) are also important indicators for understanding risk factors towards the development of LBP. With this evidence in mind, understanding modifiers of thoracolumbar posture are important for quantifying thoracolumbar and associated joint musculoskeletal function.

While recruiting and collecting this ROM and curvature data, the relationship of obesity and MSD was of interest. Previous literature reported comorbidity between obesity and MSD and evidence of the relationship between body composition, namely chest size for women, and thoracolumbar spine function had been collected by this author in supplementary laboratory studies (Johnston, Wanninayake, & Drake, 2021). The motivation to capture the biophysical factor of body composition suggested that participant recruitment should capture a wide range of body sizes in our participants. While recruiting for the study in Chapter 4 and upon reaching a sample size of 150 young adults it was apparent that diverse body sizes would not be reflected in the university aged sample (average BMI = 23.1 ± 4.2 kg/m^2). Previous systematic literature searches and subsequent reviews reported on non-modifiable factors like sex and age with relationship to spine function, however, there was no synthesis of evidence related to body composition. Given the wealth of literature on sex and age differences related to the thoracolumbar spine, it was anticipated that this literature would also report on the relationship between body composition and the thoracolumbar spine. A systematic review of the literature was conducted to look at this relationship body composition, a potential modifier, on the curvature and ROM of the thoracolumbar spine.

Please note the initial stages of this review were conceptualized in tandem with Chapter 4. Therefore, initial literature searches commenced in 2020. Upon realizing that the participant recruitment would not capture a breadth of body composition. The author and supervisory committee decided that a systematic review methodology would be an appropriate approach. As such, a research team was developed with expertise in search strategies and body composition to compliment the expertise in spine biomechanics. The research team also incorporated an information specialist from the University Health Network (UHN). The creation of this research team was required as outlined by the Systematic Review Methodology of the Cochrane Collaboration (Higgins et al., 2021). Below are the contributions of the research team.

Name:	Title:	Responsibility:
Maureen Pakosh	Information Specialist	Search Strategy Development
Dr. Janessa Drake	Supervisor, Professor, Spine Biomechanics	Reviewer (all stages), Consult on spine parameters
Dr. Heather Edgell	Professor Physiology	Reviewer (level 1 & 2), Consult on body composition
Tania Pereira	PhD student, KAHS	Reviewer (level 1 & 2)
Jenan Boukkar	MSc student, KAHS	Reviewer (level 1 & 2)
Heather Johnston	PhD candidate, KAHS	RQ Design, Inclusion/Exclusion, Reviewer (all stages), Primary data extraction and synthesis

6.2 Introduction

Musculoskeletal disorders (MSD) remain some of the most prevalent health-related burdens worldwide (Cieza et al., 2020; Hoy et al., 2014). While it is estimated that nearly 80% of all adults will experience low back pain (LBP) at some point in their lifetime (WHO, 2010), LBP and MSD of the shoulder remain some of the most reported work-related MSD as well. Owing to similarity in work-related ergonomic risk factors (physical, psychosocial, and organizational) MSD of the shoulder and spine are also united by their structural and functional integration of the thoracolumbar spine. Furthermore, the thoracolumbar spine is an important region of consideration for both shoulder and spine MSD due to its responsibility in whole body alignment (Adams et al., 1999). With roles in posture, balance, and movement for both the shoulder (Barrett et al., 2016) and the spine (Jang et al., 2009), understanding factors that impact the thoracolumbar spine present implications for ergonomic and manual therapy intervention of MSD.

The complex structure of the thoracolumbar spine, layered with multifactorial risk factors (e.g., physical, psychosocial, occupational) present challenges in determining modifiable factors impacting its structure and function. The sagittal shape (curvature of thoracic kyphosis and lumbar lordosis) and its ranges of motion (flexion, extension, rotation, lateral bending) of the spine are important indicators for understanding risk factors towards the development of LBP. Sex, age, anthropometry, and body composition are among some of the personal biophysical factors that impact thoracolumbar spine structure and function. For example, age-related hyper kyphosis has been demonstrated in 20-40% of adults over the age of 60 (Kado, Prenovost, & Candall, 2007), however it has confounding relationships with modifiers like muscle strength, physical activity, weight, and fat mass (Roghani et al., 2017). While factors like sex, age, and height are non-modifiable, body composition can be modifiable and presents a variable of interest in understanding spine structure and function.

The topic of body composition is equally important for understanding MSD, as obesity is often a reported co-morbidity. Obesity and unhealthy body weight have increased in our populations over the years, with a worldwide estimate of over 600 million people being classified as obese in 2016 (Bleich et al., 2008; Lebenbaum et al., 2018; WHO 2016). Obesity's strong associations with LBP further implicate its importance for the management and prevention of MSD (Shiri et al., 2013). Functional limitations and outcomes have often been reported as a result of obesity which can directly impact functional capacity in the workplace and potential risk of injury.

Body composition has associations with negative MSD outcomes like reduced quality of life, increased pain, reduced work capacity (Bulbrook et al., 2021), and functional movements (Gilleard & Smith, 2007), it is important to establish the structural and functional considerations that lead to such MSD outcomes. Thoracolumbar curvature, mobility, and ranges of motions are key links between body composition and MSD outcomes. While many reviews focus on personal factors and MSD outcomes like low back pain (Hoy et al., 2012), there is limited synthesis on the literature surrounding personal non-modifiable and modifiable factors related to thoracolumbar structure and function. Recent syntheses have investigated non-modifiable factors like age and sex on thoracic (Roghani et al., 2017) and lumbar (Arshad et al., 2019; Intolo et al., 2009) curvature and mobility. However, there is little evidence synthesizing the impact of body composition on asymptomatic thoracolumbar structure and function. This relationship is important for determining the role of a modifiable factor (body composition) and potential indicators of spine dysfunction. Moreover, understanding this relationship also helps interpret the non-modifiable factors of sex and age.

Given the collective role of the thoracolumbar spine in whole body posture, stability, mobility and movement and the link of these indicators towards MSD, it is important to investigate the relationship of body composition. In asymptomatic individuals these indicators can assist in the understanding of individual level modifiable risk or predisposing factors towards the development of LBP and other MSD. The purpose of this systematic review was to examine the biomechanical, ergonomic, and health related literature to synthesize and report on the relationship of body composition and spine indicators of posture/curvature and range of motion for in-vivo participant data.

6.3 Objective

1. Determine the relationship between body composition and thoracolumbar spine curvature and range of motion in asymptomatic adults as represented in the literature.
    a) PICO Components: Problem: Body Composition; Intervention: N/A; Comparators: Gender/Sex; Outcomes: Spine ROM Curvature.

6.4 Methods

This systematic review was conducted in accordance with the Preferred Reporting Items Systematic Reviews and Meta-Analyses [PRISMA] guidelines (Page et al., 2020). The review used a similar process to the process developed by the Cochrane Collaboration (Higgins et al., 2021). The protocol of the review followed following 5 key steps: 1) defining clear research questions; 2) conducting a comprehensive and explicit search strategy; 3) identifying relevant studies; 4) conducting a critical appraisal; 5) extracting explicit data elements to synthesize; and 6) narrative synthesis of the evidence (Figure 17).

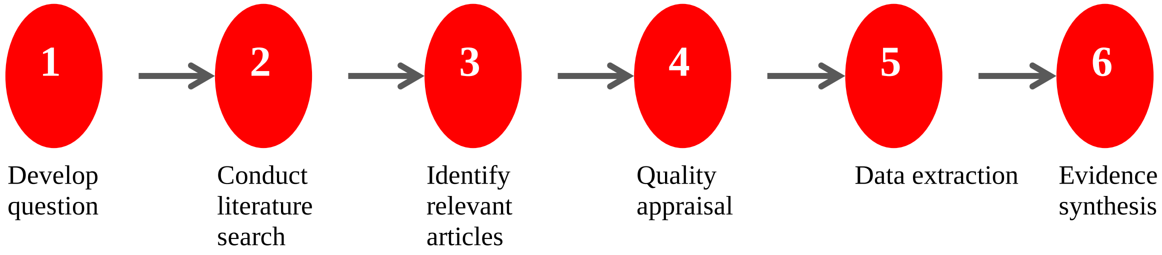


Figure 17. Adapted figure of the systematic review steps as outlined by the Cochrane Collaboration (Higgins et al., 2021).

Defining a Clear Research Question

A series of meetings were held in consultation with two knowledge experts from the domains of physiology (body composition) and biomechanics (spine indicators) to refine the research questions and search strategy for the primary components of the review question. This review was registered with PROSPERO Systematic Reviews (ID: CRD42021253109).

Data Sources and Search Strategy

A total of 11775 citations were retrieved from seven electronic databases. The databases were searched from inception and updated as of 23 March 2021: CINAHL Complete (EBSCOhost), Cochrane Database of Systematic Reviews (Ovid), Embase (Ovid), Emcare (Ovid), Medline (Ovid), PubMed (non-Medline), and Web of Science Core Collection.

The search strategies were iteratively developed in collaboration with an Information Specialist [MP] utilizing the PICO framework, valid subject headings as appropriate for each database, and free text terms relevant to each topical concept. The PICO elements were comprised of Problems related to Body Composition, Comparators Sex/Gender, and Outcome concepts related to Spine in general and then more specifically to Range of Motion or Spinal Curvature issues. The results were limited to Humans but no date or language limits were applied. The full Medline search strategy is shown in Appendix D.

The citations were imported into Mendeley software for article management, and a total of 5204 duplicates were removed from the initial search yield. The articles were then uploaded into Covidence software for title/abstract and full text screening, and data extraction, where an additional 110 duplicates were removed. In addition, the references of included studies were reviewed to capture materials not found through database searching. This hand search yielded 1 article.

Study Selection

With the large search yield, a team of five reviewers completed the study selection stages. Standardized relevance screening forms were created in Microsoft Word (Appendix E) to ensure the review team uniformly applied the inclusion/exclusion criteria at both Level 1 (Title and Abstract Screen) and Level 2 (Full Text Screen). A pilot test of the relevance screen process was completed. The selection of relevant studies took place in two stages, in which all five reviewers took part and two reviewers were required to screen each article. In the first stage, the titles and abstracts of identified references were reviewed based on three questions to narrow the inclusion/exclusion criteria. Full-text articles were retrieved in the second stage for those articles that: (i) were assessed by two reviewers as meeting the inclusion criteria; or (ii) there was insufficient information on the basis of the title and abstract to determine relevance. Disagreements between reviewers on the inclusion/exclusion of articles were reviewed by a third reviewer until consensus was achieved. French articles were reviewed by two of the team members who were fluent in the language. Team members did not review studies that they consulted on, authored, or co-authored. Regular meetings were held with all team members to monitor the reviewing process, address questions, and troubleshoot difficulties in assessing the studies.

Inclusion/Exclusion Criteria

Table 5 displays the criteria used at Level 1 and Level 2 to select studies within the scope of the research question. For the final study selection, the population included adults (>18 years) with no clinical populations (e.g., back pain, scoliosis) and the article had to discern a relationship between a body composition parameter and spine parameter.

Table 5. Inclusion and Exclusion Criteria at the Stages of Title and Abstract Screening and Full Text Review

Level	Criteria	Inclusion	Exclusion
Level 1: Title and Abstract Screen	Language	All	N/A
	Publication Type	Quantitative study designs Systematic review & Meta-analyses	Case Studies Qualitative study designs Non-peer reviewed works Editorials
	Measure of Body Composition	BMI Weight Obesity classification %Body Fat Fat Mass/Fat Free Mass	No measure of body composition or anthropometry
	Measure of Spine	Thoracic Region Lumbar Region Thoracolumbar Region	Cervical Region Sacral Region Scoliosis
	Population	All ages M/F	Clinical populations (e.g., low back pain) Scoliosis Spina Bifida
Level 2: Full Text Screen	Language	English, French	All other languages
	Publication type	Quantitative study designs	Case Studies Qualitative study designs Non-peer reviewed works Editorials Systematic review & Meta-analyses In-vitro study designs
	Measure of Body Composition	BMI Weight Obesity classification %Body Fat Fat Mass/Fat Free Mass	No measure of body composition or anthropometry
	Measure of Spine	Thoracic Region Lumbar Region Thoracolumbar Region Curvature Posture Kyphosis Lordosis ROM	Cervical Region Sacral Region Scoliosis Flexibility Fitness Tests Individual spine segment motions
	Measure of relationship	Report results that discern a relationship or difference between body composition and spine	Aggregated data (e.g., Table 1 characteristics) Interventions Modifiers
	Population	Adults (> 18 years)	Children Adolescents Pregnant females Scoliosis Low back pain

Critical Appraisal

An adapted version of the Joanna Briggs Institute (JBI) Critical Appraisal Tool of Analytical Cross-sectional studies (Moola et al., 2020) was piloted by two of the reviewers. Appendix F contains the form used for the final article appraisal. Two key questions of consideration from the JBI tool include the assessment of the validity and reliability of the measures (Questions 3 and 7 in Appendix G). For Question 3 on the JBI tool, the "exposure" in this review referred to the measures of body composition and for Question 7 the "outcomes" referred to the spine indicators. As there was no "condition" in this review, Q4 from the JBI tool was adapted to state: "Was an objective quantitative assessment of the relationship between exposure and condition made?" Articles that did not make an objective quantitative assessment and solely described a relationship without supporting data received a "no" to this question. The assessment was conducted by two reviewers. Disagreements were resolved through a process of consensus (discussion about the article after independent reviewing). Studies that had a critical appraisal score less than 5 or were reported in a predatory journal as reported by Beall’s List were excluded from the final stage of extraction.

Data Extraction

A data extraction/charting form was created based on input from research team members. The form was piloted with a subset of studies. Once consensus was reached on the data extraction/charting form, ten percent of studies that answered both review questions were independently reviewed by pairs of the review team to meet AMSTAR requirements (Shea et al., 2017); conflicts were resolved by discussion. The remaining articles were allocated to one team member [HJ] for data extraction. This team member did not extract data from studies that they consulted on, authored, or co-authored. Ten percent of the final included studies were double reviewed at as per the AMSTAR guidelines (Shea et al., 2017).

Snapshots of the data extraction form are available in Appendix G. Descriptive data regarding the study design and population characteristics were extracted. Relevant quantitative data (e.g., statistical effect sizes) describing the relationship between a measure of body composition and thoracolumbar spine curvature were extracted. In cases where studies presented statistical estimates (e.g., Pearson's correlation coefficients, odds ratios, t-values) from models, these measures were extracted. For studies where the relationship was described in the text, any statistical information was extracted along with the qualitative text summary statement. If it was not possible to infer the relationship from a study or the data was aggregated in a descriptive table, the study was excluded from the review.

Data Synthesis

Variation in the study populations, body composition measures, and spine outcome measures did not permit the pooling of data into a meta-analysis format. Data were synthesized using a level of evidence approach (van Tulder et al., 2003), considering the risk of bias, the design of the study and the outcomes of the included studies. Definitions for levels of levels of evidence are as follows: Strong: Consistent findings among multiple high-quality studies; Moderate: Consistent findings among multiple low-quality studies and/or one-high quality study; Limited: Consistent findings in one low quality study or only one study available; Conflicting: Inconsistent evidence in multiple studies irrespective of study quality.

The following characteristics were incorporated in the tabular synthesis of the studies and their data: sex/gender, age group, and body composition metrics. Sex/Gender were reported as female and male with sample sizes as provided by each study. Age was grouped into three categories for the synthesis (young adults, middle-age adults, and older adults). Young adults comprised participant groups with adults 18 through 25 years, middle-age adults comprised 26 through 64, and older adults comprised studies with adults greater than 65 years (Statistics Canada, 2007). It is important to note the author subscribe to the Healthy Ageing Framework set out by the World Health Organization; wherein functional ability is one of the most important considerations towards ageing versus solely designating chronological age (World Health Organization, 2018). The age groups were chosen based on the breadth of chronological ages in the literature and to assist in categorizing the data for comparison to other normative reviews. Body composition was primarily reported by most articles using BMI, though the author recognizes the limitations of such a measure for regional distribution and tissue type, the World Health Organization Classification system was used to describe the groups of (normal weight, overweight, and obese). The World Health Organization classifies the following for adults >20 years: normal (18.5–24.9 kg/m^2); pre-obesity (25.0-29.0 kg/m^2), and three obesity classes where (> 30.0 kg/m^2) (World Health Organization, n.d.). For reference in this current review, pre-obesity is referred to as overweight, and no classes of obesity are described.

6.5 Results

Study Selection

Figure 18 depicts the PRISMA flow chart of the article selection process. A total of 6462 articles were screened at Level 1, where 6024 were excluded based on the relevance screen. The full text article yield was 438 articles, where the inclusion and exclusion criteria were applied. Of the full text yield, 385 were excluded for the following reasons: 135 articles were excluded as Aggregate which referred to any article that had a measure of body comp or spine but could not answer whether or not there was a relationship between these parameters; 89 articles were excluded based on Fitness which referred to any article where the outcome measure was a fitness test or flexibility measure e.g., sit and reach test; 43 articles were excluded as Interventions which referred to some intervention or modifier of the body composition – spine relationship e.g., BMI and spine curvature measured before and after a 12 week yoga program; 42 articles were excluded as the Wrong Outcome which varied from measures of pelvic or hip angles to electromyography or kinetics; 30 articles were excluded as non-English or French studies; 24 articles were excluded as Children or Adolescents less than 18 years of age; 15 articles had no measure of body composition in the full text; 3 were clinical populations; 2 articles reflected changes with pregnancy; and 2 articles were reviews in which there reference lists were scanned. A total of 53 articles were evaluated for critical appraisal and data extraction. At the stage of critical appraisal ten articles did not meet the critical appraisal to be included in the final analysis due to their methodology or analysis. Table 6 reports the results of the critical appraisal for all studies. The final yield of articles that answered the relationship between body composition and thoracolumbar spine curvature and range of motion was 43 articles.

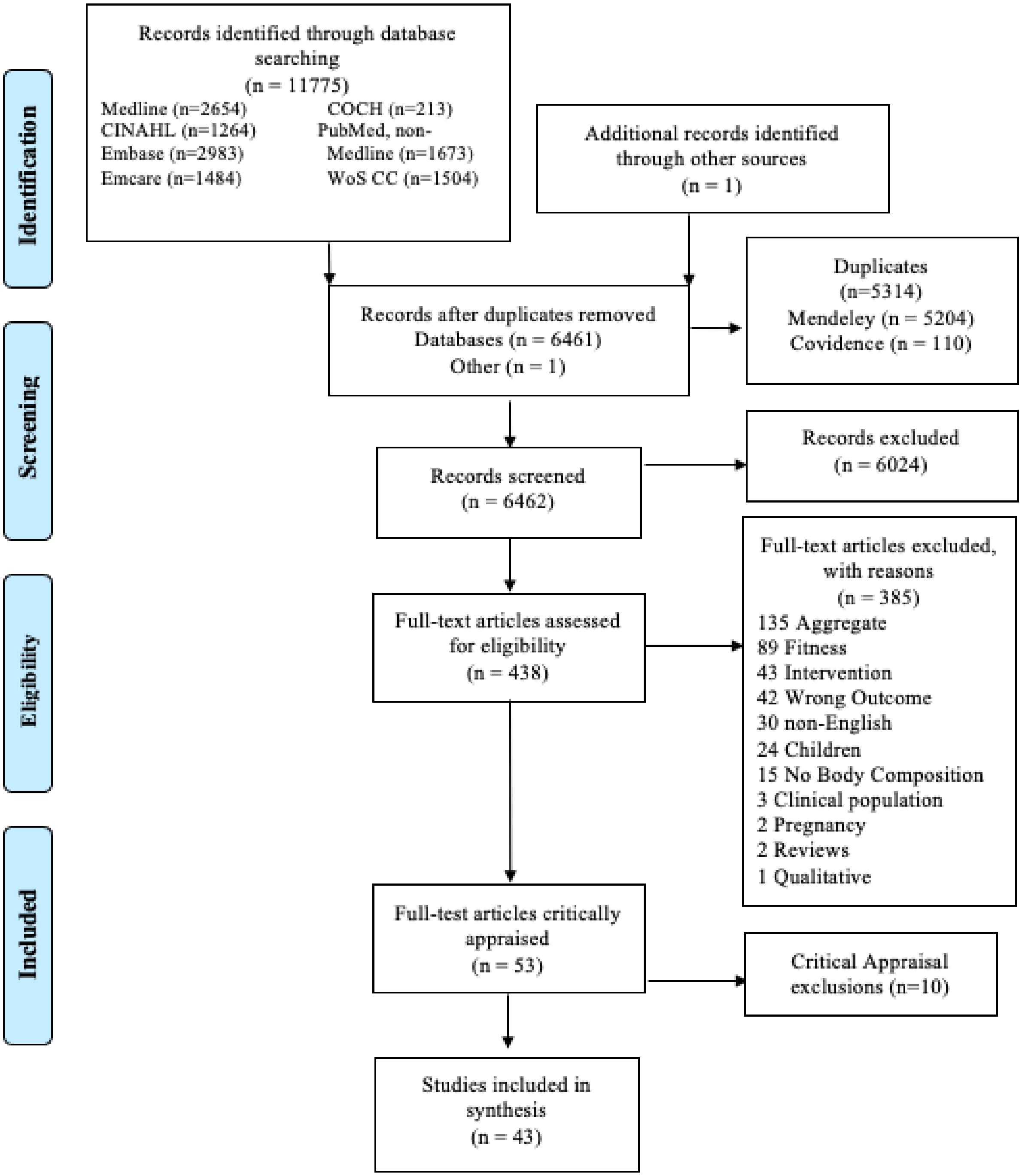


Figure 18. PRISMA Diagram retrieved from: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

Table 6. Result of the critical appraisal performed by two reviewers using an adapted version of the JBI Analytical Tool for Cross Sectional Studies

Author Year	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Score	Overall Appraisal
Ando 2020	Y	Y	N	Y	Y	U	Y	Y	6	Include
Arajuo 2014	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Assassi 2014	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Bergenudd 1989	Y	Y	U	Y	Y	Y	Y	Y	7	Include
Boulay 2006	Y	Y	Y	Y	U	Y	Y	Y	7	Include
Cau 2017	Y	Y	Y	Y	U	U	Y	Y	6	Include
Celan 2012	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Demir 2018	Y	Y	Y	Y	Y	N	Y	U	6	Include
Eagan 2001	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Gilleard 2007	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Hirano 2012	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Hirano 2013	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Horn 2019	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Jalai 2017	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Kado 2013	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Katzman 2012	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Katzman 2014	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Kudo 2021	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Lang-Tapia 2011	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Menegoni 2008	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Menezes-Reis 2018	Y	Y	Y	Y	Y	N	Y	Y	7	Include
Mitchell 2008	Y	Y	Y	Y	Y	Y	Y	U	7	Include
Miyakoshi 2017	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Moromizato 2016	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Murrie 2003	Y	Y	Y	Y	U	U	Y	Y	6	Include
Nishida 2020	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Ohlendorf 2021	Y	N	Y	Y	Y	U	Y	Y	6	Include
Park 2010	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Pavlova 2017	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Pavlova 2018	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Raty 1997	Y	Y	Y	Y	U	U	Y	Y	6	Include
Schmidt 2018	Y	Y	Y	Y	Y	U	Y	U	6	Include
Spencer 2013	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Steele 2020	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Stone 2015	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Tuzun 1999	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Vismara 2010	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Woods 2020	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Yamamoto 2017	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Youdas 1996	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Youdas 2006	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Zhou 2020	Y	Y	Y	U	Y	Y	Y	Y	7	Include
Zwierzchowska 2020	Y	Y	Y	Y	Y	Y	Y	Y	8	Include
Akosile 2013	Y	U	Y	Y	Y	N	Y	U	5	Exclude
Lee 2017	U	Y	U	Y	Y	N	N	N	3	Exclude
Gomez 1991	Y	Y	Y	N	Y	U	Y	N	5	Exclude
Katzman 2011	Y	Y	Y	N	Y	U	Y	N	5	Exclude
McGhee 2018	Y	Y	Y	N	Y	U	Y	N	5	Exclude
McGregor 1995	Y	Y	Y	U	N	N	Y	N	4	Exclude
Purohit 2020	Y	Y	Y	N	N	N	U	N	3	Exclude
Vakili 2016	N	Y	Y	Y	Y	Y	U	N	5	Exclude
Xu 2015	Y	N	N	N	Y	N	Y	N	3	Exclude
Zeng 2018	Y	Y	Y	Y	U	N	Y	U	5	Exclude

Q1 Were the criteria for inclusion in the sample clearly defined?; Q2 Were the study subjects and the setting described in detail?
Q3 Was the exposure (body comp) measured in a valid and reliable way?; Q4 Was an objective quantitative assessment of the relationship between the exposure (body comp) and outcome (spine) made?; Q5 Were confounding factors identified?; Q6 Were strategies to deal with confounding factors stated?
Q7 Were the outcomes (spine) measured in a valid and reliable way?; Q8 Was appropriate statistical analysis used?
Y: Yes; N: No; U: Unclear;

Study Design

The final 43 articles reflected data from 16 different countries, which are depicted in Figure 19. With respect to the study design, most studies were cross-sectional, followed by cohort, and one study of measurement properties of a spine outcome (Figure 19).

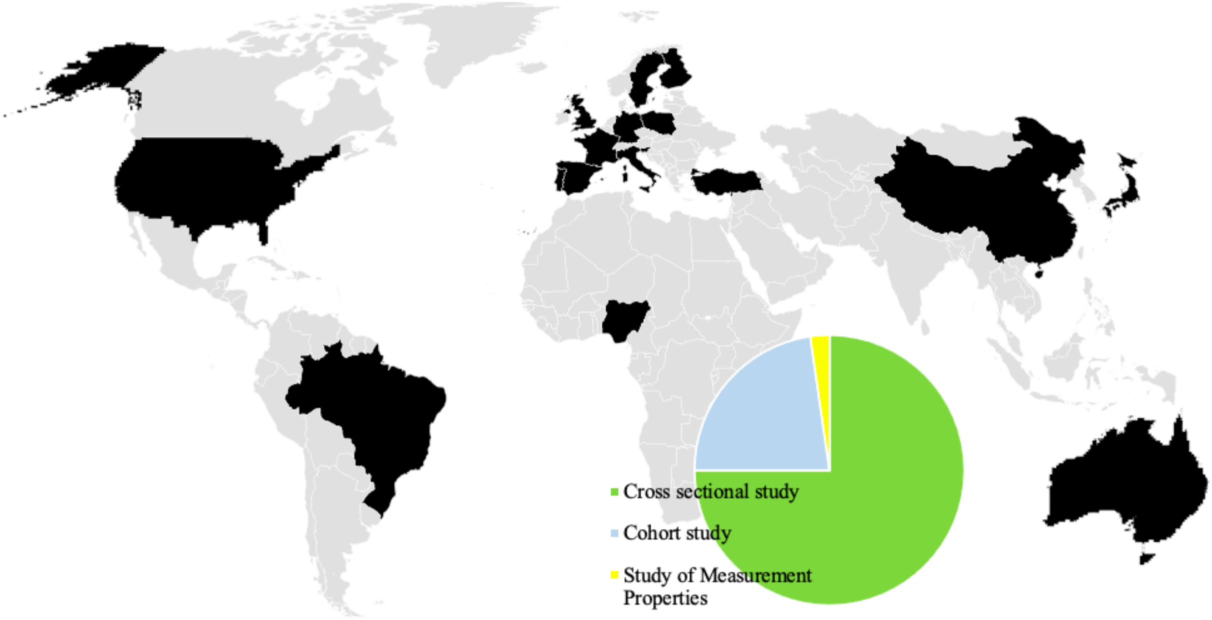


Figure 19. Characteristics of the included studies by country of origin (filled in black) and study design (proportions) created using Microsoft Excel® Fillable Maps.

Study Characteristics

Of the 44 articles, 25 collected data on both males and females, 14 collected data on females, and 5 collected data solely on males. Most articles reflected age groups over the years of 55+, with 17 articles reporting on this age group. Sixteen articles reflected multiple age groups, while six articles reported on middle age (35-54 years), and five articles on young adults (18-34 years).

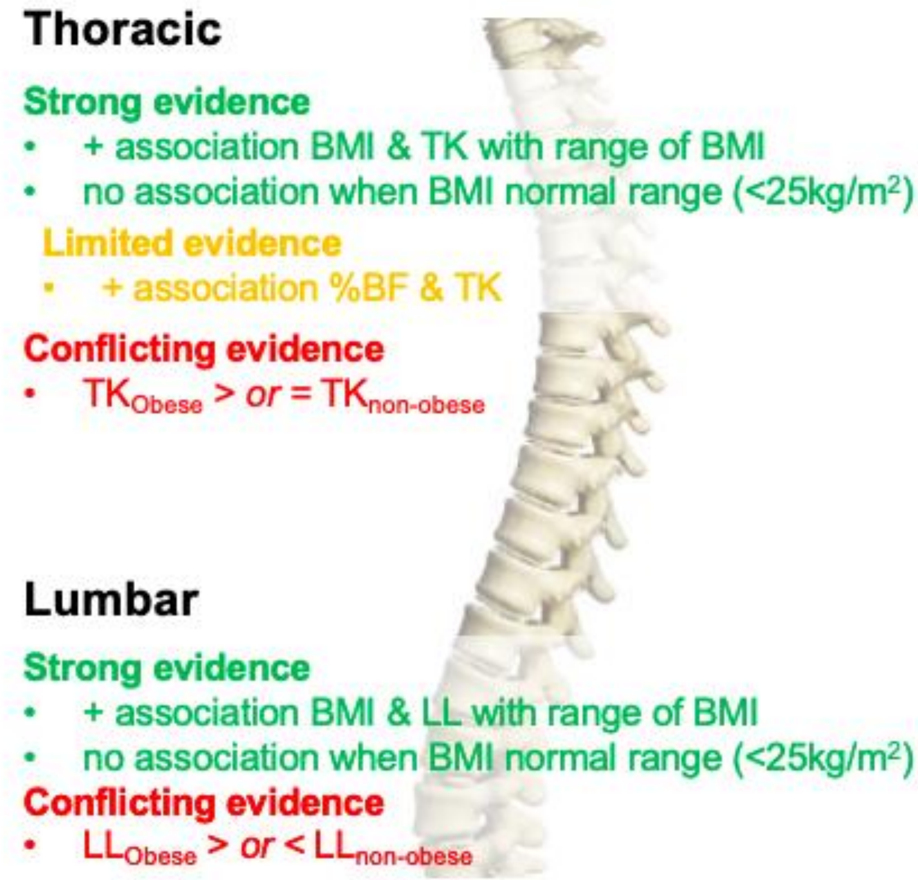
Body composition was primarily measured by body mass index (BMI) with 37 of the included articles reporting this metric either as the main variable or a classification for obesity.

Additional measures of body composition included weight (n=6), body fat percentage (n=4), waist circumference (n=2), fat mass/fat free mass or fat infiltration (n=5), body adiposity index (n=1) with some articles reporting multiple measures. The main outcomes of the spine included a quantitative measure of thoracolumbar spine curvature or range of motion in upright standing.

Most articles measured thoracolumbar spine curvature (n=32), or another measure of posture like spine mode (n=1) or postural typology (n=1). Seven articles measured thoracolumbar ROM, with an additional 3 articles that measured both curvature and ROM. Appendix H reports the detailed characteristics of the included articles, specifically the sample sizes, sex/gender, and results of body composition and spine parameters. A variety of methods were used for assessment of thoracolumbar curvature. Eleven studies used imaging techniques to measure the curvature of the spine, where 10 of these were completed using radiographs and one used computed tomography. Seven studies used a pliable ruler such as the flexi-curve measuring from either the thoracic level or starting at cervical C7, the flexi-curve was also used in one study to calculate ROM. Other validated methods used to capture spine curvature included the Spinal Mouse (also used to capture ROM in one study), spine pantographs, Debrunner’s method, or the Block’s method. Two articles by Pavlova also used spine modes which investigated the shape variation of the lumbar curvature. For ROM, 3 articles recorded range of motion using three-dimensional motion capture. Two studies used goniometric measurements and provided the measurement details from previous citations. The back ROM (BRoM IITM; Performance Attainment Associates, Lindstrom, MN, USA) device was used in one study.

Relationships

Figure 15 displays a visual representation of a summary of the overall findings on the relationship between measures of body composition and the thoracolumbar spine. The study characteristics along with detailed results located in Appendix H. As per van Tulder et al. (2003) level of evidence strategy, there were only two findings that had a moderate level of evidence, the remaining evidence was conflicting or limited (Figure 13). The findings of the relationships are described by each parameter (thoracic kyphosis, lumbar lordosis, and ROM) below.



Thoracic

Strong evidence
- + association BMI & TK with range of BMI
- no association when BMI normal range ($<25kg/m^2$)

Limited evidence
- + association %BF & TK

Conflicting evidence
- TK_{Obese} > *or* = $TK_{non\text{-}obese}$

Lumbar

Strong evidence
- + association BMI & LL with range of BMI
- no association when BMI normal range ($<25kg/m^2$)

Conflicting evidence
- LL_{Obese} > *or* < $LL_{non\text{-}obese}$

Figure 20. Data visualization of the level of evidence and relationships synthesized from the included studies, reported by thoracic, lumbar curvatures.

Thoracic Kyphosis

Nineteen of the 43 included articles reported on a relationship between body composition or difference due to body composition with thoracic kyphosis. There was strong evidence of a positive association between BMI and thoracic kyphosis for individuals in obese BMI categories (> 30 kg/m^2). Specifically, articles reported a positive association, where an increase in BMI

(Bergenudd 1989; Celan 2012; Hirano 2012; Hirano 2013; Katzman, 2014), an increase in weight (Kado 2013), and an increase in body fat percentage (Eagen 2001) were associated with increased thoracic kyphosis. The difference and relationship between BMI and thoracic kyphosis was found only for females and not for males in the study by Bergunudd (1989). Celan (2012), Lang-Tapia (2011), Ohlendorf (2021), and Steele (2020) reported larger kyphotic angles for obese individuals compared to overweight and not overweight. Katzman (2013) reported that older adults with hyperkyphosis, on average, weighed more than those with normal kyphosis. Ando (2020) reported no difference between obese and non-obese populations, however, the cut-off used to determine the BMI classifications was >25kg/m^2 which was not comparable to the WHO cutoff of >30kg/m^2. Horn (2019) reported no differences between obesity categories in univariate analyses, however, after adjusting for spino-pelvic parameters, thoracic kyphosis was greater for obese participants. In younger adults within a range of BMI (Zweirzchowska 2020), no relationship was found. However, these authors compared cut-points described as body adiposity index (BAI) to BMI and demonstrated the similar low positive significant relationship between body composition and spine curvature.

There was also a strong level of evidence that within a healthy/normal BMI range there was no relationship between BMI and thoracic kyphosis. This finding was reported across different age groups including middle age and older adults (Boulay, 2006; Jalai 2017; Miyakoshi 2017; Nishida 2020; Spencer 2013; Stone 2015; Woods 2020). For these seven articles, the average measures of BMI were all within a healthy normal average range as described by the World Health Organization BMI classification as a BMI between 18.5 and 24.9 kg/m^2. These articles and their interpretations are reported in Table 7..

Table 7. Studies reporting on the relationship between body composition parameters and spinal curvature (thoracic kyphosis and lumbar lordosis).

Author	Sex	Sample	Age Group	Body Composition	Relationship
Ando (2020)	M/F	N = 286 M: n=109 F: n=177	Older Adults	BMI Range: Non-obese, Obese	Thoracic Kyphosis M: No difference F: No difference Thoracolumbar Kyphosis M: No difference F: No difference Lumbar lordosis F: Obese < Non-obese (p<0.05) M: No difference L4-S1 Lumbar Lordosis M: No difference F: Obese < Non-obese (p<0.05) **When adjusted for age, sex: no differences found.*
Araujo (2014)	M/F	N = 489 M n=178 F n =311	Middle Age, Older Adults	BMI Range: Normal, Overweight, Obese	Lumbar Lordosis No difference by BMI group (p=0.184) Sagittal Postural Pattern (Roussouly) + association between obesity and non-neutral posture + association between overweight and non-neutral posture
Bergenudd (1989)	M/F	N= 575 M n=323 F n=252	Middle Age Adults	Weight Range	Thoracic Kyphosis: F: + association between weight and thoracic kyphosis (r=0.25, p<0.001) M: no association between weight and thoracic Lumbar Lordosis F: + association between weight and lumbar lordosis (r =0.26, p<0.001) M: no association between weight and lumbar lordosis
Boulay (2006)	M/F	N = 149 M n = 78 F n =71	Middle Age Adults	BMI Normal	No association between BMI and thoracic kyphosis + association between BMI and lumbar lordosis (r=0.3315, p=0.024)

Author	Sex	Sample	Age Group	Body Composition	Relationship
Celan (2012)	M/F	N= 250; M n =126 F n=124	Multiple	BMI Range: Normal, Overweight, Obese	+ association between BMI and thoracic kyphosis (r = 0.32, p<0.0001) + association between BMI and lumbar lordosis (r = 0.17, p = 0.008) Thoracic kyphosis Less nourished (low BMI) < more nourished (high BMI) (p<0.001) Lumbar Lordosis Less nourished (low BMI) < more nourished (high BMI) (p<0.001)
Demir (2018)	M/F	N = 150 M n = 70 F n=80	Young Adults	BMI Normal	+ association between BMI and lumbar lordosis (r = 0.211, p-0.013)
Eagan (2001)	F	N = 61	Older Adults	Weight Range %BF Range Acceptable, Obesity	+ association between weight and thoracic kyphosis (r=0.15, p<0.05) + association between %BF and thoracic kyphosis (r=0.26, p<0.05)
Hirano (2013)	F	N = 187	Older Adults	BMI Range: Normal, Overweight	+ association between BMI and thoracic kyphosis (r=0.278, p<0.05) + association between BMI and lumbar lordosis (r=0.188, p<0.05)
Hirano (2012)	M	n=105	Older Adults	BMI Range: Normal, Overweight	+ association between BMI and thoracic kyphosis (r=0.218, p<0.001) no association between BMI and lumbar lordosis
Horn (2019)	M/F	N= 1600 M n=773 F n= 827 Groups: Obese = 800 Non-obese = 800	Middle Age, Older Adults	BMI Range: Non-obese, Obese	Thoracic Kyphosis Obese = Non-obese (p =0.086) After adjusting Obese > Non-obese (p=0.015) Lumbar Lordosis Obese < Non-obese (p<0.001)

Author	Sex	Sample	Age Group	Body Composition	Relationship
Jalai (2017)	M/F	Total N = 554 Obese=277 Non-Obese=277 M=209 F=345	Middle age, Older Adults	BMI Range: Non-obese, Obese	Thoracic Kyphosis Obese = Non-obese Lumbar Lordosis Obese = Non-obese Global Sagittal Angle Obese > Non-obese (p<0.001) + association between BMI and global sagittal angle (r = 0.752, p<0.001)
Kado (2013)	F	N=980	Older Adults	Weight Range: Normal, Overweight	+ association between weight and thoracic kyphosis (OR: 0.08, 95%CI 0.01, 0.16) - association between increase in weight and thoracic kyphosis (OR: -0.20, 95%CI -0.26, -0.15)
Katzman (2012)	M/F	N= 1172 M n=624 F n= 548	Older Adults	Weight Trunk Fat (g)	Weight Difference Hyperkyphosis > Normal Kyphosis (p<0.001) Trunk Fat Difference Hyperkyphosis = Normal Kyphosis
Katzman (2014)	M	Total N= 475	Older Adults	BMI Range: Normal, Overweight, Obese	- association between paraspinal muscle volume + BMI>30 and thoracic kyphosis (p=0.02)
Lang-Tapia (2011)	M/F	N= 659 M n= 362 W n= 297	Middle Age Adults	Weight Range: Normal, Overweight, Obese	Thoracic Kyphosis Overweight and Obese > Normal Weight (p<0.001) Lumbar Lordosis Overweight and Obese < Normal Weight (p=0.014)
Menezes-Reis (2018)	M/F	N= 93 M n= 43 F n=50	Young Adults, Middle Age Adults	BMI Normal	no association between skeletal fat infiltration and sagittal spine curvature (kyphosis and lordosis)
Miyakoshi (2017)	F	N=329	Older Adults	BMI Normal	no association between BMI and thoracic kyphosis
Murrie (2003)	M/F	N= 56 M n = 24 F n = 32	Middle Age Adults	BMI Range: Normal, Overweight, Obese	+ association between BMI and lumbar lordosis (r=0.27, P <0.04)

Author	Sex	Sample	Age Group	Body Composition	Relationship
Nishida (2020)	M/F	N = 113 M n=56 F n=57	Young Adults, Middle Age Adults, Older Adults	BMI Normal **few participants reported as Obese by authors.*	no association between BMI and thoracic kyphosis no association between BMI and lumbar lordosis
Ohlendorf (2021)	F	N= 101	Middle Age Adults	BMI Range: Normal, Overweight, Obese Weight Range: Normal, Overweight, Obese	Obese > Normal weight thoracic kyphosis (P<0.001) Obese > Normal weight lumbar lordosis (p<0.01) Obese, Pre-Obese > Normal weight lumbar flexion angle (p<0.05) Obese > Underweight lumbar flexion angle (p<0.05) Obese, Pre-obese > Normal weight sagittal trunk inclination (P<0.001)
Ridola	M/F	N = 28 M= 11 F = 17	Young Adults, Middle Age Adults	Weight Normal	no association between body build index* and lumbar lordosis
Schmidt (2018)	M/F	N= 332	Young Adults, Middle Age Adults, Older Adults	BMI Range: Underweight, Normal Weight	no association between BMI and lumbar lordosis
Spencer (2013)	F	N= 51	Middle Age, Older Adults	BMI Normal	no association between BMI and thoracic kyphosis no association between weight and thoracic kyphosis
Steele (2020)	F	N = 378	Middle Age Adults	BMI Range: Normal, Overweight, Obese	Obese > Non overweight thoracic kyphosis (p<0.001)
Stone (2015)	M/F	N=246	Older Adults	BMI Normal	no association between BMI and thoracic kyphosis no association between BMI and lumbar lordosis
Tuzun (1999)	M/F	N = 150	Middle Age Adults	BMI Range: Normal, Overweight	+ association between BMI and lumbar lordosis (r= 0.191, p = 0.019)
Vismara (2010)	F	N = 37	Middle Age Adults	BMI Range: Normal, Overweight, Obese	Lumbar Lordosis Obese > Healthy (p<0.05)
Woods (2020)	M	N = 1092	Older Adults	BMI Normal Weight Normal	no association between weight and thoracic kyphosis

Author	Sex	Sample	Age Group	Body Composition	Relationship
Yamamoto (2017)	M/F	N= 72 M n= 20 F n= 52	Older Adults	BMI Range: Normal, Overweight Trunk lean mass (kg)	+ association between trunk lean mass and thoracic kyphosis *Beta (95%CI) pvalue by method:* Debrunner 1.93(0.15;3.72).03* Flexi-curve 0.83(0.14;1.53).02* Blocks 0.21(0.03;0.40).02* Cobb 2.07(0.31;3.82).02*
Youdas (1996)	M/F	N = 90 M n = 45 F n = 45	Middle Age, Older Adults	BMI Range: Normal, Overweight	no association between BMI and lumbar lordosis
Youdas (2006)	M/F	N = 235 M n= 119 F n= 116	Young Adults, Middle Age Adults, Older Adults	BMI Range: Normal, Overweight	no association between BMI and lumbar lordosis
Zhou (2020)	M/F	N = 235 M n = 89 F n = 146	Young Adults, Middle Age Adults	BMI Normal	no association between BMI and lumbar lordosis
Zwierzchowska (2020)	M/F	N = 1281 M n= 539 F n = 742	Young Adults	BMI Normal, Overweight, Obese % BAI Normal, Overweight, Obese	no association between BMI and thoracic kyphosis no association between BAI and thoracic kyphosis + association between BAI and lumbar lordosis (r=0.20, p<0.05) + association between %BF and lumbar lordosis (r=0.15, p<0.001)

Lumbar Lordosis

Twenty-four of the 43 articles reported on body composition and lumbar lordosis (Table 7). Eight articles reported a positive association between BMI and lumbar lordosis with low risk of bias as per the critical appraisal (Bergunudd 1989 – females only; Boulay 2006; Celan 2012; Demir 2018; Hirano 2013 – females only; Murrie 2003; Tuzun 1999). The positive associations were low to moderate (r < 0.500) across all studies. Nine studies reported no association between BMI and lumbar lordosis (Bergunudd 1989 – males only; Hirano 2012 – males only, Jalai 2017; Nishida 2020; Ridola 1994; Schmidt 2018; Stone 2015; Youdas 1996; Youdas 2006; Zhou 2020; Zweirzchowska 2020). Similar to the findings in thoracic relationship, these articles reported on individuals with normal or overweight categories but did not include obese individuals. Zweirzchowska (2020) was the only article to report on body adiposity index (BAI) and body fat percentage and found a positive association between BAI and %BF and lumbar lordosis, albeit a low correlation (r=0.15).

Seven articles reported on the difference between body composition groups (obese compared to normal weight), where Bergunudd (1989) and Ando (2020) reported smaller lumbar lordosis angles in obese females compared to nonobese but not for males. Similarly, Horn (2019) and Lang-Tapia (2011) found smaller lumbar lordosis angles across males and females in univariate analyses, however when analyses were adjusted for sex and age, no differences were reported. Celan (2012) reported greater lumbar lordosis across males and females with obesity. Whereas Ohlendorf (2021), and Vismara (2010) reported greater lumbar lordosis angles for obese women only.

Range of Motion

Range of motion data of the thoracolumbar spine was collected for ten of the 44 included articles. Three articles reported a negative association or difference with BMI and ROM. Park (2010) – male data only, reported obese individuals as having smaller range of lumbar extension and lateral flexion. Gilleard (2007) -female data only and Raty (2007) – male data only reported a strong negative association between BMI and thoracolumbar flexion. Hirano (2012)-male data only found a negative association between BMI and thoracic and lumbar ROM. Hirano (2013) reported on women and found a negative association between BMI and lumbar ROM and no association with thoracic ROM. Menegoni (2008) observed thoracic and lumbar curvature and ROM parameters during forward flexion and lateral bending. During forward flexion, obese individuals started with greater trunk inclination but had smaller trunk inclination ROM, maximum kyphosis, and maximum lordosis. During lateral bending, obese individuals had no differences upon initiation and had smaller overall thoracic movement. Two articles reported positive associations or greater ROM: Body fat percentage was associated with greater trunk flexion and rotation Moromizato (2016) and Ohlendorf (2021) reported that obese and pre-obese individuals had greater lumbar bending angles than normal weight individuals. Cau (2017)-females only, reported no differences between obese and non-obese participants during trunk lateral bending and trunk rotation, however, the authors noted a change in center of pressure required to maintain stability. The analyses did not take into account the confounding variable of COP with respect to ROM, as such this article received a score lower than the aforementioned articles on the critical appraisal. Mitchell (2008) segmented lumbar into upper and lower lumbar segment motion and found a weak positive association between BMI and the upper segment ROM and a moderate negative association between BMI and the lower lumbar segment ROM.

Other Measures of Body Composition and Posture

Six of the 43 articles reported on the relationship between body composition and a measure of curvature/posture. These articles were different from the aforementioned articles in the Thoracic Kyphosis and Lumbar Lordosis sections as they either had a measure other than BMI, weight, or body fat percentage **or** they reported a posture outcome in addition to thoracic kyphosis/lumbar lordosis (Arajuo 2014; Jalai 2017; Kudo 2021; Menezes-Reis 2018; Ohlendorf 2021; Pavlova 2017; Pavlova 2018). Arajuo (2014) reported on sagittal posture pattern defined by Roussouly type (a measure based primarily on sacral slope and number of lumbar vertebrae in lordosis), with a positive association between obesity and overweight and non-neutral postures. Jalai (2017) reported a positive association between BMI and global sagittal angle which describes the line between the middle of C7 vertebral body to the knee, to the midpoint between the two femoral condyles and the line extended from this point to the posterosuperior aspect of S1. With respect to muscle mass and fat infiltration no associations were found as Kudo (2021) reported no association between trunk skeletal muscle mass and trunk alignment and Menezes-Reyes (2018) reported no association between fat infiltration and thoracic kyphosis or lumbar lordosis. Pavlova (2017) and Pavlova (2018) investigated spine shapes and variations and spine modes, there were positive associations between BMI with spine mode, and shape variation, which differed for males and females and by age.

6.6 Discussion

To the best of the authors' knowledge, this systematic review was the first review to systematically appraise the English and French literature reporting on the relationship between body composition and curvature and range of motion of the thoracolumbar spine. There was a greater amount of evidence reporting on the relationship with spine curvature compared to range of motion. The levels of evidence (van Tulder et al., 2003) for the relationship between each of these thoracolumbar spine parameters and body composition are discussed.

Thoracic Kyphosis

There was a strong level of evidence (van Tulder et al., 2003) related to thoracic kyphosis as indicated by consistent findings among 6 high quality studies that there was a low-moderate positive relationship between BMI and thoracic kyphosis when BMI was within overweight and obese categories. Within a healthy range of BMI (18.5 and 24.9 kg/m^2) there was moderate evidence that there was no relationship between BMI and thoracic kyphosis. These findings highlight that within a healthy range, there is no association with thoracic kyphosis, however when BMI is above the 25 kg/m^2 cut-off there is a positive relationship resulting in an increase in thoracic kyphosis.

Increased kyphosis, while commonly associated with age, was determined across age groups. Hyperhyphosis is commonly investigated in older adults, an often referred to as an age-related condition furthering age-related stereotypes (Hirano et al., 2012; 2013). As older adults may have other comorbidities such as disc disease, vertebral fractures, reduced physical fitness, it is unsurprising that muscular weakness and decreased mobility are highlighted (Katzman et al., 2010). However, it is important to note that this review demonstrated increased kyphosis across middle age adults which was associated with high BMI. Though few studies in this review characterized a breadth of BMI and young adults, evidence of increased kyphosis has been demonstrated in young adults, especially for women. Studies on women's chest size, a further body composition metric, highlight how young females are similarly subjected to increases in kyphosis and changes in musculoskeletal responses due to increased anterior loading (Johnston et al., 2021; Schinkel-Ivy et al., 2016; Steele et al., 2018). This review demonstrates that increases in thoracic kyphosis should be considered with other biopsychosocial variables like body composition rather than assuming age as a sole risk factor for thoracolumbar mechanisms of MSD.

Within the thoracic region, increased kyphosis and resultant multi-segmental vertebral compressive loads and trunk muscle forces are potential mechanisms for MSD. The increase in anterior mass creates a greater moment arm from the spine (Bruno et al., 2012). The increased forces are directly related to the moments required to maintain posture and withstand gravitational forces (Briggs et al., 2007). Demonstrated in simulated models, increasing weight further adds to the increased loading of kyphosis (Bruno et al., 2012). Detrimental increases in loading are potential mechanisms leading to intervertebral disc degeneration, fatigue, soft tissue creep upon other negative MSD related conditions (Adams & Dolan, 2005). Hyperkyphosis can also cause other anthropometric changes such as forward head posture, scapular protraction, reduced lumbar lordosis, and decreased standing height (Katzman et al., 2010). Moreover, the relationships between thoracic kyphosis and shoulder function, as described by Barrett et al., (2016), highlight that these changes may influence the shoulder-spine relationship described in earlier Chapters. Therefore, in addition to the other health-related burdens related to being overweight and obesity, the increase in thoracic kyphosis may result or play a role in spine MSD and potentially extend to shoulder function where further research will be needed.

Lumbar Lordosis

Strong evidence (van Tulder et al., 2003) was reported for the relationship between body composition and lumbar lordosis. All eight studies had low risk of bias according to the critical appraisal and therefore were considered equally in the synthesis. There was a positive relationship between BMI and lumbar lordosis when BMI was within overweight and obese categories. Within a healthy range of BMI (18.5 and 24.9 kg/m^2) there was moderate evidence that there was no relationship between BMI and thoracic kyphosis. Similar to the results for thoracic kyphosis these findings highlight that within a healthy range, there is no association however when BMI is above the 25 kg/m^2 normal cut-off there is a positive relationship resulting in an increase in lumbar lordosis.

The low to moderate positive association between BMI and lumbar lordosis was found for both females and males and across age groups. The effects of these two additional biophysical variables have been cited in previous reviews where although there were differences, no clear linear relationship was found across age (Arshad et al., 2019). The meta-analysis from this review stated that females on average had greater lumbar lordosis than males however only two studies were included to draw these conclusions (Arshad et al., 2019). Sex and age may play roles as confounding variables in the conflicting relationships described between BMI and lumbar lordosis. However, more evidence is needed using homogenous metrics and a range of sex and ages to explore these interactions.

Lumbar lordosis is a key component of maintaining sagittal balance. The lordotic curve assists in bringing central mass over the line of the pelvis and hip joints, additionally supporting locomotion among other postural functions (Been & Kalichman, 2014). Changes to this alignment such as loss of or hyperlordosis have implications for MSD. Chun et al. (2017)

highlighted that a loss in lumbar lordosis is commonly associated with low back pain in the literature. However, Been & Kachliman (2014), highlighted that hyperlordosis had associations with other potential MSD mechanisms. In a study of individuals with spondylolysis, being overweight and a relatively vertical inclination of the S1 endplate (increased lordosis) were predisposing for an anterior translation of L4 on L5 (Schuller et al., 2011). Therefore, the positive relationship with BMI and lordosis, may play a role in MSD due to known concerns associated with greater lordosis angle such as the development of spondylolysis and ventral slippage lumbar vertebrae (Schuller et al., 2011).

Given the strong evidence that BMI increases lumbar lordosis and thoracic kyphosis, it is posited that the increased curvatures of both regions is an adaptation to the increased mass. Although inconsistent evidence whether greater lordosis is associated increased or decreased kyphosis (Been & Kalichman, 2014), positive relationships have been demonstrated (Roussouly & Nnadi, 2010). Swayback and flatback postures are commonly used terms to describe relationships between the two thoracolumbar curves (Roussouly & Nnadi, 2010). However, neither capture increases with both kyphotic and lordotic alignment. Therefore, the ramifications of such alignment are less known. While implications of hyperkyphosis and hyperlordosis are independently known, further research shoulder investigate the implications of both and the interaction with BMI for future MSD.

Range of Motion

Conflicting evidence was determined for the association of body composition with ROM, and there were significantly less articles to report on a relationship. The heterogeneity of the ROM studies did not permit many associations to be described. While three articles described a negative association or limitation in ROM due to high BMI, others also reported positive associations, specifically for trunk flexion. Cau and colleagues, further evaluated ROM measures for the upper extremity in addition to the thoracolumbar region and determined limitations in ROM in the upper limb movements but not the spine (Cau et al., 2017). As indicated by Cau (2017) and Gilleard (2007) changes in centre of pressure and hip joint movements are potential stability measures that may adapt or compensate for thoracolumbar ROM. Further, the distribution of body composition for example visceral versus appendicular mass is another confounding factor towards understanding such a relationship between these parameters (Pavlova, 2018). Future studies on the implications of body composition on specific planes of motion for the thoracolumbar region would be an integral step towards interpreting the mechanisms behind the associations between body composition, physical capacity, and MSD.

Additional Considerations

The method in which body composition or spine parameters are collected may impact the relationship between the relationship and outcomes. The article by Zwierzchowska (2020), reported no association between BMI and lumbar lordosis, however, there was an association between body adiposity index (BAI) and lumbar lordosis. While both BMI and BAI are equations used to estimate body composition, this article reflects that a subtle difference in calculation presents changes in the relationship between these two measures. It is also well acknowledged that BMI does not accurately reflect body composition in its simplest form, as the equation only considers height and weight, and does not consider fat mass versus fat free mass. As such, body composition, despite BMI, should also consider multiple components of body composition such as fat mass, muscle mass, and regional distributions as investigated by Menezes-Reis (2018); Pavlova (2017; 2018) The articles by Pavlova (2018) and colleagues and Gilleard (2007) highlight where regional differences in fat distribution and mass can play a role in the relationship of these parameters, especially for ROM. Similarly, for spine parameters, there were many different measurement tools used to reflect spine curvature (Been & Kalichman, 2014). Two numerically similar calculated curvature measurements may correspond to two unique anatomical arrangements of thoracic or lumbar lordosis (Been & Kalichman, 2014). This finding was a major limiting factor to perform further statistical comparisons between papers for this review. Moreover, this highlights methodological considerations, echoed by many researchers, necessitating the standardization of assessment measures.

Sex and gender remain important considerations in the body composition-spine relationship. In this review, the heterogenous sample populations did not permit synthesis on the sex-body composition interaction with thoracolumbar spine structure and function. However, there were 5 studies in which the interaction between sex and body composition highlighted differences in the relationship for spine outcomes between males and females. Previous reviews on outcomes of the thoracolumbar spine have reported on sex and age differences citing differences in these factors (Arshad et al., 2019; Intolo et al., 2009). Asrhad and colleagues reported that younger populations in both sexes had a greater lumbar lordosis and ROM, and that aging significantly reduced lumbar lordosis and the range of ROM in older subjects. In the review by Intolo and colleagues, it was reported that there was a non-linear age-related reduction in lumbar ROM. Sex-related difference is an important covariable as they are related to both body composition and thoracolumbar spine parameters. Musculoskeletal structural differences are one potential explanation for some of the sex differences reported in this review and previous reviews, respecting the notion that regional distributions of adiposity may differ between men and women which would not be capture in the calculation of common metrics like BMI (Swainson, Batterham, & Hind, 2019). For females, chest size also plays a role in body composition, where increases in chest size is related to increased kyphosis (Steele et al., 2020), spine motion (Schinkel-Ivy & Drake, 2016), and trunk muscular responses (Johnston, Wanninayake, & Drake, 2021). The interpretation of sex/gender in relation to the association between body composition and spine outcomes requires further research within a biopsychosocial approach recognizing that the described biophysical differences (chest size, adiposity distributions) also interact with psychosocial factors.

This review provided evidence of a thoracolumbar musculoskeletal relationship to body composition across age groups and diverse samples. While age can be an important modifier of consideration, it is a continuum and can be difficult to categorize. Body composition highlights that biopsychosocial variables are equally important in interpreting potential changes in thoracic kyphosis and lumbar lordosis. As such changes in the thoracolumbar spine, such as decreased muscle mass and strength are often described as age-related degeneration but are actually reflective of accumulated deficits over time (Mitnitski & Rockwood, 2014). However, it is well established that such accumulated deficits can be mitigated through healthy ageing. Examples include appropriate exercise and nutrition which are beneficial for the musculoskeletal system and overall health (Mitnitski & Rockwood, 2014). Imagama and colleagues demonstrated that low BMI, greater back muscle strength, good physical ability, mild pain, good body balance, good spinal parameters and ROM were all factors related to absence of MSD in older adults (Imagama et al., 2019). Therefore, while chronological age is important to establish boundaries of normative data, there are potential biopsychosocial variables such as body composition that are modifiable and potential influences musculoskeletal function towards MSD.

6.7 Conclusion

There is a moderate level of evidence that BMI has a positive relationship with thoracic kyphosis and lumbar lordosis in overweight and obese ranges but not in normal/healthy ranges of BMI. This relationship includes a small to medium positive association. There is limited evidence of a positive association between %BF and thoracic kyphosis. However, the magnitude of difference in curvature angles between obese individuals and non-obese individuals has conflicting evidence.

As highlighted in Chapter 4 and by a previous review by Barrett et al., thoracic kyphosis and lumbar lordosis are substantial contributors to shoulder musculoskeletal function. While this review did not include search terms on the shoulder, the previous evidence indicates that alterations in thoracolumbar function subsequently can impact shoulder function. Moreover, it is well established that obesity and overweight can lead to a multitude of health conditions, multiplying potential for comorbidity with MSD. Therefore, consideration of body composition should be likely be performed when assessing or investigating musculoskeletal function at any region of the body. To accurately do so, there is a need for further standardization of the methods to capture body composition and spine curvature which will assist researchers and clinicians to report on the magnitude of these associations and/or differences. This review highlights that body composition, as a non-modifiable factor, is an important consideration in thoracolumbar spine posture and function, specifically in the thoracic region.

Chapter 7 General Discussion & Conclusion

7.1 General Discussion

As described at the beginning of this document the global aim of this research was to investigate relationships between the shoulder and the spine to further understand factors that impact musculoskeletal disorders and function. This aim was achieved through integrating research approaches from biomechanics as highlighted in Chapter 4 and Chapter 5 with health psychology Chapter 5 and Chapter 6 informed using data from cross-sectional and systematic review methodologies.

Under the biopsychosocial approach and ICF model of function and disability, this research developed an understanding of measurement and modifier considerations in asymptomatic populations, positioning these findings as the body structures/functions and personal factors highlighted in Figure 21. Interpreting factors in asymptomatic populations enables researchers to look at the multi-factorial nature of MSD to further understand why and to whom they happen.

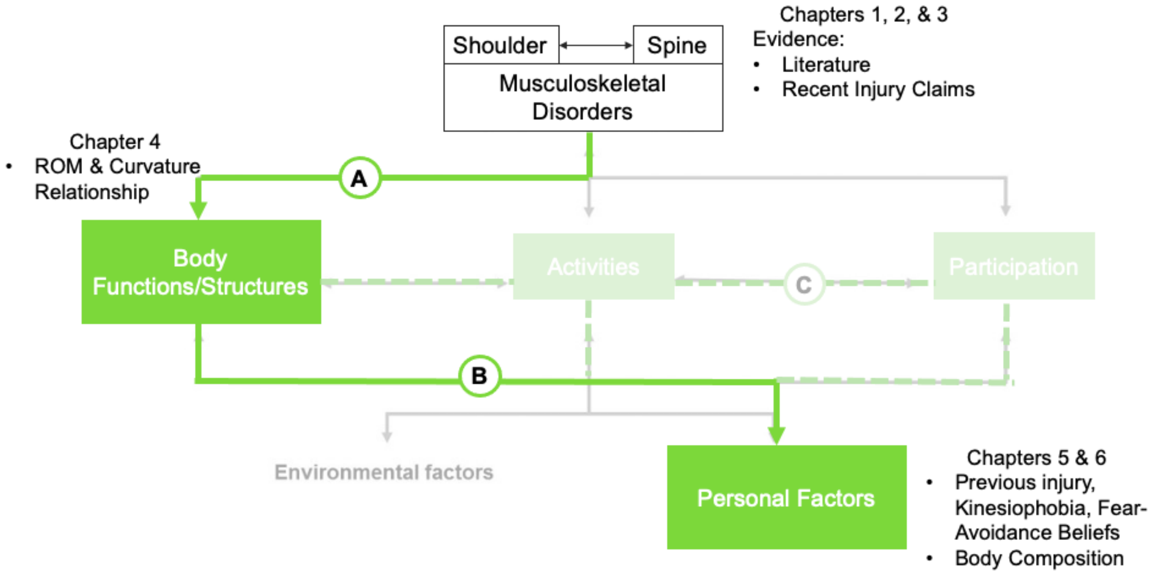


Figure 21. Adapted ICF Model from the World Health Organization (2001) highlighting the key pathways of inquiry (A) (B) and model components investigated in this dissertation (solid lines) and potential directions (dotted lines) for the results of this research.

Complimenting previous literature demonstrating the structural and functional relationship between the shoulder and the spine, Chapter 1 the description of lost time injury claims related to the shoulder and spine in Canada provided an applied rationale to further motivate MSD research to observe factors that impact both the shoulder and the spine. Contrary to the proposed hypothesis, injuries of the shoulder, lumbar (L1-L5), and lower back (non-specific back pain), were consistently high over the years of 2010 through 2018 and had similar injury rates across males and females, with few differences between age groups. This finding motivates future research to dive greater into regional differences and similarities in injury claims trends. The similar high claims for both the shoulder and the spine also motivated further exploration into common factors or modifiers between these two regions set out in the remaining chapters of this dissertation.

Given the shared anatomical and injury claim relationships, Chapter 4 set out to explore current assessment techniques of these two regions, recognizing that these techniques are not commonly interpreted in tandem in clinical practice. Supporting the proposed hypotheses, there were few differences between the bilateral ROM parameters, where males on average had greater anthropometrics yet females had greater ROM. The shoulder and spine shared a multivariate relationship when measured using planar assessment of ROM and curvature supporting the second hypothesis of this section. This finding further supported the pressing need to consider both regions in the assessment of either region, as commonly performed in clinical or biomechanical studies. This multivariate relationship between the shoulder and spine was demonstrated on self-reported asymptomatic young adults, therefore, setting the directions for the subsequent studies within this dissertation.

Asymptomatic young adults were practical participants to study for movement patterns as they are common samples of convenience at research institutions but also are assumed to be free from musculoskeletal damage that might occur with injury or age-related changes. To be included in research studies, these participants are often excluded if they report any injury within the last 12 months or any previous surgical alteration to joint or tissue structure. It is well established that there are psychological consequences of injury and equally accepted that previous experiences can impact human behaviour. Previous injuries and fear-avoidance beliefs were not always considered in participant recruitment and selection and present an important area of variability in measuring human movement. Chapter 6 highlighted that over 40% of asymptomatic young adults have previously sustained shoulder and low back injuries by the time they reach their twenties. Even more concerning, 20% of those injuries can be attributed to work. When asked about fear of reinjury and fear-avoidance pertaining to previous injuries, a large majority (70%) of young adults had clinically high ratings of Kinesiophobia. Those who had sustained previous work injuries also had high fear-avoidance beliefs related to work. These findings highlighted a necessary step in participant classification and a potential psychotherapeutic gap in MSD rehabilitation for young adults.

The specific parameter associations in the multivariate relationship of Chapter 4 demonstrated further evidence that the thoracolumbar spine had a moderate impact on shoulder ROM which motivated this dissertation to investigate a modifiable factor in thoracolumbar posture: body composition. Given the scope of previous literature and published reviews on non-modifiable factors like age and sex on these parameters, it was anticipated such studies would also collect information on body composition. Using the systematic review methodology outlined by the Cochrane collaboration, articles reporting on this relationship in heterogenous populations were retrieved. There was moderate evidence to suggest no association between BMI and thoracic kyphosis or lumbar lordosis within healthy ranges (up to 25 kg/m^2), however beyond that range into overweight and obese categories there is a low to moderate positive association between BMI and thoracic kyphosis and lumbar lordosis. Finally, there was limited evidence (10 heterogenous articles) to discern a relationship between BMI and ROM, however there is a small amount of literature to suggest that thoracolumbar ROM may be limited by obesity.

7.2 Implications

This dissertation provided relationships in the form of the approaches and methods (integrating biomechanics and health psychology through quantitative methods), the regions of the body under investigation (investigating the shoulder and spine), and biological and psychological factors. To capture and interpret this document's relationships for practical implications in research, ergonomics, rehabilitation, and clinical practice, a few considerations emerged. These considerations were grouped into two themes: **Measurement & Modifiers.**

Measurement and Modifiers for Practice (Prevention & Rehabilitation)

The shoulder and the spine are anatomically and functionally related based on previous literature and the evidence in this research. The following modifiers are important in interpreting shoulder and spine function. ***Body composition***, a modifiable factor, may have implications on the posture and function of the thoracolumbar spine. Given the contribution of the thoracolumbar spine posture to shoulder ROM, body composition may not just be a modifier to be considered in spine MSD but also in shoulder MSD as well. ***Kinesiophobia*** may be a latent modifier in young adult behaviour after injury that is often considered during injury recovery and rehabilitation. The long-last effects of a previous injury may include psychological modifiers, like

Kinesiophobia which should be considered as a psychotherapeutic gap in rehabilitation. The following measurement considerations are proposed to improve overall assessment, diagnosis, and management of MSD of the shoulder and spine regions. The assessment of ROM for the shoulder should be performed in consultation with assessment of the ROM and curvature of the thoracolumbar spine. Equally, assessment for spine posture and ROM should be performed with an interpretation of shoulder ROM. The ***relationship between these shoulder and spine regions*** is a measurement that will improve the ability to distinguish compensatory movements versus recovery through inter-joint coordination. In additional to physical assessments, management and rehabilitation of shoulder and spine related MSD should apply a biopsychosocial approach ensuring that return to physical function is paralleled with support for psychological ramifications of injury such as fear of movement or reinjury. Measurement of ***Kinesiophobia*** may highlight where recovery is incomplete.

Measurement and Modifiers for Research (Ergonomics & Biomechanics)

Detailed, controlled research is required to investigate specific mechanisms of MSD for both the spine and the shoulder. However, this research along with the continuum of research looking at inter-joint coordination, trade-offs, and co-activation demonstrate that more studies investigating multiple regions of the body are necessary to further prevent and manage MSD. Future research should begin to look at what other relationship in function exists between the shoulder and spine (i.e, strength, functional capacity tests), as a starting point to describing overall functional relationship between these two regions. Subsequently, more detailed kinematic and kinetic studies can be performed to explore such functional tradeoffs. Naturally, the asymptomatic young adult population continues to be a good starting point for investigation. However, this research demonstrated ***that previous injuries***, ***Kinesiophobia, and body***

composition should be factored into the research design. Future studies should characterize ***previous injuries and the potential psychological consequences*** which may impact future behaviour and be important for interpreting variability in kinematic and kinetic patterns of human movement behaviour of the shoulders and spine. Moreover, future research should further classify research participants with a wide spectrum of ***body composition*** as highlighted by the relationship between high BMI (>30kg/m^2) and spinal curvature and investigate more detailed measures of body composition in relation to the parameters of interest.

7.3 Conclusion

This body of evidence reports that the shoulder and spine share a functional ROM and curvature relationship and that the biophysical consideration of body composition and the psychological outcome of Kinesiophobia after a previous injury are important modifiers in the measurement of the musculoskeletal function of the shoulder and spine. Incorporating measures from clinical biomechanics with a biopsychosocial approach facilitated the adoption of health psychology as a complimentary discipline to biomechanics. Biophysical and psychological modifiers of behaviour were important considerations in young adults, common populations used in biomechanical studies. Shoulder and spine MSD research will improve through future investigation of shoulder and spine musculoskeletal relationships. However, potential variability in such research findings may be addressed by considering personal factors that modify variables of interest like previous injury, impacts on fear of movement and reinjury, and body composition.

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APPENDICES

APPENDIX A: Canadian Labour Force 2010-2018

To determine the lost time injury rates, data were extracted from the Labour Force Survey from Statistics Canada. Depicted in Figures A3 and A4 are age group changes and changes in the distribuion of male and female employed persons from 2010 to 2018. The tables for the data used to calculate injury rates are available through:

https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1410032701#tables

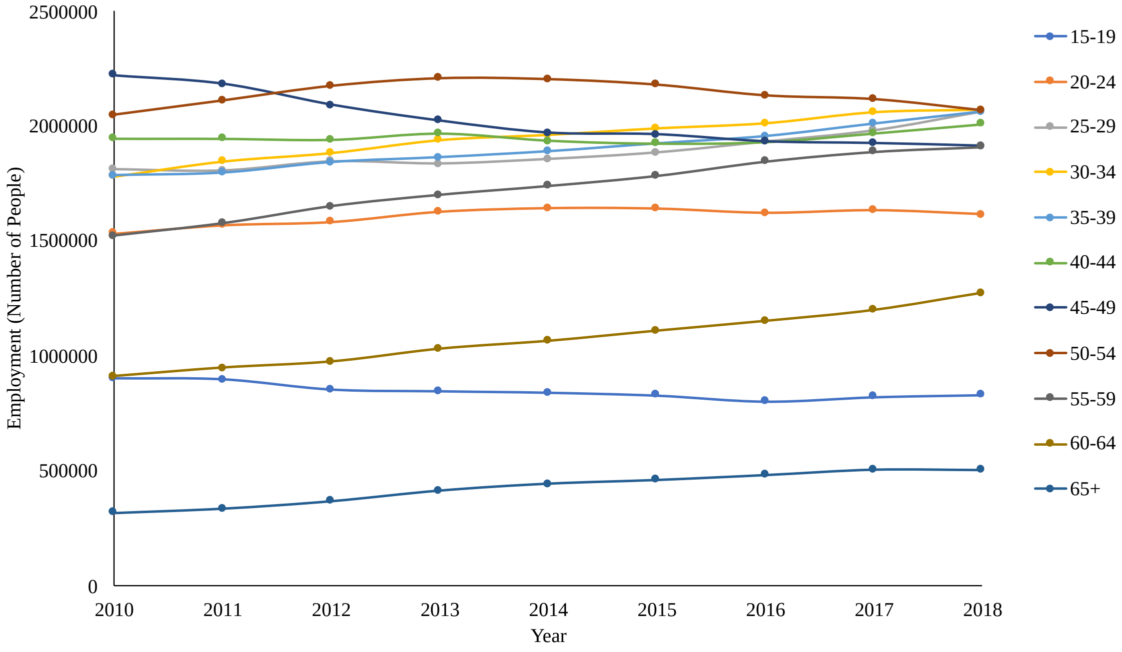

Figure A3 Number of Canadians employed by age group as reported by Statistics Canada. (2019). Labour force characteristics by sex and detailed age group, annual [Table 14-10-0327-01]. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1410032701#tables

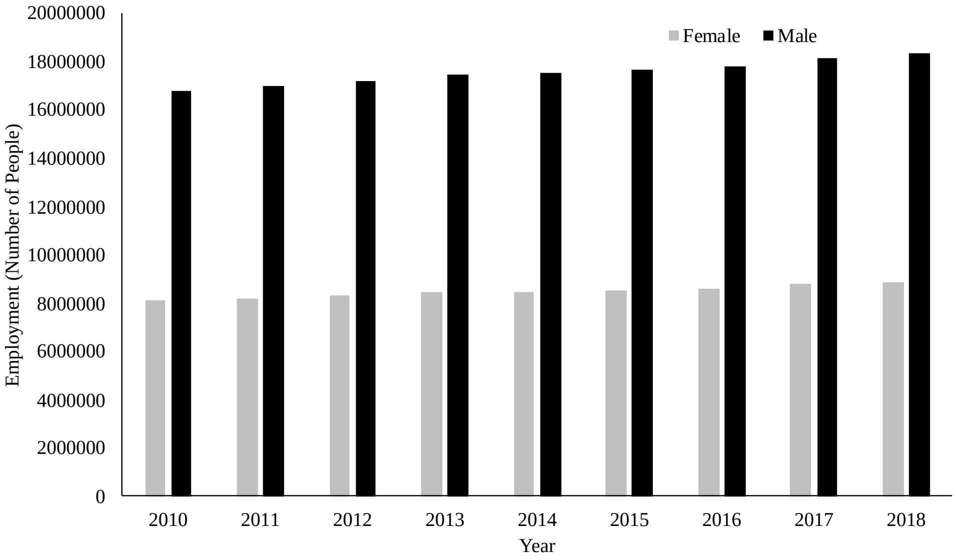

Figure A4 Number of Canadian employed by sex as reported by Statistics Canada's Labour Force Survey (2019) Statistics Canada. (2019). Labour force characteristics by sex and detailed age group, annual [Table 14-10-0327-01]. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1410032701#tables

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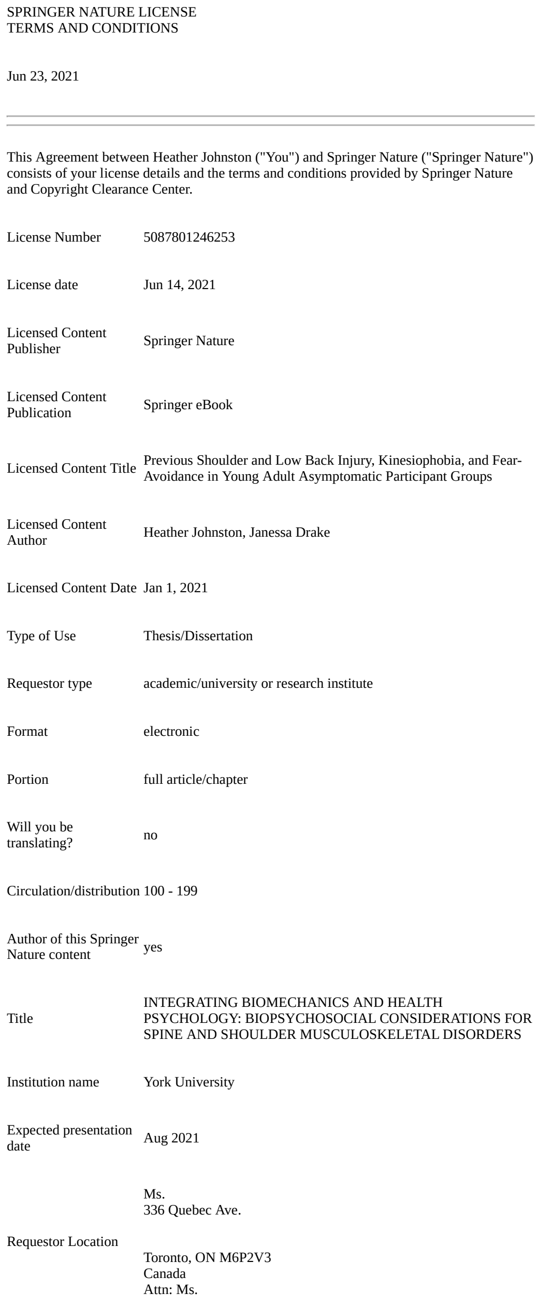

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APPENDIX C: Descriptive Statistics of the TSK and FABQ

The TSK had an internal consistency of α =0.856 demonstrating acceptable internal consistency, however, there was a range of item to total correlations (0.012 to 0.564) as displayed in Table D.1. The FABQw had an internal consistency of α =0.850 demonstrating acceptable internal consistency, where as the FABQpa had an unacceptable internal consistency of α =0.614 Table D.2.

Table D.1. Univariate description of the TSK.

TSK Item (Chronbach's alpha = 0.856)	Missing	Response: 1 = strongly disagree, 4 = strongly agree				Item-Total-Correlation
		1	2	3	4	
1. I’m afraid that I might injury myself if I exercise	0	40	53	35	5	0.545
2. If I were to try to overcome it, my pain would increase	1	34	72	27	1	0.564
3. My body is telling me I have something dangerously wrong	0	60	42	26	6	0.461
4. My pain would probably be relieved if I were to exercise*	0	10	36	77	11	0.049
5. People aren’t taking my medical condition seriously enough	2	64	46	18	4	0.508
6. An accident has put my body at risk for the rest of my life	3	86	35	10	0	0.379
7. Pain always means I have injured my body	0	63	48	17	5	0.353
8. Just because something aggravates my pain does not mean it is dangerous*	0	14	38	62	20	0.012
9. I am afraid that I might injure myself accidentally	0	29	43	47	15	0.381
10. Simply being careful that I do not make any unnecessary movements is the safest thing I can do to prevent my pain from worsening	0	33	48	38	15	0.232
11. I wouldn’t have this much pain if there weren’t something potentially dangerous going on in my body	0	53	55	23	3	0.415
12. Although my condition is painful, I would be better off if I were physically active*	0	17	19	66	32	0.237
13. Pain lets me know when to stop exercising so that I don’t injure myself	1	6	29	73	25	0.277
14. It’s really not safe for a person with a condition like a [shoulder/back musculoskeletal injury] to be physically active	0	79	43	11	1	0.414
15. I can’t do all the things normal people do because it’s too easy for me to get injured	1	77	45	9	2	0.507
16. Even though something is causing me a lot of pain, I don’t think it’s actually dangerous*	0	30	51	42	11	0.253
17. No one should have to exercise when [he/she/they] is in pain	0	31	60	34	9	0.407

Table D.2. Univariate description of the FABQ.

FABQ item	Missing	Response: 0 = completely disagree, 6=completely agree							Item-to- total correlation
		0	1	2	3	4	5	6	
FABQw (Chronbach's Alpha =0.850)									
6. My pain was caused by my work or an accident at work	1	57	27	17	17	12	1	2	0.638
7. My work aggravated my pain	1	41	30	18	23	14	4	3	0.730
9. My work is too heavy for me	0	84	21	17	9	2	1	0	0.619
10. My work makes or would make my pain worse	1	52	19	26	22	5	5	4	0.809
11. My work might harm my [shoulder and/or elbow]	0	47	29	23	24	7	2	2	0.665
12. I should not do my normal work with my present pain	2	56	27	27	18	4	0	0	0.552
15. I do not think that I will be back to my normal work within 3 months	1	94	19	9	9	2	0	0	0.318
FABQpa (Chronbach's Alpha =0.614)									
2. Physical activity makes my pain worse	3	13	34	34	34	12	2	2	0.436
3. Physical activity might harm my [back or shoulder]	1	17	25	34	27	24	5	1	0.430
4. I should not do physical activities which (might) make my pain worse	2	21	21	21	23	26	10	10	0.523
5. I cannot do physical activities which (might) make my pain worse	2	24	32	27	24	16	5	4	0.528
Not related to sub-scale									
1. My pain was caused by physical activity	2	23	21	15	33	29	9	2	N/A
8. I have a claim for compensation for my pain	0	89	23	14	7	1	0	0	N/A
13. I cannot do my normal work with my present pain	0	67	25	20	15	3	2	2	N/A
14. I cannot do my normal work till my pain is treated	0	63	32	18	15	4	1	1	N/A
16. I do not think that I will ever be able to go back to that work	1	92	21	9	9	2	0	0	N/A

APPENDIX D: Systematic Review Search Strategy

Medline Database Example provided.

Body Composition, Gender/Sex Differences & Spinal Curvature
Search Strategy: Ovid MEDLINE(R) ALL <1946 to March 23, 2021>

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1 [Problem: Specific Body Composition Factors]
2 Body Composition/ (43603)
3 "body weights and measures"/ (6617)
4 anthropometry/ (39490)
5 kinanthropometry/ (10)
6 exp body fat distribution/ (15453)
7 body mass index/ (131742)
8 exp body weight/ (475933)
9 exp waist circumference/ (10993)
10 waist-height ratio/ (576)
11 skinfold thickness/ (6131)
12 waist-hip ratio/ (4245)
13 Body Height/ (36632)
14 (adiposity or body mass index or quetelet* index or underweight or thinness or leanness or overweight or obes* or pre-obes* or adiposity or anthropometr* or kinanthropometr*).tw,kw. (508577)
15 (body adj3 (fat or compos* or mass or size or weight or measur* or distribut*)).tw,kw. (495421)
16 (body fat adj3 (percent* or distribut* or pattern* or status)).tw,kw. (14668)
17 (waist* adj3 (circumference or height or hip or ratio*)).tw,kw. (38535)
18 or/2-17 (1020771)
19 [Comparator: Gender/Sex Differences]
20 Sex Characteristics/ (55869)
21 exp sex distribution/ (65101)
22 Sex Factors/ (269967)
23 (sex* or gender*).tw,kw. (1087291)
24 ((male or female or women or men) adj3 (subject* or participant* or volunteer* or client* or patient* or student* or physical exam* or attendee*)).tw,kw. (422810)
25 (male or female or women or men).ti. (511074)
26 ((men or male) adj3 (compar* or versus or between or differen*) adj3 (women or female)).tw,kw. (39934)
27 or/20-26 (1976313)
28 [Outcomes: Spine-Related]
29 exp Spine/ (148581)
30 Spinal Curvatures/ (1354)
31 kyphosis/ (6670)
32 lordosis/ (2542)
33 (spine or spinal or lumbar or vertebra* or intervertebra* or thoracolumbar or trunk* or thoracic).tw,kw. (713693)
34 (kyphos* or hyperkyphos* or lordosis or hunchback or round* back).tw,kw. (16589)
35 or/29-34 (752322)
36 [Outcome Qualifier: Assessment/Measures]
37 exp "Range of Motion, Articular"/ (53535)
38 (assess* adj3 (physical or ROM or functional or clinical)).tw,kw. (143117)
39 (align* adj3 (spine or spinal or lumbar or vertebra* or intervertebra* or thoracolumbar or trunk or thoracic or postur*)).tw,kw. (2308)

40 (lateral bend* or motion characteristic* or coupled motion).tw,kw. (3471)
41 ((spine or spinal or lumbar or vertebra* or intervertebra* or thoracolumbar or trunk* or thoracic) adj5 (curv* or flex* or exten* or mobil* or motion* or movement* or kinematic* or assess* or function* or range* or align* or characteristic* or angle* or postur* or position* or biomechanic* or rotation* or twist* or exten* or shape or uneven or impair* or mechanic*)).tw,kw. (85432)
42 (ROM adj3 (total or segmental)).tw,kw. (462)
43 (motion adj3 (spinal or dynamic or characteristic* or range)).tw,kw. (40988)
44 exp Posture/ (74993)
45 reference values/ (161145)
46 ((method or angle or score) adj3 (flexi-curve or Cobb or vertebral centroid or blocks or Debrunner or RDQ or Roland-Morris or SSA or spino-sacral or spine)).tw,kw. (6305)
47 Physical Examination/ (41437)
48 (physical adj3 exam*).tw,kw. (74705)
49 or/37-48 (618441)
50 18 and 27 and 35 and 49 (2765)
51 limit 50 to "humans only (removes records about animals)" (2654)

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APPENDIX E: Systematic Review Screening Forms for Level 1 (Title and Abstract) and Level 2 (Full Text)

Review on Body Composition, Sex/Gender, and Spine Outcomes Level 1 Reviewer Guide

The objective of this review is to determine the relationship between body composition, sex/gender, and spine outcomes (curvature and range of motion).

The guide is designed to provide all reviewers with the same information. Each reviewer should become thoroughly familiar with the guide prior to conducting the review. Inter-rater variability should be minimized by each rater's familiarity with the guide.

These questions are designed to remove articles not relevant to our research question. Once an article has been excluded at a particular question, all remaining questions will be skipped and do not need to be answered.

To facilitate the review process, a summary of inclusion/exclusion criteria has been provided under each question. Please do not interpret or vary from the definitions/criteria supplied in the guide.

Reviewers are reminded to err on the INCLUSIVE side at Level 1 – relevance screen. If it is difficult to determine from the title and/or abstract whether the article meets the inclusion criteria, select "MAYBE" and carry on to the next article. At Level 2 – Full Text review, reviewers should be more critical in screening articles against our inclusion/exclusion criteria.

If only the title is provided, without an abstract, select "UNCLEAR" unless it is absolutely obvious the title is not relevant for this review.

Please contact Heather [redacted] if you are unclear or have problems using the guide as written. We are trying to minimize differences between reviewers by strictly following the definitions as outlined in this guide.

Q1. Is this an original research study?

Possible responses:

○ Yes (proceed to Q2)
○ No (article is NOT relevant and should NOT proceed to Level 2; click NO)
○ Unclear (proceed to Q2)

The reviewer is asked to identify the study methodology used in order to exclude publications that are not original research studies.

At Level 1 (Relevance Screen), if the methodology is not mentioned or unclear from the abstract, reviewers should classify these articles as 'UNCLEAR'. Please err on the inclusive side if you are unsure.

Below is a summary of the relevant operational definitions and inclusion/exclusion criteria to consider when answering this question.

	Inclusion	Exclusion
Language	- All languages	

Publication Type	- Original research studies from the peer-reviewed and grey literature - Published or in press as full reports, including dissertations	- Any work that is not an original research study (e.g., editorials, book chapters, abstracts, conference proceedings)
Study Design	- Quantitative study designs - Systematic Reviews & Meta	- Case studies - Qualitative study designs

Q2. Does this study appear to measure body size, weight, or composition (include obesity, body weight, overweight) in any way?

Possible responses:

- Yes (proceed to Q3)
- No (article is NOT relevant and should NOT proceed to Level 2 click NO)
- Unclear (proceed to Q3)

Q3. Does the study appear to measure any measurement of movement or posture of spine/back/trunk/thoracolumbar region?

Possible responses:

- Yes (screening is complete, click **YES**)
- No (article is NOT relevant and should NOT proceed to Level 2; click **NO**)
- Unclear (screening is complete, click **MAYBE**)

Systematic Review on Body Composition, Sex/Gender, and Spine Outcomes

Level 2 Reviewer Guide

The objective of this systematic review is to determine the relationship between body composition and spine outcomes (curvature and range of motion).

The guide is designed to provide all reviewers with the same information. Each reviewer should become thoroughly familiar with the guide prior to conducting the review. Inter-rater variability should be minimized by each rater's familiarity with the guide.

These questions are designed to remove articles not relevant to our research question. Once an article has been excluded at a particular question, all remaining questions will be skipped and do not need to be answered.

To facilitate the review process, a summary of inclusion/exclusion criteria has been provided under each question. Please do not interpret or vary from the definitions/criteria supplied in the guide.

Please contact Heather [redacted] if you are unclear or have problems using the guide as written. We are trying to minimize differences between reviewers by strictly following the definitions as outlined in this guide.

Language Check: Is the whole article in English or French (check entire document)?
Response:

- ○ Yes (proceed to Q1)
- ○ No (click Exclude & TAG: Non-English)

Q1. Does this study only include any of the following outcomes:

- Sit and reach test
- One leg stance
- Timed up and go
- Balance
- Trunk lift test
- Toe touch
- V sit test
- Side plank
- Muscular Strength or Endurance
- Biering-Sorensen Test

Response:

- ○ Yes (click Exclude & Add TAG: [INSERT: Fitness])
- ○ No or Maybe (proceed to Q2)

Q2. Is this study an intervention or appear to investigate another modifier other than body composition?
Response:

- ○ Yes (click Exclude & TAG: Intervention)
- ○ No or Maybe (proceed to Q3)

Q3. Does this study report a different outcome other than spine curvature or ROM?
Response:

- ○ Yes (click Exclude & TAG: Wrong Outcome)
- ○ No or Maybe (proceed to Q3)

Q4: Does this study present the results/data or comment/describe in the text the relationship between body comp and spine curvature or ROM? Can you answer the research objective and are the outcomes in scope?
Response:

- ○ Yes (Include)
- ○ No (click Exclude & add TAG: Aggregate)

TAG LABELS

Excludes (These tags will drop down once you click EXCLUDE see image below)

- Non-English
- Intervention (Any study that looks at altering or modifying the relationship of spine curvature, for example a yoga intervention that does not comment on the relationship. Rationale: unable to determine what the relationship between body comp and spine is due to confounding/moderating/mediating variables)
- Fitness (Any of the above listed measures e.g., Sit and reach, One leg stance, Timed up and go, Balance, Trunk lift, Toe touch, V sit tests. Rationale: these

capture measures of hip/hamstring/pelvic parameters and are not in scope; or Side plank, Muscular Strength, Muscular Endurance, Biering-Sorensen Test. Rationale: these capture measures outside the scope of curvature or ROM).

- Aggregate (Any article that presents the final results/data that is aggregated or does not present the direct relationship of interest)
- Control for Comparison (Any study where areas of interest are present, but for only healthy as compared to a clinical group (surgical, scoliosis, osteoporosis, etc.))
- Wrong Outcome(Any outcome that is not spine curvature or ROM
I.e., questionnaire data as an outcome, IPAQ, OSWETRSY, Pain Scale, Disability)

APPENDIX F: Systematic Review JBI Critical Appraisal Checklist for Analytical Cross Sectional Studies

JBI CRITICAL APPRAISAL CHECKLIST FOR ANALYTICAL CROSS SECTIONAL STUDIES

Reviewer____Date________________________________

Author____Year_________ Record Number_________

	Yes	No	Unclear	Not applicable
1. Were the criteria for inclusion in the sample clearly defined?	☐	☐	☐	☐
2. Were the study subjects and the setting described in detail?	☐	☐	☐	☐
3. Was the exposure measured in a valid and reliable way?	☐	☐	☐	☐
4. Were objective, standard criteria used for measurement of the condition?	☐	☐	☐	☐
5. Were confounding factors identified?	☐	☐	☐	☐
6. Were strategies to deal with confounding factors stated?	☐	☐	☐	☐
7. Were the outcomes measured in a valid and reliable way?	☐	☐	☐	☐
8. Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

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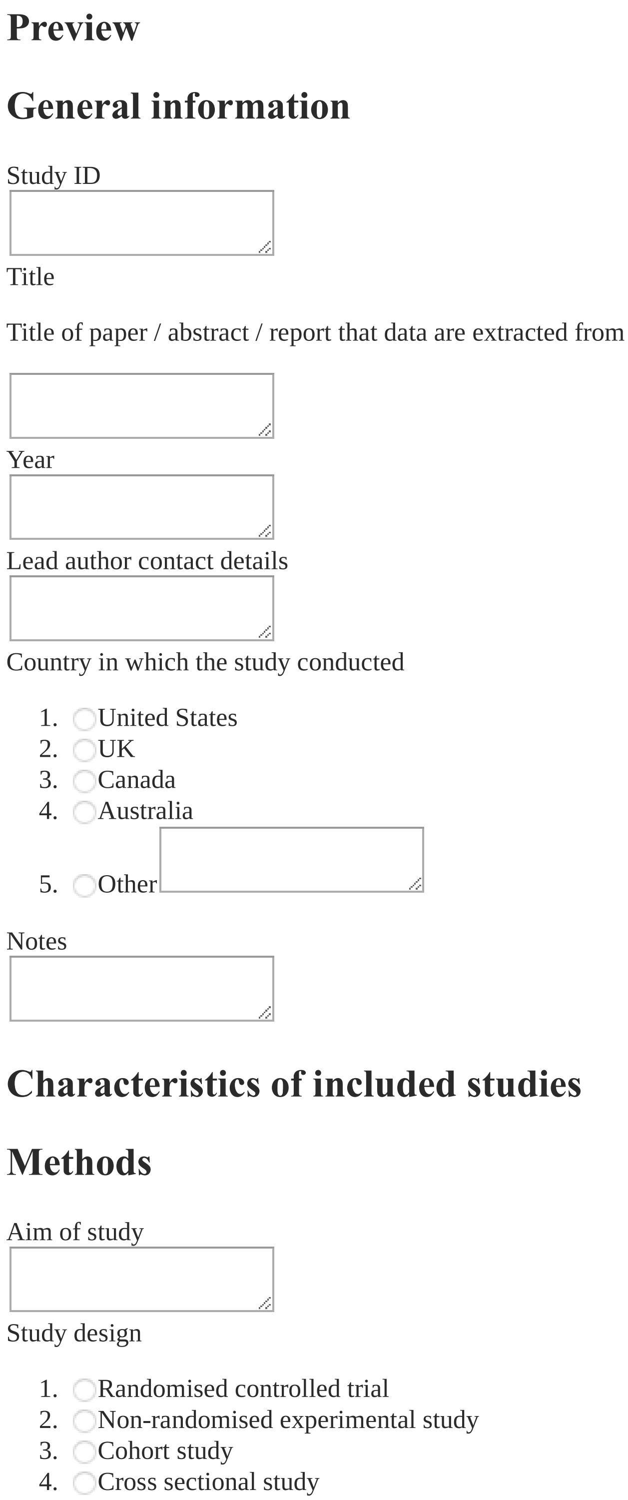
APPENDIX G: Systematic Review Data Extraction Form



Preview

General information

Study ID

Title

Title of paper / abstract / report that data are extracted from

Year

Lead author contact details

Country in which the study conducted

1. ○ United States
2. ○ UK
3. ○ Canada
4. ○ Australia
5. ○ Other

Notes

Characteristics of included studies

Methods

Aim of study

Study design

1. ○ Randomised controlled trial
2. ○ Non-randomised experimental study
3. ○ Cohort study
4. ○ Cross sectional study

5. ○Systematic review
6. ○Prevalence study
7. ○Diagnostic test accuracy study
8. ○Other

Participants

Population description

Inclusion criteria

Exclusion criteria

Method of recruitment of participants

1. ○Phone
2. ○Mail
3. ○Clinic patients
4. ○Voluntary
5. ○Other

Total number of participants

Methods

Measure of Body Composition

1. ○Body Mass Index (BMI)
2. ○Body Fat (BIA or %BF)
3. ○Waist Circumference
4. ○Weight (kg)
5. ○Waist-to-hip ratio (WHR)
6. ○Fat mass/Fat free mass
7. ○Other

Measurement Method/Tool/Technique

list the method used to determine the measure of body comp

Body composition results

Report all relevant group data, for example, if the study has a clinical population and general population. Only report general population. If a study has 2 groups (obese vs. non obese) report the body comp results for both.

"Outcome" Spine Indicators

Measure of Spine

1. ○ Posture
2. ○ Kyphosis
3. ○ Lordosis
4. ○ Range of Motion
5. ○ Other

Measurement Method/Tool/Technique

list the method used to determine the measure of spine function

Body Comp and Spine Relationship Results

Analysis Type

What type of analysis was used to determine the body comp-spine relationship? Test of association = correlations (r values), ratios (odds ratios). Test of difference = t-test, ANOVA (t values/ f-ratios)

1. ○ Tests of Association
2. ○ Tests of Difference
3. ○ Other

Statistical Results

Copy and paste any relevant statistics on the relationship between body comp and spine.

Text Results and Conclusions

Copy and paste any written results or discussion comments made by the author on the relationship between body comp and spine.

Interpretation

Write your interpretation of the relationship between body comp and the spine indicators. For example in a study of association, you may report "There was a positive relationship between body mass and angle of kyphosis in pre-menopausal women." In a study of difference you may report "Individuals with greater BMI had smaller range of motion."

APPENDIX H: Systematic Review Detailed Results Table

Relationship between Body Composition and Spine Systematic Review Results Table

The following table consists of the data extracted to compile the results reporting the relationship between varying measures of body composition and spine outcomes. Descriptive statistics of the population include sex, age groups, measures of central tendency for body composition and spine outcomes. An interpretation of the relationship is portrayed in the final column along with supporting statistical information as relevant.

Notes and Terms from Chapter 6: Table 7

Terms

M: Male
F: Female
BMI: Body Mass Index (units: kg/m^2)
BAI: Body Adiposity Index (units: index)
%BF: Body Fat Percentage (units: %)
Weight (units: kg unless otherwise specified)
Kyphosis (units: degrees unless specified as index)
Lordosis (units: degrees unless specified as index)
(-) negative association
(+) positive association

Age Group Classification

Young adults: 18 through 25 years
Middle age adults: 26 through 64 years
Older adults: 65 years and greater

Body Composition Classification

Normal: BMI 18.5–24.9 kg/m^2
Overweight: BMI 25.0 – 29.0 kg/m^2
Obesity: BMI > 30.0 kg/m^2

Table I.1: Descriptive results from the 44 included studies of the Systematic Review on Body Composition and Spine Outcomes

Author	Design	Sex	Sample	Age (years)	Body Composition	Spine	Relationship
Ando (2020)	Cross sectional study	M/F	N = 286 M n=109 F n=177	64.5 (10.2)	*Mean (SD)* BMI 23.5 %BF 29.2 *F* Non-obese BMI = 22.3(1.9); %BF = 21.2 (3.5) Obese BMI = 27.3 (2.2); %BF =27.5(2.6) *M* Non-obese BMI = 21.2(2.2); %BF = 30.2 (4.7) Obese BMI = 27.5 (2.5); %BF =38.8(5.2) *Total Number of Participants (%)* Non-obese 193 (67.5%) Obese: 93 (32.5%)	*Mean (SD)* Thoracic kyphosis Non-obese 22.9 (10.1) degrees Obese 22.0 (10.6) degrees Thoracolumbar kyphosis Non-obese 7.6 (11.3) Obese 10.1 (11.4) L4-S1 lordosis Non-obese 40.8 (9.9) Obese 37.9 (9.2) Lumbar lordosis Non-obese 45.5 (12.7) Obese 39.4 (10.0)	Thoracic Kyphosis M No difference F: No difference Thoracolumbar Kyphosis M: No difference F: No difference Lumbar lordosis F: Obese < Non-obese (p<0.05) M: No difference L4-S1 Lumbar Lordosis M: No difference F: Obese < Non-obese (p<0.05) ***When adjusted for age, sex: no differences found.**

Table I.1: Descriptive results from the 44 included studies of the Systematic Review on Body Composition and Spine Outcomes

Author	**Design**	**Sex**	**Sample**	**Age (years)**	**Body Composition**	**Spine**	**Relationship**
Araujo (2014)	Cross sectional study	M/F	N = 489 M n=178 F n =311	Age Groups: < 40 n=57(11.7%) 40-64 n = 238 (48.7%) >65 n = 194 (39.7%)	Classified by BMI: Normal Weight n=170 (34.8%) Overweight n = 211 (43.1%) Obese n =108 (22.1%) Classified by Waist Circumference No central obesity n=287 (58.9%) Central obesity n =200 (41.1%)	*Median (25%ile, 75%ile)* Lumbar lordosis All participants 61.6 (54.5, 69.2) Normal Weight 61.9 (54.9, 69.5) Overweight 61.4 (53.9, 69.5) Obese 61.8 (54.7, 71.3) No Central Obesity (WC) 61.9 (54.7,69.2) Central Obesity (WC) 61.4 (53.9, 69.1) Sagittal Vertical Axis All participants -15.9 (-38.8, 6.2) Normal Weight -25.2 (-44.8, 4.1) Overweight -14.7 (-36.6, 8.1) Obese 61.8 -13.1 (-34.7,4.4) No Central Obesity (WC) -22.2 (-42.9, 10.8) Central Obesity (WC) -10.4 (-31.9, 11.6)	Lumbar Lordosis No difference by BMI group (p=0.184) Sagittal Postural Pattern (Roussouly) + association between obesity and non-neutral posture + association between overweight and non-neutral posture *Overweight adults had higher crude and adjusted odds of Type 2 pattern (vs. Type 3) than normal weight subjects (adjusted OR=1.92; 95% CI: 1.13–3.27). The association of overweight with Type 4 postural pattern (vs. Type 3) was statistically significant when adjusted for other characteristics. Being obese (adjusted OR=6.10; 95% CI: 1.52–24.57) and presenting central obesity (adjusted OR53.54; 95% CI: 1.13–11.11) were positively related with Type 1 postural pattern (vs. Type 3), but no statistical relation was observed with Type 2 or 4 patterns.*
Bergenud d (1989)	Longitudinal Design (cross-sectional measure)	M/F	N= 575 M n=323 F n=252	Age Range: 55 years	*Mean (SD)* Weight M 79 (12) F 65(11)	*Mean (SD)* Thoracic Kyphosis M 44(10) F 39 (12) Lumbar Lordosis M 27 (8) F 38(11)	Thoracic Kyphosis: F: + association between weight and thoracic kyphosis (r=0.25, p<0.001) M: no association between weight and thoracic Lumbar Lordosis F: + association between weight and lumbar lordosis (r =0.26, p<0.001) M: no association between weight and lumbar lordosis
Boulay (2006)	Cross sectional study	M/F	N = 149 M n = 78 F n =71	Average 30.8(6.0) years M 30.3 (5.9) years F 31.2 (6.1) yeas	*Mean (SD)* BMI Total 22.7 (2.05) M 23.5 (1.64) F 21.97 (2.15) Weight Total 65.96 (11.7) M 73.2 (9.5) F 58.1 (8.4)	*Mean (SD)* Thoracic Kyphosis 53.77 (10.08) Lumbar Lordosis 66.36 (9.47)	No association between BMI and thoracic kyphosis + association between BMI and lumbar lordosis (r=0.3315, p=0.024)

Table I.1: Descriptive results from the 44 included studies of the Systematic Review on Body Composition and Spine Outcomes

Author	**Design**	**Sex**	**Sample**	**Age (years)**	**Body Composition**	**Spine**	**Relationship**
Cau (2017)	Cross sectional study	F	N= 28 Groups: Obese group (OG) n= 15 Control group (CG) n= 13	Average OG = 42(6) years CG = 36 (9) years	*Mean (SD)* OG Weight (kg) 108.0(21.0) kg BMI: 42.1 (9.10) kg/m CG Weight (kg) 58.0 (8.0) kg BMI: 21.40 (2.80) kg/m2	Median (quartile range) Trunk lateral bending LB-MAX [°] OG :43.04 (6.89) CG: 44.87 (10.05) LB-MIN [°] OG:3.19 (2.30) CG: 3.23 (3.05) LB-ROM [°] OG: 38.61 (9.11) CG: 40.54 (10.7) Trunk Rotation TR-MAX [°] OG: 91.72 (29.05) CG: 86.68 (23.37) TR-MIN [°] OG: 2.48 (1.45) CG: 2.62 (1.78) TR-ROM [°] OG: 86.90 (32.91)CG: 83.04 (23.20)	ROM Trunk Lateral Bending Obese = Non-Obese Trunk Rotation Obese = Non-Obese
Celan (2012)	Cross sectional study	M/F	N= 250; M n =126 F n=124	Average 42.2 (12.2); Range 20-69 years	*Mean (SD)* BMI 26.1 (4.4)	*Mean (SD)* Thoracic Kyphosis All 46.8 (10.1) M 44.6 (9.0) F 49.1 (10.7) Younger (20-45 years) 46.8 (10.2) Older (46-70 years) 46.8 (10.0) Lumbar Lordosis All 31.7 (12.5) M 23.6 (8.0) F 37.7 (12.3) Younger (20-45 years) 31.1 (12.4) Older (46-70 years) 29.8 (12.6)	+ association between BMI and thoracic kyphosis (r = 0.32, p<0.0001) + association between BMI and lumbar lordosis (r = 0.17, p = 0.008) Thoracic kyphosis Less nourished (low BMI) < more nourished (high BMI) (p<0.001) Lumbar Lordosis Less nourished (low BMI) < more nourished (high BMI) (p<0.001)
Demir (2018)	Cross sectional study	M/F	N = 150 M n = 70 F n=80	Average 20.83 (1.80); Range 18-27 years	*Mean (SD)* Weight 63.76 (12.15) BMI 23.30 (2.73)	*Mean (SD)* Lumbar lordosis F 43.16 (9.17) M 42.23 (10.11)	+ association between BMI and lumbar lordosis (r = 0.211, p-0.013)
Eagan (2001)	Cross sectional study	F	N = 61	Average 69.0 (5.3); Range 60.0-78.0 years	*Mean (SD)* Weight 71.7 (15.8) % Body Fat 34.4 (4.8)	*Mean (SD)* Thoracic Kyphosis 53.0 (8.5)	+ association between weight and thoracic kyphosis (r=0.15, p<0.05) + association between %BF and thoracic kyphosis (r=0.26, p<0.05)
Gilleard (2007)	Cross sectional study	F	N=20 Obese: 10 Normal Weight: 10	Average by Group: Obese 44.5 (10.3) years Normal Weight 44.2 (10.1) years	Average SD BMI Obese 38.9 (6.6) Normal Weight 21.7 (1.5)	*Mean (SD)* Thoracolumbar ROM Obese 72.3 (13.9) Normal Weight 96.2 (10.9)	ROM - association between BMI and thoracolumbar flexion (ρ=-0.60, p<0.001) Thoracolumbar ROM Obese < Normal Weight (p<0.001)

Table I.1: Descriptive results from the 44 included studies of the Systematic Review on Body Composition and Spine Outcomes

Author	**Design**	**Sex**	**Sample**	**Age (years)**	**Body Composition**	**Spine**	**Relationship**
Hirano (2013)	Cross sectional study	F	N = 187 Groups: Locomotive syndrome positive (+) n=80 Locomotive syndrome negative (-) n=107	Average 68.0 (3.8) years; Range 50 - 89 years	*Mean (SD)* BMI Total 23.4(3.2) + Locomotive syndrome 24.1 (3.2) - Locomotive syndrome 22.9 (3.1)	*Mean (SD)* Thoracic Kyphosis Total 41.5 (10.3) +Locomotive syndrome 43.0 (11.5) - Locomotive syndrome 40.4(9.30 Lumbar Kyphosis Total -20.3(11.9) +Locomotive syndrome -18.4(13.2) -Locomotive syndrome -21.7(10.7) Thoracic ROM Total 14.7(12.8) +Locomotive syndrome 14.1(14.6) -Locomotive syndrome 15.1(11.3) Lumbar ROM Total 46.2 (17.1) +Locomotive syndrome 43.1(15.7) -Locomotive syndrome 48.6 (17.7) Total ROM Total 105.6 (27.6) +Locomotive syndrome 102.5 (30.0) -Locomotive syndrome 108.0 (25.6)	+ association between BMI and thoracic kyphosis (r=0.278, p<0.05) + association between BMI and lumbar lordosis (r=0.188, p<0.05) ROM - association between BMI and lumbar ROM (r=-0.288, p<0.001) no association between BMI and thoracic ROM

Table I.1: Descriptive results from the 44 included studies of the Systematic Review on Body Composition and Spine Outcomes

Author	Design	Sex	Sample	Age (years)	Body Composition	Spine	Relationship
Hirano (2012)	Cross sectional study	M	n=105 Groups: Locomotive syndrome positive (+) n=31 Locomotive syndrome negative (-) n=74	Average 69.5 (8.2), Range 50-90 years	*Mean (SD)* BMI Total 24.2 (2.6) +Locomotive syndrome 24.3(2.4) -Locomotive syndrome 24.2(2.6)	*Mean (SD)* Thoracic Kyphosis Total 45.3(8.2) +Locomotive syndrome 46.1(8.2) -Locomotive syndrome 44.9 (8.3) Lumbar kyphosis Total -17.4(9.4) +Locomotive syndrome -16.5(10.4) -Locomotive syndrome -17.8(8.9) Thoracic ROM Total 20.2 (11.3) +Locomotive syndrome 22.6(10.7) -Locomotive syndrome 19.1(11.4) Lumbar ROM Total 40.3(17.0) +Locomotive syndrome 36.4(16.0) -Locomotive syndrome 41.9(17.3) Total Spinal ROM Total 98.6(24.0) +Locomotive syndrome 92.9(18.7) -Locomotive syndrome 101.0(25.6)	+ association between BMI and thoracic kyphosis (r=0.218, p<0.001) no association between BMI and lumbar lordosis ROM - association between BMI and thoracic ROM (r=-0.226, p<0.05) - association between BMI and lumbar ROM (r=-0.204, p<0.05)
Horn (2019)	Cohort study	M/F	N= 1600 M n=773 F n= 827 Groups: Obese = 800 Non-obese = 800	Average 56.5 (19.4) years	*Mean (SD)* BMI 29.6 (7.1)	*Mean (SD)* Thoracic Kyphosis Obese 40.62 (16.20) Non-obese 39.18 (17.18) Lumbar Lordosis Obese 47.47 (16.92) Non-obese 51.21 (16.45)	Thoracic Kyphosis Obese = Non-obese (p =0.086) When adjusted for spino-pelvic parameters Obese > Non-obese (p=0.015) Lumbar Lordosis Obese < Non-obese (p<0.001)
Jalai (2017)	Cohort study	M/F	Total N = 554 Obese=277 Non-Obese=277 M=209 F=345	Average 60.29 (15.38) years	*Mean (SD)* BMI 30.32 (7.15)	*Mean (SD)* Thoracic Kyphosis Obese 41.5 (16.68) Non-Obese 39.81 (16.97) Lumbar Lordosis Obese 47.31 (16.65) Non-Obese 46.10 (21.21) Global Sagittal Angle Obese 5.13 (5.28) Non-Obese 3.34 (4.87)	Thoracic Kyphosis Obese = Non-obese Lumbar Lordosis Obese = Non-obese Global Sagittal Angle Obese > Non-obese (p<0.001) + association between BMI and global sagittal angle (r = 0.752, p<0.001)

Table I.1: Descriptive results from the 44 included studies of the Systematic Review on Body Composition and Spine Outcomes

Author	**Design**	**Sex**	**Sample**	**Age (years)**	**Body Composition**	**Spine**	**Relationship**
Kado (2013)	Cohort study	F	N=980	Average 69.1 (3.7) years	*Mean (SD)* Weight 67.5(11.6)	*Mean (SD)* Thoracic Kyphosis Baseline 44.7 (11.9) 1st Assessment (~3 years later) - Progression + 2.6 (4.0) 2nd Assessment (~ 15 years later) - Progression + 7.1 (6.8)	+ association between weight and thoracic kyphosis (OR: 0.08, 95%CI 0.01, 0.16) - association between increase in weight and thoracic kyphosis (OR: -0.20, 95%CI -0.26, -0.15)
Katzman (2012)	Cohort study	M/F	N= 1172 M n=624 F n= 548 Groups: Normal Kyphosis n = 925 Hyperkyphosis n =247	Average by Group: Normal kyphosis 73.6 (2.8) years Hyperkyphosis 74.1 (3.0) years	*Mean (SD)* Weight Normal Kyphosis 75.8(13.9) Hyperkyphosis 72.5(15.9) Trunk Fat (g) Normal Kyphosis 13878.0 (4860.5) Hyperkyphosis 13541.5 (4865.7)	*Mean (SD)* Thoracic Kyphosis Normal Kyphosis 27.2 (8.1) Hyperkyphosis 47.0 (6.5)	Weight Difference Hyperkyphosis > Normal Kyphosis (p<0.001) Trunk Fat Difference Hyperkyphosis = Normal Kyphosis
Katzman (2014)	Cross sectional study	M	Total N= 475 Groups: BMI < 30 n = 399 BMI > 30 n = 76	Average 74.2 (5.86) years Average by group: BMI < 30: 74.7 (5.86) years BMI > 30: 71.6 (5.09) years	*Mean (SD)* BMI Total 26.8 (3.21) BMI < 30 25.8 (2.37) BMI > 30 32.0 (1.54)	*Mean (SD)* Thoracic Kyphosis Total 37.5 (11.90) BMI < 30 37.9 (12.0) BMI > 30 35.2 (11.3)	- association between paraspinal muscle volume + BMI>30 and thoracic kyphosis (p=0.02)
Kudo (2021)	Cross sectional study	F	N = 202	Median 66.9 years; IQR 61.4 - 71.9 years	Median (IQR) BMI 21.4 (19.8-23.3) Trunk skeletal muscle mass 7.45 (6.85 - 7.97)	*Median (IQR)* Thoracic Kyphosis 33.3 (25.1-40.6) Lumbar lordosis 51.6 (42.9-59.3)	no association between skeletal muscle mass and trunk sagittal alignment

Table I.1: Descriptive results from the 44 included studies of the Systematic Review on Body Composition and Spine Outcomes

Author	**Design**	**Sex**	**Sample**	**Age (years)**	**Body Composition**	**Spine**	**Relationship**
Lang-Tapia (2011)	Cross sectional study	M/F	N= 659 M n= 362 W n= 297	Average by sex: F: 36.6 (7.3) years M: 39.8 (7.5) years	*Mean (SD)* Weight F 62.6 (10.5) M 83.9 (12.2)	*Average (SE)* Thoracic Kyphosis Sex F 40.4 (0.6) M 42.8 (0.5) Age 20-29 years 37.5 (1.3) 30-39 years 41.8 (0.5) 40-49 years 42.6 (0.6) > 50 years 42.6 (1.3) Weight Nonoverweight 40.6 (0.5 Overweight 42.7 (0.6) Obese 42.8 (1.1) Lumbar Lordosis Sex F 29.6 (0.7) M (17.3 (0.5) Age 20-29 years 26.7 (1.5) 30-39 years 23.6 (0.7) 40-49 years 20.8 (0.6) > 50 years 20.9 (1.4) Weight Nonoverweight 25.1 (0.7) Overweight 20.9 (0.7) Obese 19.4 (1.4)	Thoracic Kyphosis Overweight and Obese > Normal Weight (p<0.001) Lumbar Lordosis Overweight and Obese < Normal Weight (p=0.014)

Table I.1: Descriptive results from the 44 included studies of the Systematic Review on Body Composition and Spine Outcomes

Author	**Design**	**Sex**	**Sample**	**Age (years)**	**Body Composition**	**Spine**	**Relationship**
Menegoni (2008)	Study of Measurement Properties	F	N = 20 Groups: Obese Group n = 10 Control Group n =10	Average by Group: Obese Group 38.4 (10.2) years Control Group 30.2 (6.8) years	*Mean (SD)* BMI Obese Group 38.7(3.5) Control Group 19.9 (0.8)	*Mean (SD)* *O: Obese* *C: Control* ROM forward flexion movement Forward trunk inclination (deg) START (*) O: 1.3 (2.7) C: 4.9 (2.6) MAX O: 120.0 (9.1) C: 114.2 (7.2) ROM (*) O: 118.9 (9.5) C: 109.3 (6.8) Angle related to kyphosis (deg) START O: 24.5 (6.0) C: 26.0 (4.4) MAX (*) 35.2 (8.4) 27.0 (5.6) ROM (*) 10.5 (8.1) 3.0 (5.0) Angle related to lordosis (deg) START O: 30.8 (5.0) C: 34.2 (11.6) MAX (*) O: -21.2 (2.7) C: -14.9 (6.0) ROM O: 52.0 (4.9) C: 49.1 (6.8) Lumbar movement (deg) START O: -1.4 (5.4) C: -5.5 (14.9) MAX O: 22.9 (5.4) C: 19.7 (13.0) ROM O: 24.4 (5.9) C: 24.3 (12.0) Thoracic movement (deg) START O: -10.7 (6.7) C: -10.9 (17.1) MAX (*) O: 34.4 (5.0) C: 26.0 (7.8) ROM O: 45.0 (8.8) C: 36.4 (11.2) ROM lateral bending movement Lateral trunk inclination (deg) START O: -0.3 (1.0) C: 0.7 (1.2) ROM O: 78.7 (15.4) C: 79.1 (7.3) Lumbar movement (deg) START O: -1.7 (1.7) C: -1.2 (3.2) ROM O: 21.4 (10.3) C: 25.7 (10.2) Thoracic movement ((deg) START O: 2.4 (2.3) C: 3.2 (2.7) ROM (*) O: 59.5 (10.6)C: 48.6 (13.1)	ROM Forward Flexion Obese > Non-Obese greater trunk inclination at start Obese < Non-Obese smaller trunk inclination ROM Obese < Non-Obese smaller maximum kyphosis angle Obese < Non-Obese smaller total kyphosis angle Obese < Non-Obese smaller maximum angle related to lordosis Lateral Bending Obese < Non-Obese smaller thoracic movement ($p<0.05$)
Menezes-Reis (2018)	Cross-sectional	M/F	N= 93 M n= 43 F n=50	Average 27.09±5.3 years	*Mean (SD)* BMI 23.0 (3.3)	Thoracic Kyphosis 37.3 (11.2) Lumbar Lordosis L1-S1 49.5 (11.2) L3-S1 43.8 (9.1)	no association between skeletal fat infiltration and sagittal spine curvature (kyphosis and lordosis)

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Author	Design	Sex	Sample	Age (years)	Body Composition	Spine	Relationship
Mitchell (2008)	Cross sectional study	F	N= 170 Groups: No LBP n = 26 Minor LBP n =81 Significant LBP n = 53	Average by group: No LBP 21.7 (3.5) years	*Mean (SD)* BMI No LBP 21.9 (2.8)	*Mean (SD)* Upper Lumbar Angle 23.4 (11.2) Lower Lumbar Angle 15.5 (9.6) Total Standing ROM Upper Lumbar Angle 55.7 (18.6) Lower Lumbar Angle 39.8 (17.0)	+ association between BMI and upper lumbar angle during standing (r=0.194, p=0.011) ROM + association between BMI and lower lumbar segment motion (r=0.172, p =0.025) - association between BMI and upper lumbar segment motion (r=-0.508, p<0.001)
Miyakoshi (2017)	Cross sectional study	F	N=329 Groups: Osteoporosis n = 236 Volunteer n = 93	Average and 95%CI by group: Osteoporosis 68.7 (68.0, 69.5) years Volunteer 71.0 (69.6, 72.4) years	*Mean (SD)* BMI Osteoporosis 21.9 (21.5, 22.3) Volunteer 23.2 (22.4, 23.9)	*Mean (Range)* Thoracic Kyphosis Osteoporosis 33.8 (30.5, 37.1) Volunteer 27.2 (23.6, 30.8) Lumbar lordosis Osteoporosis 46.5 (42.3, 50.7) Volunteer 14.9 (12.6, 17.3)	no association between BMI and thoracic kyphosis
Moromizato (2016)	Cross sectional study	M/F	N=78 M n= 42 F n = 36	Average by sex: F: 20.8 (1.2) years M: 21.4 (1.9) years	*Mean (SD)* Weight All 57.0 (9.3) F 51.8 (6.4) M 61.1 (9.3) % Body Fat All 20.6 (5.2) F 22.1 (3.3) M 19.4 (6.1) Lean body mass (kg) All 45.3 (8.0) F 40.3 (5.0) M 49.2 (7.8)	*Mean (SD)* Trunk flexion All 35.3 (9.5) F 32.9 (9.3) M 37.3 (9.2) Trunk extension All 28.2 (8.7) F 28.3 (7.6) M 28.2 (9.7) Trunk rotation All 48.3 (10.8) F 43.9 (11.3) M 52.2 (8.8) Trunk lateral bending All 23.2 (4.6) F 21.3 (4.2) M 24.8 (4.4)	ROM + association between %BF and trunk flexion (OR: 0.28 p=0.016) + association between %BF and trunk rotation (OR: 0.29, p = 0.009)
Murrie (2003)	Cross sectional study	M/F	N= 56 M n = 24 F n = 32	Average by sex: F: 45.4 (11.9) years M: 45.1 (16.1) years	*Mean (SD)* BMI F 26.7 (6.5) M 27.3 (3.5)	*Mean (SD)* Lumbar Lordosis F 51.7(9.3) M 44.0 (11.9)	+ association between BMI and lumbar lordosis (r=0.27, P <0.04)

Table I.1: Descriptive results from the 44 included studies of the Systematic Review on Body Composition and Spine Outcomes

Author	**Design**	**Sex**	**Sample**	**Age (years)**	**Body Composition**	**Spine**	**Relationship**
Nishida (2020)	Cohort study	M/F	N = 113 M n=56 F n=57	Count and Range by sex: F: 47 (21 -69) M: 43 (24-80)	Average (Range) M 25 (17.1 - 42.7) F 22.1 (18.1-39.4)	*Mean (SD)* Thoracic Kyphosis 24.1 (8.41) Thoracolumbar Kyphosis 5.7 (8.11) Lumbar Lordosis 35.6 (9.58)	no association between BMI and thoracic kyphosis no association between BMI and lumbar lordosis
Ohlendorf (2021)	Cross sectional study	F	N= 101	Average 55.1 (2.89) years; Range 51 to 60 years	*Mean (SD)* Weight 69.3 (11.88) BMI 25.02 (4.55)	*Mean (SD)* Thoracic Kyphosis 60.49 (16.97) Lumbar Lordosis 56.21 (16.26) Thoracic Bending Angle 14.51 (4.41) Lumbar Bending Angle 14.44 (3.85) Lateral Deviation 3.63 (1.98) Rotation 3.81 (2.19)	Obese > Normal weight thoracic kyphosis (P<0.001) Obese > Normal weight lumbar lordosis (p<0.01) Obese, Pre-Obese > Normal weight lumbar flexion angle (p<0.05) Obese > Underweight lumbar flexion angle (p<0.05) Obese, Pre-obese > Normal weight sagittal trunk inclination (P<0.001)

Table I.1: Descriptive results from the 44 included studies of the Systematic Review on Body Composition and Spine Outcomes

Author	Design	Sex	Sample	Age (years)	Body Composition	Spine	Relationship
Park (2010)	Cross sectional study	M	N=40 Groups: Obese 20 non-obese 20	Average by group: Obese 6.2 (5.6) years Non-obese 22.3 (1.7) years	*Mean (SD)* Body Mass Obese 39.7 (29.7) Non obese 70.0 (7.7) BMI Obese 44.0 (7.4) Non obese 22.5 (1.8)	*Mean (SD)* *ROM* Unilateral Flexion Obese 58.1 (5.8) Non-obese 53.7 (8.8) Extension Obese 24 (4) Non-obese 18.8 (6.4) Left Rotation Obese 12.9 (3.4) Non-obese 12.7 (4.3) Lateral flexion Obese 35 (4.5) Non-obese 28 (5.6) Right Rotation Obese 13.3 (2.7) Non-obese 12.6 (4.3) Lateral flexion Obese 34.8 (4.2) Non-obese 28.4 (6.8)	ROM Obese < Non-Obese lumbar extension (p<0.004) Obese < Non-Obese lateral flexion Right (p<0.001) Left (p<0.001) No difference all other motions.

Table I.1: Descriptive results from the 44 included studies of the Systematic Review on Body Composition and Spine Outcomes

Author	Design	Sex	Sample	Age (years)	Body Composition	Spine	Relationship
Pavlova (2017)	Cohort study	M/F	N= 1511 M n= 729 F n=782	Average by sex: M = 63.2 (1.17) years F = 63.3 (1.09) years	*Mean (SD)* BMI M = 27.7 (3.9) F = 27.2 (4.6)	*Mean (SD)* SM1 M -0.08 (0.97) F 0.07 (1.03) SM2 M 0.02 (1.01) F - 0.02 (0.98) SM3 M - 0.50 (0.98) F 0.47 (0.77) SM4 M 0.05 (0.97) F- 0.04 (1.02) SM5 M 0.04 (1.00) F-0.03 (1.00) 0 SM6 M 0.19 (0.97) F-0.18 (0.99) SM7 M 0.03 (1.04) F - 0.03 (0.96) SM8 M-0.26 (1.00) F 0.24 (0.93)	+ association between BMI and certain spine modes *Partial correlations with BMI **sig. bold*** SM1 M 0.00 F - 0.01 SM2 M 0.08 F - 0.04 SM3 **M - 0.13** **F-0.11** SM4 M 0.00 F 0.07 SM5 M - 0.03 F- 0.07 SM6 **M - 0.12** **F - 0.10** SM7 M - 0.04 F 0.01 0.02 SM8 M 0.06 F - 0.13
Pavlova (2018)	Cohort study	M/F	N=1529 M n= 740 F n= 789	Range: 60-64 Years *Note: followed up as a cohort at 36, 43, 53, 60-64	*Mean (SD)* BMI 36 years M 24.4 (2.86) F 22.9 (3.05) 43 years M 25.3 (3.05) F 24.4 (3.67) 53 years M 27.1 (3.63) F 26.5 (4.42) 60-64 years M 27.7 (3.90) F 27.2 (4.62)	*Mean (SD)* Spine shape modes SM1 M -0.08 (0.97) F 0.07 (1.02) SM2 M 0.01 (1.02) F -0.01 (0.99) SM3 M -0.50 (0.97) F 0.47 (0.77) SM4 M0.05 (0.97) F-0.04 (1.03) *Spine mode described by Pavlova et al.	+ association between BMI and shape variation in lumbar curvature β (95%CI) SM1 – no association SM2 M 0.0841 (-0.162, -0.005) F -0.029 (-0.112, 0.055) SM3 M -0.126 (-0.202, -0.051) F -0.114 (-0.18, -0.049) SM4 M 0.011 (-0.065, 0.087) F 0.085 (-0.003, 0.173)

Table I.1: Descriptive results from the 44 included studies of the Systematic Review on Body Composition and Spine Outcomes

Author	**Design**	**Sex**	**Sample**	**Age (years)**	**Body Composition**	**Spine**	**Relationship**
Raty (1997)	Cross Sectional Study	M	N = 114 Groups: Weightlifters = 29 soccer = 30 Runners = 27 Shooters = 28	Range: 45 - 68 years Average by group: Weightlifters 59.4 (5.4) years Soccer 56.6 (5.7) years Runners 59.6 (4.8) years Shooters 61.6 (4.4) years	*Mean (SD)* BMI Weightlifters 28.8 (3.6) Soccer 26.9 (3.4) Runners 25.3 (2.8) Shooters 26.6 (2.5) P=0.0007	*Mean (SD)* Flexion 18 (7) Extension 35 (8) Total ROM 54 (10) No differences between groups	ROM - association between BMI and trunk flexion (r = -0.26, p=0.005) No association between BMI and trunk extension
Ridola	1994	M/F	N = 28 M= 11 F = 17	Range: 20-48 years	*Mean* *Weight* F 58.1 M 65.7	*Mean* Lumbar Lordosis F 61.8 M 61.6	no association between BBI and lumbar lordosis
Schmidt (2018)	Cross sectional study	M/F	Total asymptomatic = 332 Asymptomatic F 187 M 145 Groups: Soccer M 21 LBP F 45 M 38	Count and Range by sex: F 36 (20-75) years M 39 (20-74) years	*Mean (Range)* BMI F 22.0 (16.7-26.9) M 23.4 (17.9 - 26.9)	Lumbar Lordosis *Infer from Figure 2.*	no association between body weight and lumbar lordosis
Spencer (2013)	Cross Sectional Study	F	N= 51	50-84 years	*Mean (SD)* Weight 71 (11.0) BMI 26.5 (4.7) Breast Size Score 7.8 (2.8)	*Mean (SD)* Thoracic Kyphosis 11.7 (2.9)	no association between BMI and thoracic kyphosis no association between weight and thoracic kyphosis
Steele (2020)	Cross sectional study	F	N = 378 Groups: Not overweight =163 Overweight = 103 Obese = 112	Average by group: Not Overweight 37.2 (1.4) years Overweight 45.2 (1.9) years Obese 54.5 (1.7) years	*Mean (SD)* BMI Not Overweight 22.5 (0.2) Overweight 27.4 (0.3) Obese 35.4 (0.3)	Thoracic Kyphosis *Infer from Figure.*	Obese > Non overweight thoracic kyphosis (p<0.001)

Table I.1: Descriptive results from the 44 included studies of the Systematic Review on Body Composition and Spine Outcomes

Author	**Design**	**Sex**	**Sample**	**Age (years)**	**Body Composition**	**Spine**	**Relationship**
Stone (2015)	Cohort Study	M/F	N=246	*Mean (SD)* 64.5 (7.6) years	*Mean (SD)* BMI Monozygotic twins (MZ) 25.3 (3.9) Dizygotic twins (DZ) 26.5 (4.2)	*Mean (SD)* Thoracic Kyphosis MZ 45.03 (15.65) DZ 42.21 (12.22) Lumbar Lordosis MZ 53.34 (15.12) DZ 54.69 (12.95)	no association between BMI and thoracic kyphosis no association between BMI and lumbar lordosis
Tuzun (1999)	Cross sectional study	M/F	N = 150 Groups: Acute Pain M n=18 F n=32 Chronic Pain M n= 6 F n =44 Control M n=8 F n = 42	Control Group 46.5 (13.1) years	*Mean (SD)* BMI 26.2 (2.9)	*Mean (SD)* Thoracic Kyphosis 28.0 (10.7) Lumbar Lordosis 46.0 (13.9)	+ association between BMI and lumbar lordosis (r= 0.191, p = 0.019)
Vismara (2010)	Cross sectional study	F	N = 37 Groups: Obese without LBP n=13 Obese with LBP n =13 Healthy n=11	Average by group: Obese 38.3 (8.9) years Chronic LBP 42.8 (11.9) years Control 31.9 (8.6) years	*Mean (SD)* BMI Obese 39.2 (3.6) Control Group 20.1 (1.2)	Lumbar Lordosis Obese 32.7 (8.6) Control 30.2 (5.2)	Lumbar Lordosis Obese > Healthy (p<0.05)
Woods (2020)	Cohort study	M	N = 1092	72.8(SD = 5.5)	*Mean (SD)* BMI Groups: Cobb Angle > 50 degrees 26.91 (3.72) Cob Angle < 50 degrees 27.54 (3.92)	*Mean (SD)* Thoracic Kyphosis 38.9 (11.4)	no association between weight and thoracic kyphosis

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Author	Design	Sex	Sample	Age (years)	Body Composition	Spine	Relationship
Yamamoto (2017)	Cross sectional study	M/F	N= 72 M n= 20 F n= 52	Average 77.8 (7.1) years Average by sex: M 80.5 (7.8) years F 76.8 (6.7) years	*Mean (SD)* BMI Total 25.3(4.6) M 25.9(2.8) F 25.1(5.1) Trunk lean mass (kg) Total 20.2(4.2) M 25.2(3.8)* F18.4(2.4)	*Mean (SD)* Thoracic Kyphosis (4 different methods) Cobb Angle All 42.0 (12.4) M 39.8(11.4) F 42.9(12.8) Debrunner All 44.5(11.8) M 47.6(9.3) F 43.2(12.6) Flexi-curve All 13.9(4.9) M 14.1(3.0) F 13.8(5.5) Blocks All 3.2(1.5) M 3.9(1.6) F 2.9(1.3)	+ association between trunk lean mass and thoracic kyphosis *Beta (95%CI) pvalue by method:* Debrunner 1.93(0.15;3.72).03* Flexi-curve 0.83(0.14;1.53).02* Blocks 0.21(0.03;0.40).02* Cobb2.07(0.31;3.82).02*
Youdas (1996)	Cross sectional study	M/F	N = 90 M n = 45 F n = 45	3 Age Groups: 40-49 years, 50-59 years, 60-69 years Average by Sex M 54.8 (8.5) years F 58.9 (8.8) years	*Mean (SD)* Weight M 82.1 kg (13.7) F 67.8 kg (13.4) BMI M 26.6 (3.5) F 26.1 (5.0)	*Mean (SD)* Lumbar Lordosis M 37.5 (11.0) F 52.7 (15.3)	No association between BMI and lumbar lordosis

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Author	Design	Sex	Sample	Age (years)	Body Composition	Spine	Relationship
Youdas (2006)	Cross sectional study	M/F	N = 235 M n= 119 F n= 116	Total n in each age group: 20-29 years n = 21 30-39 years n= 21 40-49 years n = 22 50-59 years n= 18 60-69 years n = 24 70-79 years n = 13 F 20-29 years n = 24 30-39 years n=16 40-49 years n=22 50-59 years n=21 60-69 years n=18 70-79 years n=15	*Mean (SD)* BMI M 20-29 years 24.0 (2.0) 30-39 years 26.4 (2.9) 40-49 years 26.5 (3.5) 50-59 years 26.3 (3.8) 60-69 years 26.2 (3.1) 70-79 years 27.7 (4.1) F 20-29 years 22.8 (2.5) 30-39 years 24.3 (3.6) 40-49 years 23.7 (3.9) 50-59 years 26.9 (5.5) 60-69 years 25.8 (5.5) 70-79 years 23.8 (3.5)	*Mean (SD)* Lumbar Lordosis M 20-29 years 41.2 (8.9) 30-39 years 41.3 (7.1) 40-49 years 40.4 (9.1) 50-59 years 46.8 (8.5) 60-69 years 43.2 (7.7) 70-79 years 27.1 (4.1) F 20-29 years 43.0 (5.5) 30-39 years 49.8 (7.7) 40-49 years 46.5 (11.0) 50-59 years 51.6 (8.8) 60-69 years 49.4 (8.2) 70-79 years 48.9 (5.0)	no association between BMI and lumbar lordosis
Zhou (2020)	Cross sectional study	M/F	N = 235 M n = 89 F n = 146	Average by group: Group A 23.2 (2.6) years; Range 19 - 39 years Group B 53.3 (6.2) years Range 42 - 71 years	*Mean (SD)* Group A (Younger) Weight 60.2 (11.2) BMI 21.1 (2.6) kg/m2 Group B (Older) Weight 65.8 (10.1) BMI 24.5 (3.0)	*Mean (SD)* Thoracic Kyphosis Group A 26.0 (10.3) Group B 34.0 (9.6) Lumbar Lordosis Group A -50.5 (9.4) Group B -51.7 (10.5)	no association between BMI and lumbar lordosis
Zwierzchowska (2020)	Cross sectional study	M/F	N = 1281 M n= 539 F n = 742	Range: 18-22 years	*Mean (SD)* BMI M 22.94 (3.3) F 21.1 (2.9) % BAI M 22.1 (3.9) F 26.0 (3.64)	*Mean (SD)* Thoracic Kyphosis M 37.5 (8.5) F 35.7 (8.5) Lumbar Lordosis M 30.4 (9.4) F 34.4 (8.6)	no association between BMI and thoracic kyphosis no association between BAI and thoracic kyphosis + association between BAI and lumbar lordosis (r=0.20, p<0.05) + association between %BF and lumbar lordosis (r=0.15, p<0.001)