Can ultrasound imaging be used to detect adaptations in the thoracolumbar fascia of people with lower back pain?

Claire Melanie Boucher

School of Sport and Exercise Sciences

University of Kent

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COVID-19 impact statement.

The COVID-19 pandemic has caused multiple disruptions to the work undertaken for this thesis. The subsequent shielding requirements, university closure and various local and national lockdowns have both directly and indirectly impacted the ability to collect data and contribute to this body of work in the expected manner. The intervention chapters have been adapted on multiple occasions to ensure that a full thesis and PhD could be completed.

The disruptions began just 5 months into this PhD on the 24th February 2020 when I began shielding due to being classified as clinically vulnerable, shortly following this date the university closed both campuses (18th March 2020) just before the first national lockdown was implemented on the 26th March 2020. This date marked a pivotal point in the data collection for this PhD, as it was the first date of data collection for the reliability study which of course had to be postponed. Shielding for clinically vulnerable individuals would continue until the 1st April 2021, a full 12-months later. Data collection for this PhD was only able to restart on the 29th September 2021, causing a 18-month delay.

There have been 3 main direct limitations to the completion of this thesis:

The main limitation caused by the COVID-19 pandemic was caused by the inability to access specialist gyms. The original planned longitudinal intervention for this PhD thesis sought to investigate the role of motor-assisted group exercise classes on those with chronic non-specific lower back pain. There are only 3 motor-assisted gyms in the country at the time of writing this statement, all of which were closed throughout the lockdowns, preventing any data collection. As a result, the main longitudinal intervention study, a significant research activity for this thesis changed from investigating motor-assisted exercise to remote 6-month longitudinal online group-based exercise study.

A second limitation caused by the COVID-19 pandemic was caused by the shielding of clinically vulnerable participants. As this thesis seeks to understand the impact of the thoracolumbar fascia on chronic non-specific lower back pain recruited participants need to present with lower back pain themselves. The majority of individuals with lower back pain are often elderly and have other health conditions, this meant that a large number of potential participants were partaking in national shielding for just over 12 months. As a result, despite moving the intervention studies to incorporate online group exercise, the data collection itself could not begin until shielding had officially ended.

A third limitation caused by the COVID-19 pandemic was caused by the closure to university laboratories coupled with the inability to test external participants for just over 12 months. The testing of external participants is an essential part to any exercise physiology research. Equally it is particularly difficult to recruit clinical populations from within the university workforce. As a result, data collection for the reliability study and intervention-based study was halted until after external participants could be bought back into the laboratory.

It should also be noted that Chapter 5 was impacted by COVID-19 related illness, leading to an effect on recruitment and data collection. During the data collection period for this study, I was signed off sick for 2-weeks and as such a number of participants were unable to be scanned a second time by me (the novice rater). To compensate for this, a further recruitment and data collection phase was added but some of the original participants had to be removed from the inter- rater analysis.

Moreover, the unplanned adaptations and prevention of data collection has allowed for a greater multimodal variety to this thesis. Chapter 4 was developed in response to limitations imposed by the third national lockdown and has provided a greater understanding in how to disseminate research findings and literature to physical therapists and fitness professionals treating individuals with lower back pain. The ability to bridge the divide between researchers and clinicians is essential moving forward for any clinical based exercise intervention. This chapter also introduced me to qualitative areas of research and allowed me to be more critical of my own research studies and importantly the impact of interventions.

Abstract.

Chronic non-specific lower back pain (LBP) is a widespread, multi-faceted condition which affects over 80% of the population in their lifetime. Moreover, LBP has been rated as the highest cause of worldwide disability, costing the NHS over £1632 million each year. There are many treatment methods used for the management of LBP with exercise widely recommended as the most effective and cost-effective method, however the mechanism by which exercise can reduce LBP symptoms is still equivocal. Over the past 30 years, the thoracolumbar fascia has become an area of research interest in the aetiology of LBP. Using ultrasound imaging, in-vivo evidence has shown morphological differences in the thoracolumbar fascia of those with and without LBP. The study in Chapter 4 presents the perceptions, preferences, and knowledge of the thoracolumbar fascia of clinicians and practitioners working with patients with LBP. There was an agreement between practitioner groups to treat LBP patients with one-to-one rehabilitation exercises but a lack of consensus around the role of the thoracolumbar fascia which is perhaps in part due to lack of coverage on fascia in educational courses, with over 85% of participants expressing that fascia was not included in their initial anatomy training. Moreover, less than 20% of participants were aware of research on the thoracolumbar fascia and LBP despite a growing literature base in this area. The study reported in Chapter 5 assessed the inter- and intra- rater reliability of a novice and expert rater to use ultrasound imaging to capture and analyse the thoracolumbar fascia. The two raters captured and analysed images from 27 participants, 16 with chronic LBP. Results for inter-rater

reliability between the novice and expert rater reported ICCs ranging from 0.91-0.99 coupled with small SEMs ranging from 0.01-0.02 for echogenicity and 0.14-0.43 mm for thickness measurements. For intra-rater reliability, the novice rater reported very high reliability for the subcutaneous and combined thoracolumbar fascia thickness and moderate for the perimuscular thickness. For echogenicity intra-rater reliability was reported as high for all zones. The study presented in Chapter 6 used ultrasound imaging to investigate morphological differences of the thoracolumbar fascia in individuals with and without LBP. A total of 33 participants were recruited (17 with LBP), however no significant differences between the thickness and echogenicity of the perimuscular thoracolumbar fascia layer of people with and without LBP. The final study reported in chapter 7 was an investigation into the impact of a 6-month movement and exercise intervention on the thickness and echogenicity of thoracolumbar fascia of people with chronic LBP. A total of 45 participants self-reporting with LBP took part in the study and were randomly allocated to one of three groups: an exercise intervention group, a movement prompt intervention and a control group. This study found that a 6-month remote multi-modal exercise programme and a movement prompt intervention had no significant effect on the thickness or echogenicity of the thoracolumbar fascia compared to a control. In conclusion, ultrasound imaging can be used to reliably measure the morphology of the thoracolumbar fascia by both novice and expert raters alike. However, differences in thickness and echogenicity may not be enough to measure adaptations due to LBP. The exercise and movement prompt randomised controlled trial in this thesis found no significant adaptations of the thoracolumbar fascia. However, as this study is the first intervention of this type and duration, evaluating the impact on the thoracolumbar fascia in those with LBP, the findings have provided important insights into the need for further and potentially interventions of longer duration of this kind. The perceptions of fitness professionals and physical therapists study advocates for the inclusion of fascial anatomy in the curricula of physical therapists and those in the health and fitness industry.

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Conference presentations

Poster presentation:
European Pain Federation EFIC – Pain in Europe XII, Dublin, April 2022:

Boucher, C.M, Mauger, L., & De Coninck (2022) Altered morphology of the thoracolumbar fascia in those with lower back pain: An ultrasound study, *European journal of pain,* 2022, pp. 105-6.

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Abbreviations

ANOVA	Analysis of covariance
BMI	Body mass index
ICC	Intra-class coefficient
LBP	Lower back pain
MDC	Minimal detectable change
MRI	Magnetic Resonance Imaging
MS	Microsoft
MSK	Musculoskeletal
PA	Physical activity
PRE	Perceived Rate of Exertion
SD	Standard deviation
SEM	Standard error measurement
USI	Ultrasound Imaging

Chapter 1. Introduction.

1.1 General introduction.

Chronic non-specific lower back pain (LBP) is a widespread, multi-faceted condition which affects over 80% of the population in their lifetime (Vos et al., 2016). Moreover, LBP has been rated as the highest cause of worldwide disability, costing the NHS over £1632 million each year (Hoy et al., 2014 and Maniadakis & Gray., 2000). The range of symptoms associated with LBP have led to a spectrum of definitions in the literature which are mostly commonly split by LBP area (Bogduk., 2009., Dionne et al., 2008, and Koes et al., 2006). This thesis defines LBP by pain originating between the 12th rib and the inferior gluteal folds, with or without accompanying leg pain that is severe enough to limit daily activities for more than 1 day (Dionne et al., 2008). Importantly, an estimated 23% of all LBP cases are considered chronic (Airaksinen et al., 2006) with cases increasing with age until the 6th decade (Bressler et al., 1999). It is likely that LBP increased prevalence observed from the 3rd decade is related to working patterns, a reduction in physical activity and an increase in sedentary behaviour (Hoogendoorn et al., 2000).

The current 2019 UK physical activity recommendations for adults with and without LBP, specifies a minimum of 150 minutes of moderate intensity exercise per week (or 75 minutes of vigorous intensity exercise). This should include a mix of aerobic training with resistance training on at least 2 days (in addition to 2 days of balance work for older adults) (UK Chief Medical Officer's Physical Activity

Guidelines, 2019). For those classified as disabled, it is stated that inactivity is harmful, and that regular physical activity can not only prevent chronic disease and help to improve overall quality of life (although the duration/intensity guidelines are less specific). Despite well publicised physical activity recommendations, approximately 20 million adults in the UK remain physically inactive when compared to the recommended guidelines (British Heart Foundation, 2017). Alongside, the lack of physical activity globally, it has been estimated that 60% of the UK population’s total waking hours are classified as sedentary (Buckley et al., 2015). Emerging research has found that the increased risk factors of developing chronic health conditions (including LBP) associated with reduced physical activity and sedentary behaviour can be managed by breaking up prolonged sitting time by short frequent periods of standing and/or gentle ambulation (Chastin & Granat., 2010., Thorp et al., 2013). Moreover, physical activity is widely recommended as the most effective and cost-effective method to reduce LBP severity and recurrence rates (Owen et al., 2020). Specifically, for pain reduction the greatest results were seen in interventions using Pilates style exercises, for improved physical function stabilisation/motor control exercise interventions, whilst resistance and aerobic exercise interventions proved best for managing the mental health aspects of LBP (Owen et al., 2020). However, the mechanism by which exercise can reduce LBP symptoms is still equivocal in the literature.

Over the past 30 years, the thoracolumbar fascia has become an area of research interest (Benjamin., 2009., Langevin et al., 2011., Stecco., 2015., and Willard et al., 2012). The thoracolumbar fascia covers the muscles of the lower back, sitting between the sacrum and the thoracic region (Kumbar & Bonar., 2014). Research evidence has found that the thoracolumbar fascia contributes to force transfer (Bogduk & Macintosh., 1984), pain perception due to its high level of innervation (Sanchis-Alfonso & Rosello-Sashe, 2000 and Stecco et al., 2017), and importantly LBP (Langevin et al., 2007 and 2011., and Larivière et al., 2020). Using ultrasound imaging, in-vivo research evidence has shown morphological differences in the thoracolumbar fascia of those with and without LBP (Langevin et al., 2009., Langein et al., 2011., De Coninck et al., 2018., and Almazan-Polo et al., 2020). Whilst morphological adaptations have been seen in populations with LBP, it is not yet known whether these adaptations are a cause or effect of LBP or whether the connective tissue structure can be altered following movement and exercise interventions. The reliability of using ultrasound imaging to measure the thoracolumbar fascia has been well researched within the literature (Koppenhaver et al., 2009, Sions et al., 2014, and Whittaker et al., 2013). However, little evidence has investigated the impact of the reliability of these images when captured and analysed by novice raters.

Equally, given the recommendation for the use of physical activity as a primary treatment intervention for those with LBP, of interest to this thesis is how practitioners are treating patients with LBP. Globally there is often no interdisciplinary work between the health and fitness sectors (U Din et al., 2014., and Craike et al., 2019), one study found that just 1.44 patients in every 1000 are referred for exercise physiology support from primary health care (Craike et al., 2019). Furthermore, given recent publications have begun to discuss the need for the inclusion of fascia in anatomy training at university level, (Pratt., 2019), it is important to ascertain how aware physical therapists and fitness professionals are of the thoracolumbar fascia and its potential impact on LBP.

Given this background, this thesis aims to explore if any morphological differences of the thoracolumbar fascia can be observed between populations with and without LBP, whether this can be measured by novice practitioners and whether exercise and movement interventions can be used to alter thoracolumbar fascia morphology.

Chapter 2. Literature Review.

2.1 Lower back pain.

2.1.1 Epidemiology of low back pain.

Lower back pain (LBP) has been attributed to be the leading cause of disability adjusted life years worldwide (Vos et al., 2016). LBP itself recorded an estimated lifetime prevalence could be as high as 84% (Airaksinen et al., 2006). Moreover, studies have shown that more than 80% of individuals will experience LBP at some stage in their lifetime, with up to 66% of the population experiencing an episode in a given year (Patrick et al., 2014). Estimating the prevalence of LBP is particularly difficult due to the variety in definitions used when collecting data and thus can make comparing LBP statistics difficult. Ozgular and colleagues (2000), noted that when LBP prevalence specifically mentioned the need to take days off work, the prevalence was recorded as a low as 8% whereas if the wording focused on pain lasting more than 1 day, rather than time off work, the prevalence rose to 45% in the same population (Ozgular et al., 2000). When understanding the impact on society as a whole, research into the economic burden caused by LBP in 1998 found that the cost to the health care system in the UK reached a total of £1632 million. Moreover, when including factors such as time taken off work the economic burden increases to £10668 million (Maniadakis & Gray, 2000).

The global burden of disease 2010 study rated LBP as highest cause of worldwide disability, and 6th when considering the overall burden caused by disability adjusted life years. The estimated global disability adjusted life years reached a new high of 83 million in 2010 (Hoy et al., 2014). Furthermore, LBP is the leading cause of an individual leaving the workplace; ranking higher than hypertension, coronary heart disease, pulmonary diseases, diabetes, and neoplasm combined (Schofield., 2008). Significantly, when discussing disability associated with LBP it is important to note, that studies have estimated that 40% of all LBP is disabling in nature, thus impacting the patient's ability to partake in activities of daily living (ADLs) and severely impairing their independence and quality of life (QoL) (O'Sullivan and Lin., 2014). QoL is an important factor to consider when investigating LBP, more so with LBP being so rarely experienced in isolation, and many patients experiencing concurrent pain and a decline in overall physical and mental health (Hartvigsen et al., 2013). The concurrent nature of LBP and its comorbidities amplify the negative effects on QoL and the individual's ability to maintain their independence. Moreover, research has shown that those with comorbidities typically exhibit a poorer treatment response than those with LBP alone (Hartvigsen et al., 2013).

Maher and colleagues describe LBP quite succinctly as a symptom rather than a disease, which can originate from a plethora of pathological causes and vary in terms of pain levels, episode duration and frequency (Maher, Underwood and Buchbinder, 2017). The variants in pathology and symptoms of LBP have led to a range of definitions in the literature, most often these are based on the source or type of pain. Bogduk (2009) split LBP into three distinct categories according to the source of pain; pain originating in the L1-L5 area of the spine as axial lumbosacral back pain, nerve or dorsal root ganglion irritation pain traveling to extremities via dermatomal distribution as radicular leg pain and remote pain distinct from the source, but along non-dermatomal trajectory as referred pain (Bogduk, 2009). LBP can also be defined simply as, localised pain, discomfort, muscle tension or stiffness below the costal margin and above the inferior gluteal folds, that can present with or without leg pain (Koes et al., 2006). Alternative definitions can also include a comment towards the impact on daily living (disability adjusted life years, sick days and more).

For the purpose of this thesis, we have chosen to use the Dionne and colleagues (2008) definition which describes LBP by pain originating between the 12th rib and the inferior gluteal folds, with or without accompanying leg pain that is severe enough to limit daily activities for more than 1 day (Dionne et al., 2008). Looking more closely at prevalence of pain zones, these can divide the lower back into 5 sections; the left lateral lumbar region, the immediate paraspinal lumbar region, the right lateral lumbar region, the left gluteal region, and the right gluteal region which can be seen visually below in figure 1.1. A large observational study analysed the anatomical pain location of 828 patients with non-specific LBP, interestingly the authors found that the highest proportion of pain was found in the immediate paraspinal lumbar region (n-130), followed by the right lateral lumbar region(n=68) and the left lateral lumbar region (n=56) (Thiese et al., 2014).

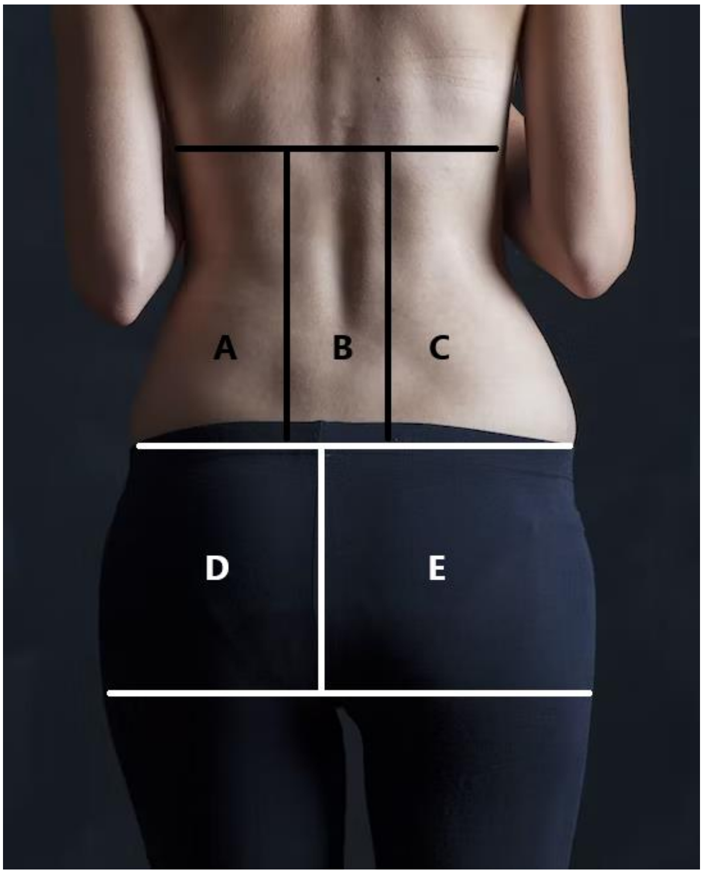


Figure 1.1: Low back pain areas of prevalence.

Zone A represents the left lateral lumbar region, zone B the immediate paraspinal lumbar region, zone C the right lateral lumbar region, zone D the left gluteal region and zone E the right gluteal region. Adapted from Thiese et al., (2014).

Traditionally, LBP was thought of solely in terms of its physical symptoms and its cause linked to any potential abnormalities compared to the multi-discipline biopsychosocial research approach to LBP these days. Of course, LBP can still result from physical abnormalities as spinal deformation, fracture, osteoporosis, infection, inflammatory disorders and more but can also be non-specific in nature whereby no underlying pathology can be identified (Hartvigsen et al., 2018). Moreover, when considering the cause of LBP, a differential diagnosis should also investigate whether the individual has any of the following conditions: aortic aneurysm, fibromyalgia, osteoarthritis of the hip, piriformis syndrome, sickle cell anaemia, amongst others (Deyo and Weinstein., 2001). Due the size constraints of this thesis, this literature review will not attempt to discuss the vast scope of research identifying LBP causes and will instead focus on non-specific LBP, including each aspect of the biopsychosocial model (physical abnormalities, psychological and sociological impacts). The majority of all LBP cases are considered non-specific, with estimates that non-specific LBP accounts for 90% of all cases (Koes, van Tulder and Thomas., 2006). Interestingly, this could be an underestimation, as a 2009 Australian study found that in 1172 acute LBP primary care patients, less than 1% of cases had an underlying pathological cause (Henschke et al., 2009). LBP can be further graded by grouping the duration of episodes into acute or chronic classifications. Dionne and colleagues (2008) developed a new model of classification they argued is most suited to the longitudinal nature of LBP, grouping LBP of less than 3 months into acute episodes and more than 3 months into chronic LBP (Dionne et al., 2008). Koes and colleagues (2017), suggest forming the acute category to include two branches, acute episodes lasting less than 6 weeks and sub-acute lasting between 6 weeks and 3 months (Koes, van Tulder and Buchbinder., 2017). Most acute episodes of LBP resolve (with or without treatment) in a few weeks, however, recurrence rates are high with most patients experiencing a secondary episode (Pengel et al., 2003). It is, however, worth noting that some acute LBP episodes develop into chronic LBP, it has been estimated that between 2-7% of cases follow this trajectory (Costa et al., 2012, Koes, van Tulder and Thomas., 2002). Chronic LBP is seen as a fluctuating condition with poor results for recovery, an earlier study by Costa and colleagues (2009) found that only 41% of chronic LBP experienced full recovery 12 months following the initial onset of pain. Furthermore, the authors noted a visible trend for recovery, where those with increased levels of pain and disability, combined with lower levels of education experienced a slower recovery period (Costa et al., 2009).

2.1.2 Lower back pain risk factors.

Research into an individual's likelihood of developing LBP, and the subsequent chronicity experienced has been widely studied, particularly when it comes to the transition from acute LBP to chronic LBP. When diagnosing LBP cases, it is essential to consider red flags which include age, anticoagulant use, fevers, genitourinary dysfunction, immunocompromise, IV drug abuse, recent surgery and/or trauma (DePalma., 2020). These red flags and there corresponding pathologies can be seen in figure 1.2 below. When red flags are identified patients need to be referred for medical intervention to reduce the risk of serious injury and mortality.

Table 1.1: Lower back pain red flags (Adapted from DePalma., 2020)

Symptoms	**Corresponding Pathology**
Age under 18 years	Congenital abnormality
Age over 50 years	Fracture, malignancy
Anticoagulant use	Spinal haematoma
Fever	Infection, malignancy
Genitourinary issues such as urinary retention or sexual dysfunction	Cauda Equina Syndrome
Immunocompromise	Fracture, infection
IV drug abuse	Infection
Recent surgery or epidural injection	Infection, spinal haematoma
Trauma	Fracture, spinal haematoma
Signs	**Corresponding pathology**
Reduced anal sphincter tone	Cauda Equina Syndrome
Hyperreflexia	Acute cord compression
Hyporeflexia or Areflexia	Cauda Equina Syndrome
Lower extremity muscle weakness	Acute cord compression or Cauda Equina Syndrome
Saddle Anaesthesia	Caua Equina Syndrome

Croft and colleagues (1998) were amongst the first to acknowledge that a combination of individual, occupation and psychosocial factors play a role in LBP development, classifying these as yellow flags. The yellow flags Croft and colleagues noted continue to be relevant, the emphasis on psychosocial markers has grown. Depressive mood and somatisation are now considered to be risk factors for developing LBP, as well as playing a role in the transition from acute to chronic LBP (Pincus et al., 2002). Table 1.1 shows a list of risk factors thought to increase the initial risk of developing LBP, and those that are implicated in the transition from acute to chronic pain. If one considers the biopsychosocial model, LBP risk factors should include not only biological influences but also psychological and sociological factors. The biopsychosocial model was first presented by Engel in 1997, this medical model has since been adapted for routine use and is now recommended for the treatment of LBP (Engel., 1997 and Lin et al., 2020). The Engel biopsychosocial model stresses the importance of treating LBP as a multifaceted condition and how biological, psychological, and sociological aspects can impact both a person’s pain experience and recovery (Gatchel et al., 2007).

Table 1.2: Biopsychosocial risk factors for developing low back pain (Adapted from Gatchel et al., 2007).

Biological	Psychological	Sociological
Age	Anxiety	Low level of physical activity
Sex	Depressive mood	Manual handling
Genetics	High levels of perceived pain	Poor social support
Obesity	Somatisation	Repetitive tasks
Smoking	Stress	Socio-economic status

2.1.2.1 Biological factors.

Further to earlier prevalence statistics, it has been estimated that 23% of all reported LBP cases are chronic in nature (Airaksinen et al., 2006) with cases increasing with age until the 6th decade where interestingly, a decline in reported cases in noted (Bressler et al., 1999). The decline in LBP after the 6th decade is somewhat ambiguous, with studies suggesting that this decline could be due to adaptations to pain perception (Dionne, Dunn and Croft., 2006) and tolerance levels (Gibson and Helme., 2001) in the elderly rather than a decrease in pain itself. Whilst LBP affects both males and females across all age brackets, highest incidence rates have been recorded for the 3rd decade (Hoy et al., 2010). It is likely that this increase in occurrence over the 3rd decade is related to working patterns with occupational factors already associated as a LBP risk factor (Matsui et al., 1997 and Hoogendoorn et al., 2000). Matsui and colleagues (1997) found that LBP prevalence rates in those working in manual labour reached 39% whereas those working in sedentary roles only reached 18.3% (Matsui et al., 1997). Early research suggested that children and adolescents were not affected by LBP unless they experienced an injury and/or life-threatening disorder (Roth-Isigkeit et al., 2003), more recent research has however begun to dispute this. Jeffries and colleagues (2007) completed a systematic review of LBP in adolescents and found that prevalence levels are similar to those found in adult populations (Jeffries, Milanese and Grimmer-Somers., 2007), this finding has been further corroborated in later studies which found that very few adolescents reported pain free periods (Aubinen et al., 2009 and Pellise et al., 2009).

The majority of studies investigating LBP have found no significant differences between male and female cohorts (Hartvigsen et al., 2009), however, the systematic review completed by Hoy and colleagues (2014) found an increased prevalence in both the mean and median values for women. This finding could be due to females being more likely to seek out medical interventions than their male counterparts rather than a specific physiological difference (Adamson, Hunt and Nazareth., 2010). However, it is worth noting that a 2002 study reported that there are no significant differences in the frequency and intensity of a LBP episode, when comparing those that do not seek medical interventions with those that do (Vingard et al., 2002). The willingness or rather lack of willingness of a LBP patient to seek medical support has previously been investigated, with findings suggesting that less than a third of patients consult their doctor within the first 12 months of

LBP (Picavet, Struijs and Westert., 2008). This is particularly important due to the recurrent nature of LBP, as a plethora of studies have found that most LBP cases follow with a recurrent episode (Chen, Hogg-Johnson & Smith., 2007, Elders and Burdorf., 2004, Hestbaek, Leboeuf-Yde and Manniche, 2003, and Wasiak, Kim and Pranksy., 2006). The Hestbaek et al. (2003) study investigated the long-term course of LBP and the subsequent recurrence rates, approximating that 50% of LBP patients will have experienced a secondary episode within the first year, rising to 70% within 5 years of the initial episode (Hestbaek et al., 2003). As such, if the majority of cases reported to medical professionals are 12 months following the initial onset, it is possible these are recurrent episodes.

Another important biological factor to consider when discussing the risk factors associated with LBP is genetic influence. When analysing the genetic influence on LBP, a cellular and molecular approach is needed. Research into plausible genetic factors which may impact LBP have discovered a correlation between maladaptions of pain perception and pain signalling (Tegeder and Lotsch., 2009). A systematic review by Ferreira and colleagues (2013) analysed twin studies on LBP and found that the genetic influence on developing LBP to be as high as 67%, with the highest influence rates found in chronic conditions (Ferreira et al., 2013). Furthermore, a comprehensive epidemiological study attributed a moderate to high correlation between the phenotypes of twins which they suggest could act as a common genetic link for spinal pain (Hartvigsen et al., 2009). The mechanism behind the genetic influence of LBP remains equivocal within the literature, some authors have hypothesized that this is due to variation in the expression of inflammatory cytokines such as interleukin-1, interlerukin-6 and tumour necrosis factor-α (Battie et al., 2007), whist others argue that the mechanism is specific to nerve pain with variation in the nerve growth factor extracted from the degenerative nucleus propulous (Yamauchi et al., 2009). Likewise, others have suggested that this mechanism is of a more psychological basis with alexithymia, fear avoidance and coping strategies all linked to LBP prevalence (Mehling & Krause., 2005, and Junqueria et al., 2014).

Another predictor of LBP is body weight, whilst initial research suggested that increased body weight is a weak risk factor (Leboeuf-Yde., 2000), it is important to consider when investigating those with a body mass index greater than 30 (obese classification) a clear increased rate of LBP occurrence has been found (Webb et al., 2003). This finding has been further corroborated in later meta-analysis studies that found that not only do overweight or obese individuals have a higher LBP occurrence rate but that they are more likely to report to a medical professional (Shiri et al., 2010). It has been implied that this increase in occurrence could be due to physical deconditioning associated with obese populations rather than a direct cause of increased body fat mass (Verbunt, Smeets & Wittink., 2010).

2.1.2.2 Psychological factors

It is important to consider LBP as a multi-dimensional condition, alongside the physiological manifestation (for example: restricted movement and pain) several psychosocial co-morbidities have been linked to LBP somatization, from anxiety and depression to changes in behavioural patterns to include fear-avoidance strategies (van Tulder et al., 2006 and Hoy et al., 2010). Importantly, Chou (2014) attributed a reduction in the effectiveness of LBP treatment strategies and an increase in LBP recurrence in LBP patients with symptoms of somatisation and maladaptive coping strategies. Interestingly, an early UK cohort study found that they could attribute a distressing psychological event in individuals aged 23 to chronic LBP at a 10-year follow up (Power et al., 2001). Further, Currie and Wang (2005), found that when studying pain free individuals, those with depression were more likely to develop LBP within 2 years when compared to those without. There is a growing body of evidence which supports Currie and Wang's (2005) findings that psychological factors can act a predictor of future LBP. Indeed, research has found that low self-efficacy, fear avoidance strategies and pain catastrophizing to be high predictors of poor LBP recovery and a reduced likelihood of returning to work (Nolan et al., 2021). Furthermore, high levels of fear avoidance can also be linked to prolonged work absence and a slower transition back into full duties upon the return to work (Wertli et al., 2014). These findings are important to understanding the full impact of LBP on an individual, this is particularly evident when looking at the effect of prolonged work absence. The literature supports the findings that the longer LBP patients remain off work the chances of them managing to return at all reduces (Waddel and Burton., 2001). As well as these psychosocial factors acting as an antecedence to LBP, these conditions have also been found to begin as a symptom of LBP, and importantly play a key role in the transition from acute to chronic LBP (Bener et al., 2013 and Linton, 2000). The underlying mechanisms between the coexistence and apparent co-dependence of psychosocial factors and chronic pain conditions such as LBP is still undecided in the literature. However, researchers generally agree that plausible linking factors are the shared pathophysiology of pain and psychological distress combined with the loss of dependence and/or social isolation (Stubbs et al., 2016).

2.1.2.3 Sociological factors

Studies investigating the role of socio-economic status and chronic diseases is well researched in the literature, socio-economic status pertains to the social standing of an individual and includes education level, working class and income (Suman et al., 2019). When investigating the impact socio-economic impacts of health, studies have shown that those with a higher status tend to have lower levels of disability and chronic disease as well as living longer (Dalstra et al., 2005). Moreover, there appears to be a linear gradient between disability and socio-economic status, with decreases in disability with each increased status level (Minkler, Fuller-Thomson & Guralnik., 2006). Low socio-economic status is thought to impact chronic diseases via increased levels of social isolation and in turn lack of a support network, a poorer accessibility to healthcare, and due to an increase in negative lifestyle and behavioural patterns; from smoking, sedentary behaviour, and inactivity to an increase in exposure to damaging environmental agent (Adler and Newman, 2002). This decrease in PA in low socio-economic status groups is particularly important when it comes to LBP, as we know that movement shown to decrease the likelihood and severity of LBP episodes (Tsauo et al., 2009). Interestingly, recent research into socio-economic status LBP have shown that higher levels of annual income and education are significantly associated with adaptive beliefs and strategies when it comes to the prevention and management of LBP (Suman et al., 2019). This study further corroborated findings from Deyo and colleagues (2006) and Dionne and colleagues (2001) who respectively found that LBP prevalence, pain level, chronicity and recurrence decline with an increase in socio-economic status. Whilst the potential mechanisms that cause socio-economic status to affect LBP are equivocal in nature, authors have hypothesised that decreased assess to PA could factor into this (Suman et al., 2017).

2.1.2.4 Behavioural factors

Physical activity (PA) consists of any musculoskeletal movement that creates a greater demand on energy expenditure than at rest, and can include both structured activities, such as those with the aim of improving fitness, and unstructured activities (such as activities of daily living, leisure, and occupational activities (Rowley et al., 2020). Regular PA, among a plethora of other health benefits, has been shown to reduce non-specific chronic LBP by 52.5% when compared to non-exercising control (Tsauo et al., 2009). The current 2019 UK PA recommendations for adults, specifies a minimum of 150 minutes of moderate intensity exercise per week (or 75 minutes of vigorous intensity exercise), this should include a mix of aerobic training with resistance training on at least 2 days (in addition to 2 days of balance work for older adults) (UK chief medical officers physical activity guidelines., 2019). Moreover, the NICE guidelines for disabled adults whilst less specific in duration requirements does add that inactivity is harmful and that regular PA can prevent chronic disease and help to improve QoL. It is important to note that despite these government led recommendations, approximately 20 million adults in the UK remain physically inactive (British heart foundation, 2017), a number which has continually increased globally over recent years (Morgan et al., 2016).

Another key factor to consider alongside physical inactivity is sedentary behaviour, often described as a combination of high levels of inactivity and prolonged time spent sitting (Owen et al., 2011). Physical inactivity and sedentary behaviour are not the opposite of each other and can be found together or separately. In order to be classed as physically inactive an individual must not be achieving the minimum physical activity guidelines, whereas to be classed as sedentary is to spend a considerable amount of time sitting and expending less than 1.5 METs (Thivel et al., 2018). Recent studies have begun to further classify this by using step-count, suggesting that completing less than 5000 steps per day equate to a sedentary lifestyle (Tudor-Locke et al., 2013). It has been estimated that 60% of the UK population’s total waking hours are classified as sedentary (Buckley et al., 2015). The widespread nature of sedentary behaviour is thought to be in part due to the increase in office-based roles, importantly when considering office workers, it has been found that up to 75% of working hours are spent sitting (Townsend et al., 2012). Sedentary behaviour is often associated with high levels of inactivity, further increasing the risk factors of developing chronic health conditions including LBP (Buckley et al., 2015). Fortunately, simple daily changes can be implemented to reduce sedentary behaviour in the workplace and beyond. Early research by Chastin and Granat (2010), found that by breaking up prolonged sitting time by short frequent periods of standing and/or gentle ambulation of just a 2-5 minutes could reduce the negative effects of prolonged sitting such as a developing obesity, abnormal glucose metabolism and metabolic syndrome. (Chastin and Granat., 2010). This was further corroborated by Thorp and colleagues (2013), who found that implementing these small changes can reduce LBP by 31.8% (Thorp et al., 2013). However, it is worth noting that whilst some studies investigating sedentary behaviour in the workplace (Corlett., 2006) and during leisure time (Pope, Goh & Magnusson., 2002) seemed to show an increase in the likelihood of an individual developing LBP, recent reviews have begun to dispute this. Tsauo and colleagues (2009) completed a systematic review and found limited evidence to support this, with only one study able to link sedentary behaviour during leisure time with increased LBP and time taken off work (Tsauo et al., 2009). However, the authors cited in their limitations that the weak association found was not enough to assert sedentary behaviour as a LBP risk factor (Hildebrandt et al., 2000).

Several articles have attempted to quantify the impact of smoking on non-specific LBP, early studies seemed to observe that smoking should be considered only as a weak risk factor for LBP (Leboueuf-Yde, 1999) but later studies have begun to contest this. In 2010, a meta-analysis investigating the impact smoking on LBP in adolescents and young adults found a modest association between the two. This association was higher in chronic and disabling LBP cases and interestingly, this association was greater in current smokers than former smokers (Shiri et al., 2010b). Shiri and colleagues (2010b) commented that this association should warrant further investigation rather than acceptance as a definitive risk factor. Noting that smoking is often reported in conjunction with high stress, physically demanding vocations and in those with a poorer mental health status. The authors suggest that smoking could instead act as marker for underlying psychological issues which could themselves contribute to LBP rather than the habit of smoking and the ingestion of nicotine. However, one cannot ignore the possibility the association is linked directly to smoking, a recent analysis by Iizuka and colleagues (2017) hypothesised that a large proportion of chronic non-specific LBP patients could be diagnosed with discogenic pain. The author based this hypothesis following the review of number of animal studies on both cellular and live animal levels. These studies conclude that nicotine treatment can result in disc degeneration via inhibition of cell proliferation & extracellular matrix synthesis, and delineation and reduction of the vertebral end plate (Iwahashi et al., 2002, Akmal et al., 2004., Uei et al., 2006).

2.2 Management of lower back pain.

With LBP affecting such a large proportion of the global population, management of LBP must take a two-fold approach, the first focusing on the prevention of LBP and the second, the treatment of existing conditions. Whilst the scope of this thesis limits the extent one can comment upon the prevention of LBP it is still imperative to understanding the condition. The focus on most literature in this area has been on treatment techniques, however evidence has shown that PA can successfully be used to reduce the likelihood of developing LBP. A recent systematic review and meta-analysis found moderate-quality evidence that exercise can prevent pain intensity levels of future LBP episodes (mean difference −4.50; 95% CI −7.26 to −1.74) and that a combination of exercise and education can prevent disability due to LBP (mean difference −6.28; 95% CI −9.51 to −3.06) (de Campos et al., 2021). This review supports the previous meta-analysis by Shiri and colleagues (2017) who found that exercise alone reduced the risk of developing LBP by 33%. The authors commented however that the only exercise type successfully used to prevent LBP occurrence were those that targeted the spinal and abdominal muscles (Shiri et al., 2017). Prevention, management, and treatment recommendations for LBP vary according to the underlying cause of the condition, the severity of pain and disability and any co-morbidities which may exist, and interventions range from surgery and medication to education and PA (Pederson and Satin., 2015). Whilst the type of PA interventions used in the literature are highly variable, structured PA is arguably the most effective method for the prevention of a range of chronic health conditions, including secondary episodes of coronary heart disease, hypertension, and diabetes (Naci and Ioannidis., 2013 and Naci et al., 2019). As LBP is rarely experienced in isolation and is more commonly found alongside other chronic health conditions, such as those listed above, considering the treatment strategies for these co-morbidities is of relevance to this population (Ritzwoller et al., 2006).

2.2.1 Lower back pain treatment strategies.

For treatment of patients with LBP, initial stage management focuses on returning to normal activities as soon a possible, education and assurance on the recovery and management of pain and the use of non-steroidal anti-inflammatory drugs (NSAIDs) for short periods (Koes et al., 2010). For ongoing chronic and recurrent LBP management focuses on exercise interventions, psychosocial therapy, and the use of NSAIDs and antidepressants (Oliveira et al., 2018). Of interest to this thesis, if the use of exercise to manage LBP.

2.3 Low back pain and exercise.

2.3.1 Exercise recommendations for LBP.

PA has been widely used as a treatment for chronic non-specific LBP since the 1990s, whether prescribed via a general practitioner through avenues such as the exercise referral scheme or self-prescribed by patients (Rainville et al., 2004). A variety of exercise modalities have been tested and reviewed over the years, with some exercise modalities providing greater improvements in pain intensity levels, physical function and mental health and wellbeing than others. As such, a number of review papers and meta-analysis have been completed in an attempt to find the optimum form of exercise for those with LBP (Hayden et al., 2021., and Owen et al., 2020). Owen and colleagues (2020) completed a network meta-analysis to try to answer this question, the authors reviewed a range of exercise interventions, and established five main outcomes for reviewing the effectiveness of each exercise type on the treatment of LBP. The chosen outcomes measures were pain, physical function, mental health, muscle strength and muscle endurance. Interestingly, all but two types of exercise training, stretching and the McKenzie exercise training technique, were seen to improve these outcome measures when compared to a control. The results from the Owen and colleagues (2020) network meta-analysis results demonstrated a clear hierarchy of exercise techniques for the management of LBP which varied according to each outcome. For pain reduction the greatest reductions in pain levels were seen in interventions using Pilates style exercises, for improved physical function stabilisation/motor control exercise intervention scored highest, whilst resistance and aerobic exercise interventions proved best for managing the mental health aspects of LBP (Owen et al., 2020). The authors commented that it is unlikely that there is one single best exercise type for the management of LBP and that instead exercises which actively encourage and guide an individual to move through a progressive approach are the most effective. Further, the authors suggested that exercise interventions should consider client preference when prescribing any exercise therapy for the management of LBP to improve participant enjoyment and importantly, adherence to the exercise programme. A growing body of evidence supports a multi-modal approach as the exercise intervention best suited to LBP. When using exercise intervention as a treatment for health benefits it is important to consider the dose-response relationship (Kesaniemi et al., 2001), this relationship seeks to identify the differences in outcomes according to the amount or dosage of intervention. It has been suggested that the steepest dose-response curve can be found when transitioning from low to moderate PA (Wasfy and Baggish., 2016). Moreover, studies have found that reducing sedentary behaviour and increasing PA gradually will still achieve health benefits even if below the PA guidelines (Manson et al., 2002 and Nelson et al., 2007).

2.3.2 Emerging exercise interventions for low back pain.

An estimated 23% of the general population do not manage to meet the WHO guidelines for physical activity (Prince, 2018). This number is likely higher still in those with chronic health conditions, evidence has shown that this populations records report an average of 8.9-10.1 hours of sitting time per day compared to 7.7 hours/day in a healthy population (Prince, 2018). Sedentary behaviour has been shown to be associated with the risk of and severity of many chronic diseases with research showing that sedentary behaviour is inversely related to health markers (Wilmot et al. 2012). Mahdavi and colleagues (2021) conducted a systematic review and meta-analysis in 2021 which reviewed the association between sedentary behaviour and LBP. After reviewing 49 articles, the authors were able to ascertain that sedentary lifestyle was a considerable risk factor for LBP (odds ratio, 95% CI = 1.24, 1.02-1.05). Interventions to reduce sedentary behaviour and increase general ambulation are beginning to emerge in the literature (Nieste et al., 2021). Prince et al., (2014) reviewed the efficacy of intervention studies which focused on sedentary behaviour and studies which combined PA and sedentary behaviour. The authors found that sedentary behaviour interventions produced clinically meaningful reduction in sitting time (Standardized mean differences = −1.28 [95% CI: −1.68, −0.87]) whilst interventions that included both a PA and sedentary behaviour intervention produced less consistent results. On the whole, combination studies produced a modest reduction in overall sitting time (Standardized mean differences = −0.37 [95% CI: −0.69, −0.05]). Both types of intervention were, however, more successful than a PA intervention alone for reducing sitting time in adults (standardized mean differences = −0.22 [95% CI: −0.35, −0.10]), supporting the incorporation of sedentary behaviour interventions alongside PA. Few studies have investigated the impact of a reduction in sedentary behaviour on LBP, one study by Gibbs and colleagues (2018) investigated the impact of a 6-month multicomponent intervention targeting sedentary behaviour reduction and self-management techniques. Interestingly, whilst pain levels did not significantly reduce between the intervention and control group after 6-months, there was a significant decrease of 50% in LBP disability ($p=0.001$). At present, the Gibbs study is the only known sedentary behaviour intervention aimed at those with LBP, further research is needed to ascertain the impact a reduction in sitting time could have on those with LBP in larger populations.

One potential avenue to increase PA in those with LBP is the use of telehealth and remote exercise classes. Telehealth can be defined as the use of telecommunication techniques (such a video conferencing) for the purpose of providing medical and health education over a distance (Brown et al., 2022). Over the course of the coronavirus pandemic the use and uptake of telehealth services within general practise has increased (Snoswell et al., 2020) and as such PA intervention studies using telehealth methodologies have begun to emerge in the literature (Lai et al., 2020 and Ptomey et al., 2020.). Telehealth interventions and the use of video conferencing may help to mitigate the poor adherence rates seen within the community. With the removal of travel and the associated costs adherence rates for telehealth interventions have been recorded as high as 70% (Brown et al., 2022). A review from Brown and colleagues (2022) found telehealth to be an effective and feasible method of increasing PA levels and importantly quality of life in those with chronic disease. Moreover, earlier studies investigating the safety of telehealth intervention programmes found no increased risk of adverse events when compared to traditional exercise venues (Koh et al., 2016). Expert guidance is needed to ensure risks of adverse events are kept to minimum, especially those with chronic disease, from the form of guided exercise instruction (Zangani et al., 2022). Telehealth, however, does come with its own challenges, technical issues including disturbances to audio-visual quality and diminished connectivity act as the main barrier for telehealth interventions. The review from Brown and colleagues (2022) reported an overall time loss of 17% of instruction time due to technical issues. To manage this, studies have recommended that the provision of technical support and administrative coaching be included in interventions to manage this (Tsai et al., 2019).

2.3.3 Fascia and exercise loading.

Traditionally the effect of exercise, physical activity and movement in people with LBP has been measured by analysing adaptions to muscle tissue, in particular changes in the cross-sectional surface area of trunk muscles and muscle activation patterns (Sions et al., 2014 and Wallwork et al., 2007). More recently, the role of inter- and intra- muscular connective tissue, also known as fascia, has attracted attention. Fascia is a continuum of connective tissue which covers the entire body, holding organs and tissues in place as well as aiding movement (Adstrum et al., 2017., and Benjamin et al., 2009). Despite this, little is known about how fascia responds to exercise, force transmission, and mechanical loading in those with or without LBP. There is however, evidence of other connective tissue types responding to mechanical loading (Kjaer et al., 2009). Kjaer and colleagues (2009) examined the concentrations of TGF-β, PGE2, IGF-I alongside its binding proteins and interleukin-6 in muscles and tendon post exercise loading, finding similar responses between the two following concentric, isometric and eccentric muscle contractions. These similarities suggest that habitual loading is associated with change in both the size and mechanical property of tendons. Despite the different collagen arrangement in tendons compared to TLF, there are some functional similarities. For instance, tensile forces travel through both fascia and tendons

(Butler et al., 1984). In addition, connective tissues such as ligaments (LaStayo et al., 2003) and tendons (Magnusson et al., 2008., and Kubo et al., 2007) have been shown to increase in size and tensile strength following loading to the supporting muscles or tendons. A recent study investigated mechanical loading of the TLF, by measuring the effect of foam rolling on healthy adults N=38 aged 23.34±2.58 years using ultrasound imaging (Griefahn et al., 2017). After 1-session of foam rolling, thoracolumbar fascia mobility improved significantly by 1.78mm ($p<0.001$) compared to the control group, however there were no significant differences seen in mechanosensitivity nor lumbar flexion. The authors hypothesized that foam rolling not only increases the elasticity of muscles as previously shown in the literature (MacDonald et al., 2014), but also the mobility of fascia itself. However, as the study only looked at measurements immediately following an acute intervention it is unknown whether any adaptations remained after the study had ended. Recently, Kablan and colleagues (2022) have investigated the stiffness, tone and pressure pain threshold of the thoracolumbar fascia following stair exercise in n=17 individuals with unilateral transtibial amputation and n=15 individuals with transfemoral amputation. Measurements were taken pre- and post- a nine-step stair exercise intervention with tone and stiffness of the thoracolumbar fascia measured using a myometer, pressure pain threshold using an algometer and LBP using a numerical pain rating scale. Interestingly, in the transfemoral amputation group, pain pressure threshold reduced significantly in both legs (amputated side $p=0.001$, intact side $p=0.021$) following the amputation, likewise thoracolumbar fascia stiffness reduced significantly following the intervention but only on the intact leg ($p=0.019$). Importantly, the authors consider this decrease in pain pressure threshold as a precursor for LBP. Suggesting that exercise programmes which target the thoracolumbar fascia may act as a prevention method for the development of LBP in those with lower limb amputation. A limitation of this study is the use of a myometer to measure the properties of the thoracolumbar fascia due to the superficial nature of the measurement, to confirm the results from this study further research should be completed using ultrasound imaging to confirm morphological adaptations are present. Research is needed to ascertain how fascia morphology and indeed LBP responds to different forms of exercise loading.

2.4 The thoracolumbar fascia.

2.4.1 The anatomy of the thoracolumbar fascia.

The emerging field of fascia research continues to investigate the role of the thoracolumbar fascia in LBP. In general, fascia is perhaps best described as a continuum of connective tissue that covers the entire body surrounding and holding organs and tissues (Benjamin et al., 2009). The term fascia itself is derived from the Latin word for band or bandage, chosen due to the coverage and wrapping the connective tissue exhibits throughout the body. Historically, fascia was thought of solely as a packing layer, surrounding each tissue in the body, dissection and anatomy researchers talked only of fascia as something to be removed to get to interesting part be it the muscles, bones, or organs (Huijing and Langevin., 2009). This approach however, neglected to consider the importance of fascia and the important mechanical and communication roles it plays around the body (Schleip et al., 2012., and Wall et al., 2018). Fascia can be divided into a number of different connective tissue layers, however, the nomenclature around fascia layers is still equivocal amongst different researchers who argue that fascia could be divided by anatomical position (Stecco, 2015), via tissue type (Langevin et al., 2007) or by function (Schleip, Jager and Klinger, 2012). Structurally there are two prominent models used to describe the structure of the thoracolumbar fascia; the two-layered model (Stecco., 2015) and the three-layered model (Scheunke et al., 2012 and Willard et al., 2012). Figure 1.3 below depicts the three-layered model; here the anterior layer included fascia adjoining the anterior edge of the quadratus lumborum, the middle layer attaches to lateral edges of the transverse processes and to the erector spinae and quatratus lumborum muscles forming the aponeurosis of the internal oblique and transverse abdominus. Lastly the posterior layer attaches to the thoracic and lumbar spinous processes and includes the superficial and deep lamina (Scheunke et al., 2012 and Willard et al., 2012). In comparison the two-layered model does not include the aforementioned anterior layer, and instead includes only the middle and posterior layer of the three-layered model (Stecco., 2015). Both models, however, agree that the posterior layer is made up of the posterior aspects of the paraspinal muscles, it is this layer that is of particular interest for this thesis.

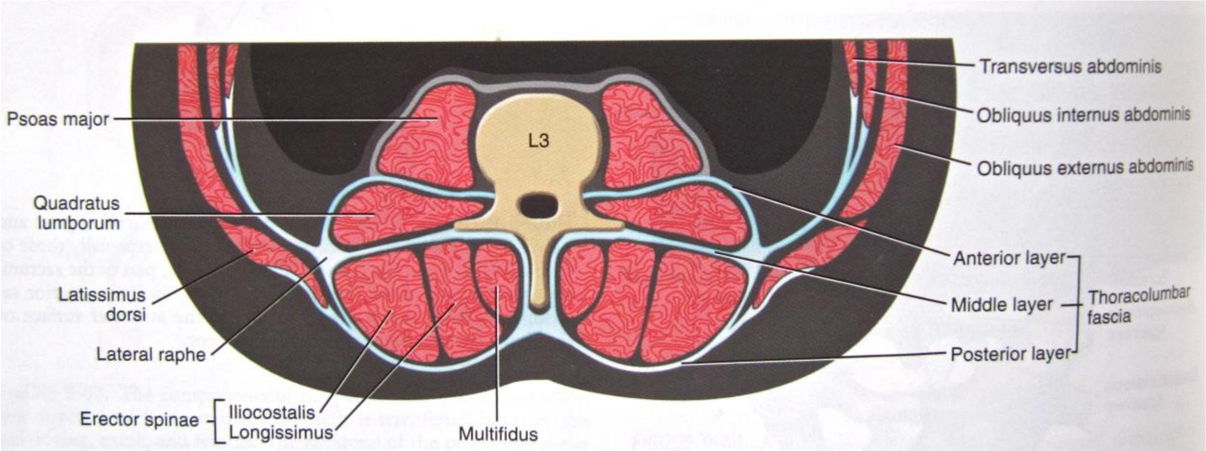


Figure 1.2: Thoracolumbar fascia layers and anatomical location (Neumann, 2010).

The thoracolumbar fascia itself is positioned on the lower back, covering the muscles between the sacrum and the thoracic region (Kumbar and Bonar., 2012). The thoracolumbar fascia which can be seen below in figure 1.4, is a heterogenous structure that consists of multi-layered sheaths densely packed collagen fibres inter-dispersed by loose connective tissue layers, surrounded by hyaluronic acid (Benetazzo et al., 2011). Researchers around the globe have begun to investigate further into the structure and role of the thoracolumbar fascia, (Benjamin., 2009, Gatton et al., 2010, Willard et al., 2012, and Vleeming et al., 1995) each focusing on different components/areas to try and understand exactly what impact the thoracolumbar fascia has on daily functioning. The structure of the thoracolumbar fascia itself varies from person to person, with differing organisation of layers, thickness, and echogenicity visible in-vivo under ultrasound. One study began to the quantify the organisation of the thoracolumbar fascia to four categories;

Organised, somewhat organised, somewhat disorganised, and disorganised, with reliable results among practitioners in the UK (De Coninck et al., 2018).

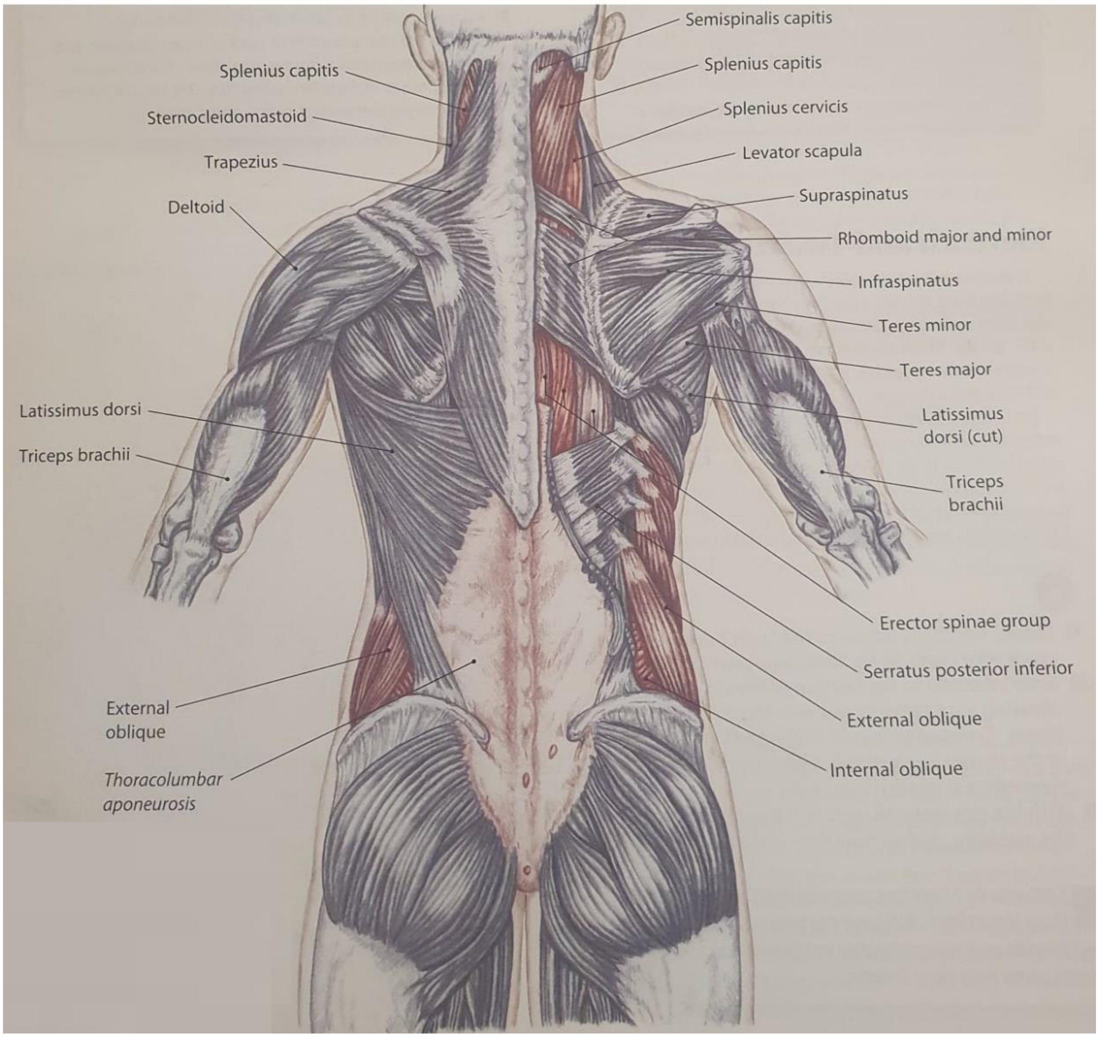


Figure 1.3: Position of the thoracolumbar fascia on the lower back (Biel., 2014).

2.4.2 Force transfer and the thoracolumbar fascia.

Functionally, fascia has been observed to have a wide range of roles, from force transfer, stabilisation, facilitating movement and to proprioceptive communication around the body (Kumbar and Bonar, 2012). The positioning of fascia around the skeletal muscle fibres allows fascia to also play an important role in the facilitation of movement. The loose connective tissue of the fascia leads to the formation of the endomysium and epimysium which allow muscles to move independently of their surrounding muscles whilst the fascia of the back and legs are predominantly formed of dense connective tissue sheets which are made of closely packed collagen fibres (Benjamin et al., 2009). Research first began in 1984, with Bogduk & Macintosh analysing the thoracolumbar fascia in cadaver dissection, here they found clear evidence that force transfer did occur across this area of connective tissue. The thoracolumbar fascia is thought to aid movement and force transfer between the spine, and the muscles of the torso and legs through the posterior layer of the fascia (Mooney et al., 2001). Following an increase in evidence in this area, Barker and colleagues (2004 and 2014) developed biomechanical models showing that when the gluteus maximus muscle is recruited during loading, the muscles fibres are originating from the thoracolumbar fascia. Early research suggested that forces from skeletal muscles are transmitted along connective tissues both within and outside the muscle itself rather than just directly along the muscle to the tendon (Huijing., 1999). Schleip and colleagues (2005) reviewed and examined the force contractions of fascia in animals and in-vitro human studies, hypothesizing that if the same force ratio found in-vitro were applied in-vivo, that fascial contractions would fall into the biomechanically significant range. A follow up review by the authors found that the short-term contraction forces within fascial cells were not strong enough to influence spinal stability or human biomechanics when measured over a period of minutes-hours, however hypothesised that when measured over a longer duration of days-months the contraction may be strong enough to influence biomechanical behaviour (Schleip & Klinger., 2019). Force contractions in this range have been previously found to contribute to spinal segmental instability by loss of fascial tone which has been associated with the onset of LBP (Preuss & Fung., 2005). Equally, this force could contribute to sacroiliac pain and hypermobility of the lumbar spine and pelvis seen during pregnancy (Schleip et al., 2005). Later studies, commented on how the fascia throughout the body was connected and that these force transmissions could travel between zones (between the legs and the torso for example), and even connect the force transfer between agonist and antagonist muscle pairs (Huijing., 2007). Schleip and colleagues (2012b) went on to suggest that the force transfer not only occurs in the posterior layers but also within all layers of the thoracolumbar fascia, detailing how contractions in the muscles surrounding the fascia will allow for tensional changes along the strong aponeurotic fascia. Moreover, the authors refer to the thoracolumbar fascia as a functionally coupled connective tissue due to the number of contractile elements within the tissue. A hypothesis in an earlier study by Schleip and colleagues (2010) proposed that the force transfer and load bearing capabilities of the thoracolumbar fascia in those with LBP can be impaired due to a reduction in muscle contractions during movement.

2.4.3 Innervation of the thoracolumbar fascia.

Several studies have investigated the innervation capabilities of fascia with findings suggesting fascia is a richly innervated tissue (Sanchis-Alfonso & Rosello-

Sastre., 2000, and Stecco et al., 2007), however understanding of fascial innervation remains incomplete. Yahia and colleagues' (1992) paper support the suggestion that fascia can be richly innervated, with their findings of encapsulated nerve endings including Ruffini and Pacinian corpuscles found within the thoracolumbar fascia supporting this (Yahia et al., 1992). Interestingly, a follow up study by Bednar and colleagues (1995), examined samples of the thoracolumbar fascia of patients undergoing surgery for LBP did not find any nerve endings. Animal studies have identified that spastic contraction of the lower back muscles can be triggered by pinching the thoracolumbar fascia in rats, interestingly this response was greater than when muscles of the back were pinched suggesting a higher level of innervation in the fascia (Wilke et al., 2017). Literature has continued to categorically confirm whether the fascia itself is innervated or instead whether the nerve fibres lie on the surface or within the surrounding adipose tissue. The latter can be seen in the iliotibial band where the surrounding tissue exhibits far more innervation properties than the fascia itself (Fairclough et al., 2006). Stecco and colleagues (2008), however argue that one should only consider the innervation properties of fascia alongside its associated muscle attachments, suggesting that when fascia is tensioned by its neighbouring muscles selected proprioceptors are activated to facilitate movement and more (Stecco et al., 2008). Recently a review by Suarez-Rodriquez and colleagues (2022) completed a systematic review of fascial innervation covering 23 studies including a mix of animal and human studies. The review concluded that fascia is a richly innervated organ composed primarily of proprioceptors and nociceptors, with the greater number of nociceptors seen in both physiological and pathological disorders. In the thoracolumbar fascia specifically, a multitude of free nerve endings form a dense, nerve network made of up primarily nociceptors which will contribute to pain perception of LBP, this network can be seen below in figure 1.5.

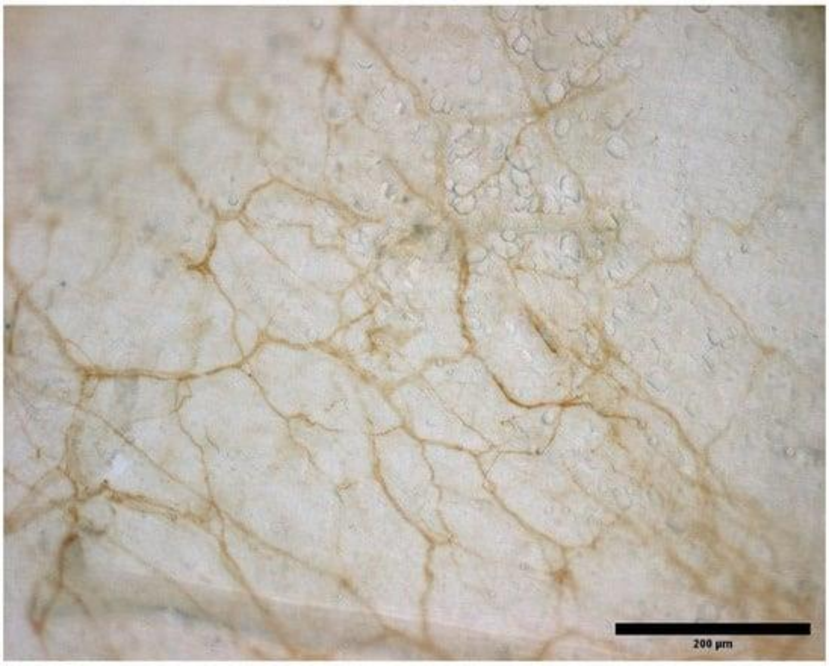


Figure 1.4. S100 stained sample showing thoracolumbar fascia innervation in a rat (Suarez-Rodriquez et al., 2022).

Several papers have emphasized the role of nociceptors in the thoracolumbar fascia in LBP (Corey et a., 2011., and Tesarz et al., 2011) with studies showing a clear link with increased pain perception following injury to the area (Schilder et al., 2016). Schilder and colleagues (2016), used electrical stimulation on the thoracolumbar fascia and muscle, finding that stimulation to the thoracolumbar fascia caused an increase in the intensity and long-term potentiation of pain. The authors hypothesized that the thoracolumbar fascia could indeed play a role in the recurrent and chronic nature of LBP. Further research investigating myofascial pain hypothesized that fascial nociceptors differ from those in muscle by being predisposed to chemical and mechanical stimuli leading to more intense pain perception (Stecco et al., 2013). Indeed, evidence has shown that previous connective tissue injury causes changes in proprioceptive matrix within the fascia can contribute injury recurrence, instability, chronic inflammation, and pain (Grace Ganjaei et al., 2020).

2.4.4 The thoracolumbar fascia, lower back pain and ultrasound imaging.

Over the past 20 years research into the role of the thoracolumbar fascia has grown, from pioneering research by Langevin and colleagues (2007 and 2011), which begun to examine morphological differences to the thoracolumbar fascia seen in individuals with LBP. Langevin and Sherman (2007) first published a thoracolumbar fascia injury model, which links initial injury to movement adaptation, a potential reduction in PA and how this process combined leads to maladaptive connective tissue remodelling. This restructuring of the connective tissues leads to an increase in fibrosis and connective tissue stiffness, reducing mobility in the area. Follow up randomised controlled trials by Langevin and colleagues used ultrasound imaging to measure the thickness and shear strain of the thoracolumbar fascia in healthy populations and those with chronic non-specific LBP, finding significantly increased thickness of up to 25% and a significant

20% reduction of shear strain during passive flexion in those with LBP (Langevin et al., 2011). However, recent studies have struggled to find significant differences between pain and no pain cohorts. A large observational ultrasound study by Larivière and colleagues (2020) investigated perimuscular thickness of the thoracolumbar fascia, recruiting n=64 participants, 30 of whom were without pain and 34 self-reporting with LBP (35% of which self-certified as physically active). Whilst the authors found a similar trend towards increased thoracolumbar fascia thickness in the LBP group, of 18%, this difference was statistically insignificant. These findings suggest that morphological differences seen in those with and without LBP are still unclear and further research is required to ascertain what differences are present and are they defined by groups (E.g., physical activity levels, pain intensity, BMI, age etc.).

The individual dense connective tissue sheaths of thoracolumbar fascia are interspersed with an Extra Cellular Matrix containing hyaluronan. This fluid has been shown to facilitate the gliding capability (or shear strain) of the connective tissue sheaths in the thoracolumbar fascia over itself and equally, surrounding muscles (Pavan et al., 2014., Fede et al., 2018, Fede et al., 2020). Crucially, the gliding capabilities of fascia depend upon a healthy structure, with some authors suggesting that physical stressors, the presence of inflammatory markers could lead to fibrosis within the fascia and disrupt this gliding ability (Kjaer., 2015., Langevin et al., 2011., and Magnusson *et al.*, 2008). Moreover, Jarvinen and colleagues (2002) established that fibrosis can be increased by decreased movement and in particular immobilisation of tissues. The authors noted how following a period of immobilisation increased collagen cross-linking can be seen in endomysial, epimysial, and perimysial connective tissue. This finding has been corroborated in animal studies on pigs by Bishop and colleagues (2016), in which a local fascia injury and/or leg immobilization intervention was measured over 8-weeks. Ultrasound imaging was used to assess thoracolumbar fascia thickness and shear strain ability during hip flexion on both the immobilised and the un-injured side. The fascia injury caused a significant increase in thickness (p=0.007) and significant reduction in shear strain (p=0.027) on both the injured and un-injured side. The combination of both injury and immobilisation led to a 52% reduction in thoracolumbar fascia mobility compared to the control group. Interestingly, the immobilisation intervention alone did not significantly alter fascia thickness but did significantly impar shear strain capabilities (p=0.027). The authors hypothesized here that injury to the lower back could continue to impair fascial movement and indeed morphology long after the injury had healed. Moreover, the significance reduction in shear strain capabilities due to immobilization could act as a mechanism linking sedentary behaviour with increased LBP.

Another interesting area of thoracolumbar fascia morphology is the organisation of the fascia itself. De Coninck and colleagues (2018) investigated the level of agreement of medical practitioners on defining the level of organisation of the thoracolumbar fascia from static ultrasound images. The authors proposed 4 sub-groups to classify thoracolumbar fascia organisation ranging from very disorganised, somewhat disorganised, somewhat organised to very organised.

More recently, an ultrasound study by Almazan-Polo and colleagues (2020) investigated the thoracolumbar fascia in a physically active group with and without LBP using this classification method. Despite not finding significant differences between the thoracolumbar thickness of those with and without LBP, the authors were able to establish significant differences in the organisation of the thoracolumbar fascia in the LBP group (p = 0.011). Interestingly, over 46% of ultrasound images in the LBP group were classified as somewhat disorganised, contributing to theories that organisation of the connective tissue layers and extracellular matrix of the thoracolumbar fascia could play a substantial role in LBP.

2.4.5 Analysis of the thoracolumbar fascia

The morphology of the thoracolumbar fascia has previously been measured in-vivo using magnetic resonance imaging (MRI) (Kang et al., 2007) and ultrasound imaging (Langevin et al., 2007). MRI is a non-invasive imaging technique which produced three-dimensional anatomical images of the human body by detecting changes in the direction of the rotational axis of protons. To detect these changes, MRI's produce a strong magnetic field to excide these protons forcing them to algin with the magnetic field (Glover., 2011). Ultrasound imaging on the other hand, creates two-dimensional anatomical images of a tissue section by detecting changes in acoustic impedance between adipose tissue, connective tissue, muscle, and bone (Noce., 1990). Ultrasound imaging uses a pulse-echo technique in which pulses of ultrasound are sent through the body where they produce echoes at this tissue change sites. These echoes return to the ultrasound transducer and are displayed as a series of greyscale dots, the brighter the dot the stronger the echo strength and the denser the tissue (Kremkau., 2006). Whilst it is essential for the body to remain still during MRI, ultrasound images can be completed whilst movement is ongoing, providing a unique ability for muscles and connective tissue to be measured during different types of muscle contraction (Kawakami et al., 2002) allowing for greater flexibility and use cases. The behaviour of fascia during movement is clinically relevant in those with LBP in particular with evidence suggesting dysfunctions to the movement of fascia could play a role with pain intensity, duration and recurrence (Langvein et al., 2011). Alongside the ability to analyse fascia during movement under ultrasound, MRI of fascia has been found to be less accurate in visualising the different layers of fascia, in part due to the pixel size of the produced images. MRI produces images with a pixel size of above 1.3mm, whereas ultrasound imaging can create much more detailed images with a pixel size of 0.058 (Storchle et al., 2018). Moreover, MRI imaging is less wildly available in musculo-skeletal practices and clinics, and carries a greater running cost than ultrasound imaging (Heidari et al., 2015). In recent years, ultrasound imaging has been described as the gold standard for analysing the thoracolumbar fascia in those with and without LBP (Langevin et al., 2011).

2.5 Summary.

LBP is a widespread and multi-faceted condition which effects a huge proportion of society, costing the NHS and other global health care establishments millions (Airaksinen et al., 2006., and Vos et al., 2016). Despite the high prevalence rates non-specific LBP remains poorly understood with no clear consensus on prevention, treatment, and management of the musculoskeletal disorder. It is recognised that PA can be used successfully to manage the condition, however there are many barriers which prevent the administration, recommendation, and uptake of PA to LBP patients (Dishman., 2001., and Owen et al., 2020). Recent literature has exposed the thoracolumbar fascia as a potential contributor to LBP, particularly in terms of the recurrence and ongoing chronic nature of the condition (Langevin et al., 2007, Langevin et al., 2011., Schleip et al., 2004., Willard et al., 2012., and Wilke et al, 2017). Evidence has shown that the thoracolumbar fascia is a richly innervated area of connective tissue which contributes to force transfer (Suarez-Rodriguez et al., 2022). Several authors have hypothesised how the thoracolumbar fascia may act as a contributor to LBP, particularly when coupled with altered movement patterns and physical inactivity (Bishop et al., 2016., Jarvinen et al., 2011., and Langevin et al., 2007). Moreover, emerging ultrasound imaging studies have begun to investigate morphology differences seen in populations with and without LBP (Almazan-Polo et al., 2020., De Coninck et al., 2018., Langevin et al, 2011 and Lariviere et al., 2020). Significant results have proven to be equivocal in the literature, however, there seems to be a trend towards an increase in thickness, reduction in shear strain as well as disorganisation in the thoracolumbar fascia of those with LBP. Further research is required to try and establish whether morphological changes found in the thoracolumbar fascia reacts to exercise loading in those with LBP.

2.6 Aims of the research.

There are four research questions for this thesis, the first research question seeks to investigate and treatment practices of LBP and the knowledge of thoracolumbar fascia in a range of practitioners. The second and third research questions seek to establish whether ultrasound imaging is reliable and can be used to accurately measure the morphology of the thoracolumbar fascia in people with and without lower back pain. Finally, the fourth research question goes one step further and investigates whether a 6-month exercise and movement intervention can be used to alter the morphology of the thoracolumbar fascia in sedentary individuals with LBP.

2.6.1 Research questions.

Research question 1:

1a Do physical therapists and fitness professionals use exercise to treat patients with lower back pain?

1b. Are physical therapists and fitness professionals aware of the thoracolumbar fascia and its potential role with lower back pain?

Research question 2:

Can novice and expert investigators reliably measure the thickness and echogenicity of the thoracolumbar fascia under ultrasound?

Research question 3:

Can ultrasound imaging be used to detect differences in the thickness and echogenicity of the thoracolumbar fascia in people with and without lower back pain?

Research question 4:

Does a 6-month exercise and movement prompt intervention affect the thickness and echogenicity of the thoracolumbar fascia in sedentary individuals with lower back pain?

Hypotheses.

1. Ultrasound imaging can be used by expert and novice practitioners to evaluate the morphology of the thoracolumbar fascia in those with and without lower back pain.

2. A novice ultrasound investigator can reliably measure the thickness and echogenicity of the thoracolumbar fascia in participants with and without lower back pain.

3. Ultrasound imaging can be used to detect morphological differences in those with and without lower back pain.

4. A 6-month exercise intervention can be used to alter the morphology of the thoracolumbar fascia in those with lower back pain.

Chapter 3. General ultrasound methodology.

3.1 Ultrasound image collection.

Each ultrasound imaging study included in this thesis was approved by the University of Kent's School of Sport and Exercise Sciences Research Advisory Group (Ref. 18_20_21, 44_2019_20 and 13_20_21). Participants first completed a PAR-Q form and informed consent form (appendix 1.6) and were given a participant information sheet detailing the methodologies used for the study and what they should expect. Ultrasound images for each study were completed by 1 novice investigator, Claire Melanie Boucher, who had received 2 months of informal training from a qualified investigator, Dr. Kyra De Coninck. For the Inter- and intra- rater reliability chapter ultrasound scanning was completed by both novice and trained investigators. Dr. Kyra De Coninck completed 12-months of musculoskeletal ultrasound training at the Centre of Ultrasound studies, Anglo-European Chiropractic College, University of Bournemouth, which included 250 hours of supervised ultrasound scanning. This training is accredited by the Consortium for Accreditation of Sonographic Education (CASE). Both investigators have advanced knowledge of musculoskeletal anatomy having worked in the health & fitness industry alongside teaching on the BSc Sports Therapy and Rehabilitation courses at the University of Kent for a period of over 10 years.

Whilst ultrasound testing does not include ionizing radiation it is worth nothing that ultrasound testing in animal studies have been shown to cause a biological effect on tissues by thermal and/or mechanical effects (Houston et al., 2011).

However, these changes were found after continuous exposure to ultrasound, in this study ultrasound exposure were limited to only a few seconds per scan. The probability of a biological effect occurring directly correlates to the acoustic output of the ultrasound machine, to limit the potential risks, upper limits are set by the manufacturers and displays are included to show the thermal and mechanical index during use (DiGiacunti et al., 2015). As such, all ultrasound image collection protocols followed the "as low as reasonably achievable" (ALARA) principle when selecting ultrasound methodologies (from ultrasound frequency to duration of the scan) (Barnett et al., 2000). Throughout the study the ultrasound frequency remained set at 18MHz, with the thermal index remaining below 1.0 (The British Medical Ultrasound Society, 2009) with care taken to ensure the minimum amount of time was taken for each scan at each tissue area.

The participant was asked to lie prone on a massage treatment bench with their arms beside their trunk for a 5- minute acclimatisation period. A recent study by Blain and colleagues, (2019) commented that by allowing the participant to remain in the prone position may help to standardise the relaxation of muscles in the lower back which in turn could help to normalise the distribution of fluid within the thoracolumbar fascia (Blain et al., 2019). After the acclimatisation period, three images were taken 2cm laterally of the L2-3 intervertebral disc space on both the left and right sides of the spinal column. The placement of ultrasound imaging can be seen below in figure 3.1 with the black rectangle detailing the 2cm scanning area, whilst the green oval depicts the thoracolumbar fascia.

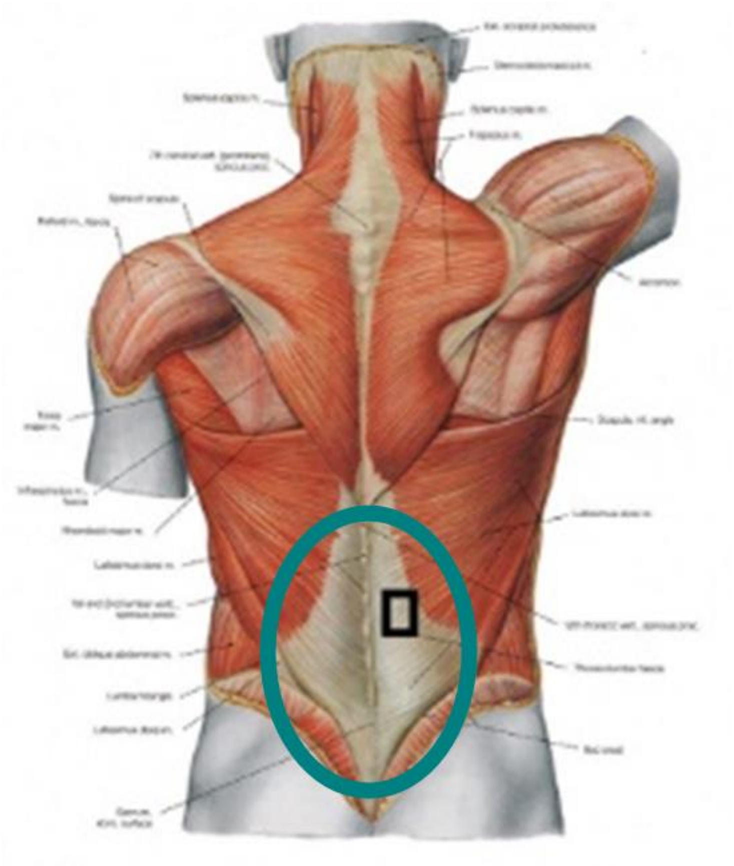


Figure 3.1: Position of ultrasound image collection 2cm laterally of the L2—3 intervertebral disc space and the thoracolumbar fascia (Gray, 1918).

The intervertebral disc space was first found by palpating the location of anatomical landmarks of the iliac crest, the sacrum and intervertebral discs, the position of the L2-3 space was then corroborated by ultrasound to ensure accuracy (Stokes et al., 2007, and De Coninck et al., 2018). The region of interest was then marked using a water soluble, allergenic surgical skin marking pen (365 Healthcare, England). Images were captured using B-mode imaging on a Esaote Mylab 25 gold (Firenze, Italy) portable ultrasound with a Esaote LA435 linear probe (Firenze, Italy), at a frequency of 18Mhz at a depth of 4cm, 3cm and 2cm in accordance with the guidelines for optimum image quality for subcutaneous structures (Kremkau, 2006). Images were repeated at each depth level using three brightness levels, 100%, 70% and 40% to find the best fit model for each group of participants. A total of 3 ultrasound images at each depth and brightness were taken on both the left and right side of the spine so that a best fit image could be chosen for each participant. Images and measurements of the thoracolumbar fascia were taken in the longitudinal plane. Figure 3.2, an example ultrasound image taken from a participant with LBP depicts the morphological layers of the thoracolumbar fascia and surrounding landmarks seen under ultrasound.

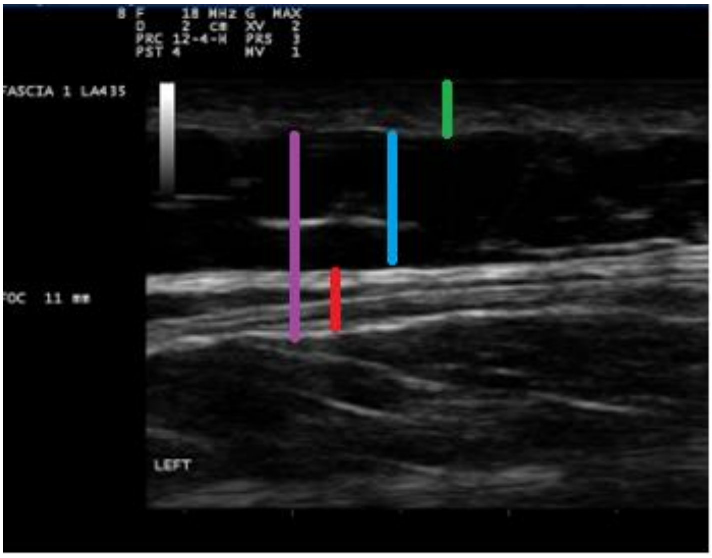


Figure 3.2: Ultrasound image of the thoracolumbar fascia of a participant with LBP.

From left to right: the purple line depicts the combined zone, the red liner shows the perimuscular zone, the blue line shows the subcutaneous adipose tissue, and the green line depicts the dermis.

There are three distinct thoracolumbar fascia zones which can be seen under ultrasound imaging, working from top to bottom we first have the subcutaneous zone (shown in blue in figure 3.2), which depicts the area between the dermis (skin) and the superficial border of the perimuscular zone (shown in blue). The perimuscular layer (blue) was defined as the brightest layer closest to the muscle underneath the subcutaneous zone. Lastly, the combined zone (shown in purple) included both the subcutaneous and perimuscular layers.

This thesis uses participants both with and without LBP to quantify pain levels, frequency and duration the Dionne and colleagues (2008) definition and corresponding questionnaire has been used throughout. Dionne and colleagues (2008) define LBP by pain originating between the 12th rib and the inferior gluteal folds, with or without accompanying leg pain that is severe enough to limit daily activities for more than 1 day. The authors further subgroup pain into the following categories, Acute lower back pain defined as experiencing pain for less than 3 months, and chronic low back pain for pain of 3 months or more. Likewise, Participants without lower back pain are classified as those with an absence of LBP in the last 12 months. (Dionne et al., 2008). This thesis included participants classified as chronic LBP using a modified Dione questionnaire (see appendix 1.2) for Chapters 5, 6 and 7.

3.2 Ultrasound image analysis.

All ultrasound images were analysed offline using Matlab version R2012a (The Mathworks, Natick, MA). The analysis measured the thickness and echogenicity of the thoracolumbar fascia. For the Intervention chapter analysis, the investigator was blinded to the participant and the intervention group at all timepoints. For analysis in all studies brightness of 70% and a depth of 3cm was used in accordance with existing guidelines for the optimum methodology for ultrasound imaging of subcutaneous structures (Kremkau., 2006). Likewise, for the LBP vs no LBP chapter the investigator was blinded as to the pain group of the participant. Throughout the inter- and intra- reliability analysis stage raters were blinded to each other's measurements and were not permitted to discuss images with each other. As previously used with the Langevin (2009) study, the ultrasound analysis methodology included the use of a 1cm-wide region of interest. First, the MATLAB script enabled the three thoracolumbar fascia zones to be marked on the ultrasound images before measurements were then calculated using the bespoke MATLAB script, the region of interest can be seen below in figure 3.3.

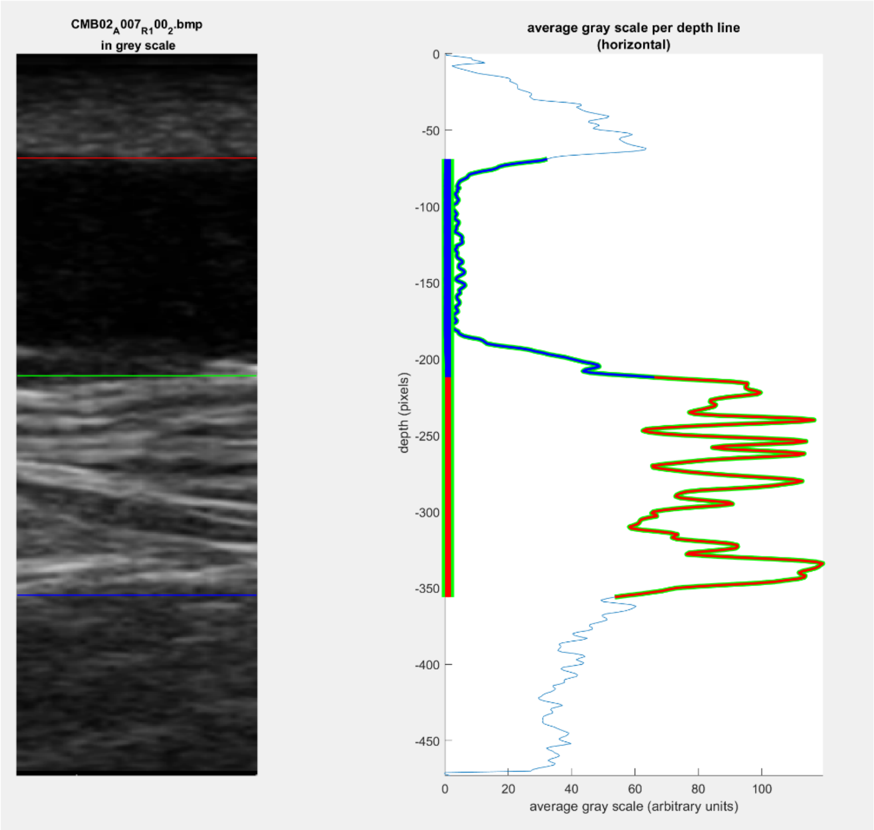


Figure 3.3: Region of interest shown using MATLAB ultrasound image analysis.

On the right-hand image, the blue depicts the subcutaneous zone, the red shows the perimuscular zone, and the green displays the combined zone.

Thoracolumbar fascia thickness measurements were recorded using a linear measurement from the superficial border of the muscle to the deep border of the dermis. Thickness measurements were recorded in pixels and then transferred into millimetres using the Hoskins et al., (2003) calculation as used in prior ultrasound studies (De Coninck et al., 2018). For echogenicity measurements, all ultrasound grey level profiles within the region of interest were converted to the vertical position before the mean grey level was calculated. Echogenicity was recorded as a numerical value from 0-255 whereby 0=black and 255=White. The grey levels were then normalized to account for any focal depth variances between participants (Langevin et al., 2009).

Chapter 4. Chronic back pain and fascia: Perceptions from physical therapy and fitness professionals.

4.1 Background.

Worldwide clinical guidelines recognise that for most lower back pain (LBP) cases little or no formal medical interventions are required (Qaseem et al., 2017). Recommendations instead promote self-management of symptoms, social support, reassurance, activities of daily living (ADLs) and regular physical activity used as primary treatment methodologies (Hartvigsen et al., 2018, and Qaseem et al., 2017). Exercise interventions for the treatment and management of LBP have been well researched within the literature (Maher et al., 2017., and Owen et al., 2020), with the evidence supporting a plethora of exercise types. Exercise recommendations should be prescribed considering participant preference to encourage engagement, adherence, and long-term behavioural change (Owen et al., 2020).

In the early 1990s, Exercise referral schemes (ERS) were developed in the UK to build physical activity treatments into the public health pathway for chronic health conditions, and these ERS schemes utilised fitness professionals in non-clinical environments (Fox et al., 1997). ERS aim to promote physical activity lifestyle changes in those with chronic health conditions to ease the burden on the NHS with patients referred through their primary care practitioners (E.g., General practitioners, nurses, and physiotherapists) (Rowley et al., 2018). Likewise, globally the American College of Sports Medicine and the American Medical Association co-developed the exercise is medicine (EIM) initiative in 2007 to help promote and educate physicians on the use of physical activity in health care. The aim of EIM is to educate physicians and health care providers about the uses of exercise and how to implement these as part of disease prevention, management, and treatment (Sallis., 2009). The EIM goes as far to recommend that physical activity levels need to be checked and monitored as an additional vital sign of all patients. However, despite programmes and incentives like ERS and EIM, globally there is often no inter-disciplinary work between the health and fitness sectors. In the UK, one study found that as little as 7 in every 1000 patients were referred for an ERS (U Din et al., 2014), whilst in Australia the number of patients referred to an exercise physiology team was even lower with just 1.44 patients in every 1000 (Craike et al., 2019).

Despite clear recommendations for practitioners to prescribe movement and exercise for those with LBP, some evidence has suggested that few allied health professionals follow this instead preferring to recommend 1-2-1 rehabilitation exercises (Ayre et al., 2022). There are very few studies that have investigated the perceptions of allied health professionals with regards to prescribing and delivering exercise nor their attitudes towards it. The limited research in this area has focused primarily on physiotherapists, with evidence suggesting that many lack both the skills and confidence to prescribe exercise programmes (Ayre et al., 2022, Cowell et al., 2018, Feldman et al., 2022., and Synnott et al., 2015). Recently, Wingood and colleagues (2023), completed semi-structured interviews on n=18 physical therapists to evaluate their knowledge of physical activity recommendations and how regularly therapists prescribe physical activity to patients with LBP. The authors found that physical therapists were able to articulate an awareness and understanding of the importance of physical activity, however, a theme was noticed where general movement practises were prescribed in place of specific physical activity interventions. This preference of movement over specific exercise programmes supports earlier studies which suggest physical therapists lack the skills and confidence to prescribe exercise.

There is increasing evidence to suggest that morphological adaptations to the thoracolumbar fascia is associated with LBP, from the pioneering research by Langevin and colleagues (2009 and 2011) establishing an 25% increase in thickness and 20% reduction in shear strain seen in adults with pain compared to a healthy control. More recently studies by De Coninck et al., (2018) and Almazan-Polo et al., (2020) investigated the organisation of the thoracolumbar fascia in pain and no pain populations and found varying degrees of disorganisation in their pain groups. Interestingly, adaptations to fascia have been seen following physical activity, with evidence suggesting that mechanical loading (such as exercise) causes all connective tissue types to respond by stretching (Schleip et al., 2013), stiffening (Schleip et al., 2012) increasing in strength (Bond et al., 2019) and/or adapting its shear strain capabilities (Langevin et al., 2011). At present, exact exercise type, load and duration recommendations for fascia remain equivocal in the literature, and further discussion on fascia and exercise can be seen in chapter 7. However, despite the growing body of evidence, fascia is often neglected in both vocational and academic education (Pratt., 2019). This lack of inclusion in education and basic training is perhaps in part due to the limited research evidence, in particular randomised controlled trials which could be used to guide clinicians when treating patients. It is important to note that some research has suggested that the anatomy content in physical therapy-based degrees is also a factor, with large variances seen between degree programmes (Shead et al., 2016). Recent reviews have begun to discuss the importance of including fascia into anatomy and medical training at undergraduate degree and postgraduate level (Pratt., 2019., and Sharkey & Kirkness., 2021), and the authors from both these papers argue that fascia anatomy training bridges across multiple aspects of medicine, health and allied health care education and provides a full body methodology for treating patients. However, investigation into the perceptions and indeed the knowledge of fascia amongst current fitness and allied-health professionals has yet to be examined. Therefore, the second aim of this study seeks to bridge that gap and ascertain the perceptions and lived experiences of physical therapy and fitness professionals towards chronic LBP and fascia. This chapter therefore aims to contribute to our understanding of how practitioners are treating patients with LBP, and importantly, how much awareness of the thoracolumbar fascia exists amongst physical therapists and fitness professionals. This information will help guide further investigation into LBP and the thoracolumbar fascia and direct treatment interventions for patients. Therefore, the first aim of this study was to ascertain the preferred treatment methods used by physical therapists and fitness professionals for people with chronic LBP.

4.2 Methodology.

4.2.1 Participants.

This study was approved by the University of Kent's School of Sport and Exercise Sciences Research Ethics Advisory Group (Ref. 18_20_21). Participants were recruited through the University of Kent's Graduate and Researcher college email, personal social media channels, poster circulation at the University of Kent Canterbury Campus and via opportunistic sampling. Participation was voluntary with no financial reimbursement given. Before taking part in the study, participants were given an information sheet and required to complete an informed consent form (full details can be seen in appendix 1.1). Participants were required to be qualified and practising fitness professionals (see figure 4.1 for professional delineation) or physical therapists. Physical therapists were defined as a wide range of practitioners who use manual and hands-on treatment modalities. Physical therapists were chosen as they are musculoskeletal allied health professionals regularly working with those with LBP. Fitness professionals are trained in and regularly work with people with LBP, however, despite this are often omitted from LBP research. A total of 114 participants were recruited for this study, 2 participants were excluded as they did not meet the professional inclusion. Of the remaining 112 participants, n=43 were fitness professionals and n=69 were physical therapists. The full break down of professions can be seen below in figure 4.1.

Table 4.1 Fitness Professional and Physical Therapist job roles.

Fitness Professional	N= 44	Physical Therapist	N= 69
Exercise Referral Instructor	3	Chiropractor	7
Group Exercise Instructor	6	Massage Therapist	10
Gym Instructor	2	Physiotherapist	29
Personal Trainer	22	Osteopath	10
Physical Education Instructor	2	Soft Tissue Therapist	2
Pilates Instructor	3	Sports Therapist	11
Sports Coach	3		
Yoga Instructor	3		

4.2.2 Development of the questionnaire.

A bespoke questionnaire was developed for this study, with an initial pilot questionnaire developed based on four key themes: Profession and training, LBP treatment methodologies, fascia and LBP, and research experience and continuous professional development. The four key themes were identified through existing literature and informal discussions with local, and international colleagues. The questionnaire was prepared using MS Forms for ease of circulation and completion by participants. The questionnaire went through several revisions within the research team before being pilot tested on 3 physical therapists and 3 fitness professionals. Feedback on the wording of questions, and ease of use of the online were used for final edits to the questionnaire resulting in the use of mixed open response and multiple-choice questions.

The questionnaire contained three basic sections, participant information, LBP management techniques and the thoracolumbar fascia. Section 1 focused on the participant's profession, training, professional accreditation, and time in practice. Section 2 focused on type of LBP management techniques used for different populations. Sections 1 and 2 used a mixture of pre-selected responses and short written answers. Section 3 and the largest part of the questionnaire investigated the participant's knowledge of the thoracolumbar fascia and LBP. In addition to pre-selected and short written responses Section 3 asked for opinions regarding the potential link between the thoracolumbar fascia and LBP to assess their awareness of the thoracolumbar fascia and equally, their opinions on fascia targeted treatments and research. The full questionnaire can be found in appendix 1.1.

4.2.3 Data analysis.

Descriptive analysis of the distribution, central tendency and variability was completed on each of the 22 questions and responses (Creswell & Plano Clark 2018). Inferential statistics for professional groups were completed using chi-squared tests using IBM SPSS statistics v27 (SPSS Inc., Chicago: IL).

4.3 Results.

4.3.1 Participant background.

Two participants were withdrawn due to the respondents not having the relevant professional background, leaving a total of n=113. Most participants were physical therapists (n=69) with physiotherapists as the highest number of respondents (n=29). For Fitness professionals (n=44), the highest number of respondents were Personal Trainers (n=22) . Of all participants, n=54 treated patients with LBP more than 50% of the time.

4.3.2. Lower back pain treatment modalities.

This section focused on preferred and most used treatment modalities, with respondents able to select multiple options. Overall, the most frequently used treatment was one-to-one teaching of rehabilitation exercises (n=76, 67.9%), followed by individual self-care guidance (n=72, 64.3%) and manual therapy focusing on soft tissue treatments (n=56, 50%). Responses for preferred treatments can be seen below in table 4.2.

Table 4.2 Preferred LBP management methodologies

Preferred approaches to LBP management	Total N=	Fitness Professional n=	Physical therapist n=
Manual Therapy, focusing on soft tissues such as muscles	56	12 (21.4%)	44 (78.6%)
Manual therapy focusing on joint mobilisations or manipulations of joints	41	0 (0%)	41 (100%)
One to one teaching of rehabilitation exercises	76	27 (35.5%)	49 (64.5%)
Group based exercise approach, not specifically designed for LBP	18	14 (77.8%)	4 (22.2%)
Group based exercise approach, specifically designed for LBP	23	22 (95.7%)	1 (4.3%)
Self-care: Pre-prepared general guidance	30	13 (43.3%)	17 (56.7%)
Self-care: Individually designed guidance	72	39 (54.2%)	33 (45.8%)
Chronic pain education	53	31 (58.5%)	22 (41.5%)
Other	12	4 (33.3%)	8 (66.7%)

Other responses included, contemplative mindfulness (n=3), strength training (n=2), cranial osteopathy (n=2), psychotherapy techniques (n=1), acupuncture (n=1), medication (n=1), counselling(n=1), and cognitive behavioural therapy (n=1).

When split between physical therapists and fitness professionals, for both groups the preferred treatment was one-to-one teaching of rehabilitation exercise as seen above in table 4.2. For physical therapists the second most selected methodology was manual therapy focusing on soft tissues and then self-care: individually designed guidance. Whilst for fitness professionals the second most selected methodology was the group exercise approach, specifically designed for LBP, followed by self-care: individually designed guidance. Chi-squared analysis of preferred LBP treatment methodologies revealed that there is a significant strong association between profession (Likelihood ratio: 281.67, df 130, p= 0.000. Cramer's V: 0.946), years of experience profession (Likelihood ratio: 371.95, df 325, p= 0.037. Cramer's V: 0.834) and percentage of LBP patients (Likelihood ratio: 372.47, df 260, p= 0.000. Cramer's V: 0.853) and their preferred treatment type. Despite both professionals using one-to-one rehabilitation exercise the chi-squared analysis indicated that physical therapists were more likely to prescribe manual therapy. Whereas fitness professionals were more likely to prescribe group exercise.

4.3.3. The thoracolumbar fascia.

The final section of the questionnaire focused on the participant's knowledge of the thoracolumbar fascia, and awareness of research-based evidence of the role of thoracolumbar fascia in LBP. Of all participants, 99 (88.4%) were aware of the thoracolumbar fascia. When asked whether the thoracolumbar fascia has a functional role in LBP, n=101 (90.2%) of participants agreed. However, when asked if the thoracolumbar fascia is a potential contributor or factor in LBP only n=71 (<64%) of participants indicated yes. Interestingly, n=16 (15.3%) of all participants confirmed that the thoracolumbar fascia was included in their initial training as a practitioner, of these 10 (62.5%) participants were trained as osteopaths, 4 (27.5%) as physiotherapists, and 2 (12.5%) as sports therapists. Years of experience and awareness of the thoracolumbar fascia was centrally spread with n=2 with less than 5 years of experience, n=6 with 6-10 years of experience, n=5 with 11-20 years of experience and n=3 with over 20 years' experience. Chi-squared analysis of awareness of the thoracolumbar fascia revealed a moderate association between profession (Likelihood ratio: 173.00, df 6, p= <0.001. Cramer's V: 0.735), years of experience profession (Likelihood ratio: 172.09, df 15, p= 0.000. Cramer's V: 0.591) and percentage of LBP patients (Likelihood ratio: 172.18, df 12, p= 0.000. Cramer's V: 0.594) and their awareness of the thoracolumbar fascia. A chi-squared analysis revealed that physical therapists were significantly more likely to express awareness of the thoracolumbar fascia. Likewise, those with greater years of experience and those treating a higher percentage of LBP patients were more likely to have come across the thoracolumbar fascia.

Further to this, when asked about awareness of research-based evidence related to the thoracolumbar fascia being a factor in LBP only n=22 (<20%) of participants indicated that they were aware of any research in this area. Of the n=22 participants, n=18 (81.8%) were physical therapists and n=4 (18.2%) were fitness professionals. There was a central tendency of awareness of the research and years of experience with small tails of years of experience, this can be seen below in figure 4.2. Participants were then asked to provide further details of research evidence they were aware of, and responses here were limited. Frequent responses included “I have not read up too much about this”, “Research from the Fascia Research Congress”, and “Research by Robert Schleip”. Chi-squared analysis of awareness of the thoracolumbar fascia research revealed a significant moderate-to-strong association between profession (Pearson Chi-Square: 154.30, df 6, p= 0.000. Cramer’s V: 0.722), years of experience profession (Likelihood ratio: 174.16, df 15, p= 0.000. Cramer’s V: 0.602) and percentage of LBP patients (Likelihood ratio: 176.15, df 12, p= 0.000. Cramer’s V: 0.606) and their awareness of the thoracolumbar fascia. Physical therapists were significantly more likely to be aware of research surrounding the thoracolumbar fascia compared to their fitness professional counterparts.

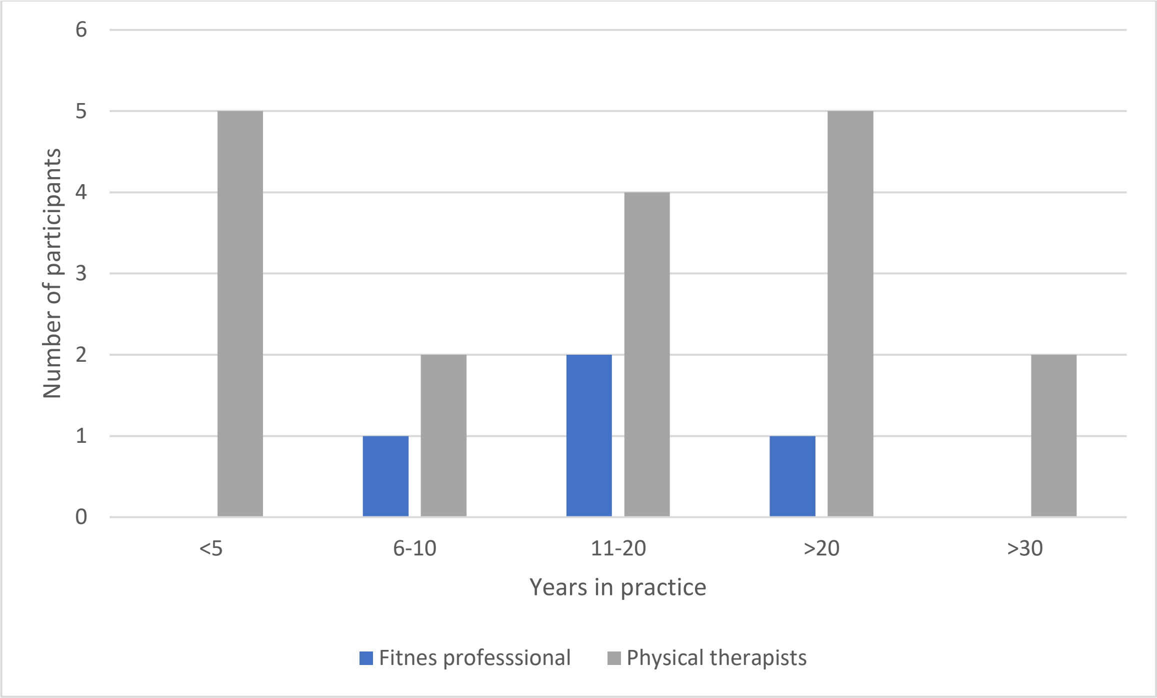


Figure 4.3. Years of experience and awareness of thoracolumbar fascia.

4.4 Discussion.

In terms of preferred treatment modalities there are key similarities with both profession groups with one-to-one rehabilitation exercises as the top choice for each. This is promising and shows that clinical guidelines, and potentially research evidence, is making its way through into clinical practise (Hartvigsen et al., 2018). For Physical therapists, soft tissue manual therapy was reported as the preferred treatment modality for LBP (n=44, 63.8%). Perhaps unsurprisingly, fitness professionals on the other hand prefer to use LBP specific group exercises (n=22, 50%). Group exercise has been recommended for use in LBP populations to reduce pain, increase quality of life and ability to take part in activities of daily living, and group exercise can help manage the social element of the biopsychosocial management of LBP (Dean et al., 2005, and Owen et al., 2020). Evidence supports the use of physical activity for the prevention, management, and treatment of LBP (Hartvigsen et al., 2018), however several studies have shown that many practitioners do not follow these recommendations (Cowell et al., 2018., Holopainen et al., 2020., Zadro et al., 2019., and Wingood et al., 2023). It is worth noting however, that the majority of published work in this area focuses on physiotherapists, whereas this study has included a range of manual therapy professions. Investigations into why physical activity is generally not actively used by many practitioners has uncovered several barriers, including practitioner beliefs about LBP (Gardner et al., 2017), a lack of training in the area (Cowell et al., 2018) and a lack of support from their organisation (Francke et al., 2008). Whilst our study disagrees in part, as physical therapists selected one-to-one teaching of rehabilitation exercises, these could focus on individual stretching and/or neuromuscular-based exercise rather than an increase in weight bearing, physical activity itself. This is supported by the lack of group exercise commonly used in the treatment of LBP patients. More research is needed to ascertain the details of the exercises recommended, including frequency, intensity, and whether these are weight-bearing or not.

Most participants (over 85%) expressed that fascia was not included in their initial training. Fascia was not included in any of the training for fitness professionals, and for the n=16 physical therapists who expressed fascia was included, n=10 were trained as osteopaths, n=4 as physiotherapists, and n=2 as sports therapists. It is important to note that the 2 sports therapists which confirmed an inclusion of fascia in their training with graduates of the university of Kent and taught by a Fascia Researcher. This finding supports an earlier review article by Shead and colleagues., (2016) who revealed a lack of knowledge of how anatomy was being taught to physiotherapy students on a global scale. There is a clear absence of fascia in the anatomy training of allied health professions' degree programmes. Sport and Exercise Science programmes and likewise, vocational training courses in the health and fitness industry are also missing fascia content. Whilst Fascia research has been steadily growing over the past 30 years (Langevin et al., 2009, Schleip, 2003., and Stecco et al., 2011), anatomy training has not significantly changed. Recently, the lack of education of fascia in medical degrees and the importance of changing curricula has been discussed in review articles but no primary data has been published until this current study (Pratt., 2019., and Sharkey & Kirkness., 2021). The findings from this study not only support a gap in higher education allied health curriculum relating to fascia, but also supports the need to expand fascia curriculum into all allied health profession study at both degree and vocational training level.

Perhaps of even greater importance is the lack of awareness of research-based evidence related to the thoracolumbar fascia being a factor in LBP. This study found that less than 20% of all participants indicated that they were aware of any research in this area, despite 2180 publications investigating fascia and LBP in

2023 alone. Supporting research dissemination between scientists and clinicians, the Fascia Research Society provides educational webinars, online events and holds the international fascia research congress every 3 years (Pratt., 2023). Despite the support of the Fascia Research Society and other fascia societies globally, knowledge about fascia research is clearly lacking in the wider scientific and clinical population. Discussion and publications have been made surrounding appropriate terminology to use when communicating fascia (Adstrum et al., 2017, and Langevin & Huijing., 2009) but a resolution is needed on how to promote research dissemination to practitioners.

Overall, the questionnaire results depict a high awareness of the thoracolumbar fascia, with >84% of participants self-reporting that they were familiar with this connective tissue. However, there was less agreement on the role of the thoracolumbar fascia. This is reflected in the literature, where there is a lack of evidence for adaptations in the TLF being the direct causative factor of LBP, this lack of concensus could contribute to the lack of inclusion in clinical practise. The high overall thoracolumbar fascia awareness results are interesting given the recent literature on the lack of education of fascia (Pratt., 2019, and Sharkey et al., 2021). There is a potential that obsequious bias affected this question, with respondents altering their answer in a way that they think would be most accepted by the researchers (Choi & Park., 2005). This poses an interesting dynamic for questionnaire studies analysing the perceptions of professionals and how can questionnaires be written to try and minimize the risk of obsequious bias.

When formatting the questionnaire, the order of questions began around the participant's background, through LBP to fascia to try and minimize the impact of obsequious bias and lead the focus to be more about general perceptions rather than focusing on fascia. However, the type of question and perhaps less overall knowledge around fascia may have led the respondents to alter their answers here. This would help to explain the varied responses seen in a follow-up question requesting participants to choose what they think is the role of the thoracolumbar fascia. As this study was shared over social media channels and completed anonymously it is difficult to quantify whether all participants were trained and working within the UK, future studies like this should include a question to ascertain the location of the participant to allow for sub-grouping and standardisation of geographical differences in training and clinical practices.

4.5 Conclusion.

In reviewing the questionnaire responses from 112 participants from physical therapy and fitness professional backgrounds, similarities in the way each profession treats clients with LBP were seen. Both professions favour one-to-one rehabilitation exercises for the treatment of those with LBP which is in line with guidelines recommending physical activity as a primary treatment methodology for this demographic (Harvigsen et al., 2018). However, there was a strong association between profession and likelihood of prescribing physical activity, with physical therapists less likely to include group exercise recommendations than their fitness professional counterparts. Overall, participants perceived themselves to understand fascia, however consensus was unclear as to the potential role of the thoracolumbar fascia. This lack of consensus is perhaps in part due to lack of education coverage around fascia, with over 85% of participants expressing that fascia was not included in their initial anatomy training, which supports evidence discussing a clear lack of fascia education in medical and allied health professional's training (Pratt., 2019., and Sharkey & Kirkness., 2021). Moreover, this study found that less than 20% of participants were aware of research around the thoracolumbar fascia and LBP despite a growing literature base in this area, suggesting a need for further research and a greater focus on research dissemination. To encourage knowledge of fascia in clinicians working with those with LBP, further promotion of research dissemination and clear clinical guidelines are required, encouraging a dialogue between researchers and those working with participants on a day-to-day basis. Future research dissemination could include guidelines and recommendations on best practise for the incorporation of the effect of exercise on fascia for both physical therapists and fitness profession. The findings from the questionnaire in this study is reflected in the literature with a lack of consensus on the involvement of a direct causation with thoracolumbar fascia being the cause of LBP. Before the role of the thoracolumbar fascia can be investigated, confirmation is required to ascertain whether ultrasound is a reliable method of investigation. As such this lack of evidence and methodology will be addressed in the next chapter which is a reliability observational study to ascertain whether a novice practitioner can accurately, and reliability measure the thoracolumbar fascia using ultrasound imaging.

Chapter 5. Measurement and analysis of the thoracolumbar fascia in ultrasound images: An intra- and inter-rater reliability study.

5.1 Background.

Over the last 20 years, studies have found that ultrasound imaging (USI) to be a non-invasive, accurate method to perform in vivo assessments of the soft tissue anatomy of the lower back (Costa et al., 2009, Langevin et al., 2011, Hicks et al., 2016, and Wallwork, Hides and Stanton., 2007). This method is now being used to understand the pathophysiology of the thoracolumbar fascia and its role in non-specific lower back pain (LBP) (De Coninck et al., 2018, Koppenhaver et al., 2009 and Sions et al., 2014). Of interest to this study are the superficial and deep fascia, found between the dermis and the epimysial fascia of the lower back, specifically the thoracolumbar fascia. The thoracolumbar facia structure varies from person to person, with differing organisation of layers, thickness and more (De Coninck et al., 2018). As such, fascia research brings its own challenges and alternative imaging methods in comparison to traditional LBP imaging methods are required to effectively analyse the connective tissue in vivo.

There is a growing evidence base that demonstrates USI is a reliable, affordable, portable and a non-invasive method to perform in vivo examinations of fascia and importantly on those with LBP (De Coninck et al., 2018 and Pirri et al., 2019). Comparable studies have examined the reliability of using USI on the lower back and found promising results, although most focus on measuring the muscles of the lower back rather than the fascia itself (Koppenhaver et al., 2009 and Sions et al., 2014). Some of these studies comment on the associated fascial tissues of the lower back and as such more research is needed to quantify the validity and reliability of this process (De Coninck et al., 2018, Kim, Park & Kim., 2014, Langevin et al., 2011., Todorov, Nestorova and Batalov., 2018 and Whittaker et al., 2013). Importantly, a number of rater reliability studies of lower back muscles have been completed using USI capture, recording high levels of accuracy in both older (Wilson et al., 2016 and Sions et al., 2014) and younger populations (Teyhen et al., 2011).

Wilson and colleagues (2016) noted an inter- rater reliability of >86% and intra-rater reliability of >98% when analysing the lumbar multifidus of older adults aged between 60-86 using ultrasound. Moreover, the authors recorded cross-sectional area measurements of the lumbar multifidus in their inter-rater reliability analysis, finding an intra-class coefficient (ICC) of 0.86-0.96 with a SEM of 0.51. The connection between the stabilising muscles of the lower back and LBP has accrued substantial research in the literature over the years. An early study by Danneels and colleagues (2001), documented that patients with chronic LBP experienced atrophy of the lumbar multifidus that could be measured under a computerised tomography scan (Danneels et al., 2001). Since then, computerised topography (CT) scans have continued to find further evidence to support a reduction in lumbar multifidus cross-sectional area alongside maladaptation of the muscle consistency in those with LBP (Calvo-Lobo et al., 2019).

Hides and colleagues (2008) were the first to examine the lumbar multifidus and LBP under ultrasound, finding that the cross-sectional area and symmetry between each side of the spine were reduced in those with LBP. The inter- rater reliability indices found in older adults correspond with the findings by Teyhen and colleagues (2011) who conducted an intra- rater reliability study of the lumbar multifidus in younger adults aged between 18-32, who found an inter-rater reliability of 87%. Moreover, Sions and colleagues (2014) examined both the inter- and intra- rater reliability of trained raters on lumbar multifidus thickness in both older (60-85) and younger adults (18-40) to note any differences. Sions (2014) found that the inter-rater reliability with older and younger adults were very similar with ICC results between 0.97-0.99 for older adults and 0.96-0.99 for younger adults, equally similar results were found when analysing intra-rater reliability, older adult reliability ICC scores measuring 0.74-0.94 (high-very high) and 0.80-0.95 (very high) in younger adults. Importantly, the Teyhen and colleagues (2011) study focused on the reliability of novice raters, the authors hypothesized that to obtain reliable results raters needed to first complete a standardized training programme (Wallwork et al., 2007). However, later studies including the Teyhen et al., study (2011) support the idea that this is unnecessary and that novice raters can indeed obtain reliable results in line with those of experienced raters (Teyhen et al., 2009, Koppenhaver et al., 2009, and Springer et al., 2006).

Furthermore, studies have found a high reliability of above 96% in both healthy populations (Wallwork, Hides and Stanton, 2007) and those with lower back pain (Wong et al., 2013). Notably, Wong and colleagues (2013) investigated the differences of inter- and intra- rater reliability when using USI of the lumbar multifidus in both LBP and non-LBP populations. The authors found no significant differences in overall reliability across a number of testing conditions (from vertebrae level to static image and video capture). A key USI study found high inter- and intra- rater reliability of the trunk muscles and associated connective tissues, including the thoracolumbar fascia (Whittaker et al., 2013). The Whittaker et al. (2013) study found high ICCs of 0.92-0.99, including the lateral raphe of the thoracolumbar fascia. Although this is anatomically lateral to the area investigated in the study presented in this chapter, the reliability and morphology of the lumbar fasciae in both studies is similar.

Trunk and abdominal muscles bind onto the thoracolumbar fascia and as such will have a similar collagen content nearer these sites, mimicking those found within the connective tissue (Stecco., 2015). Koppenhaver and colleagues (2009) conducted a reliability study to investigate intra- and inter-rater reliability of USI on the transverse abdominis and the lumbar multifidus muscle at rest. The study found a significant reduction in standard error measurement by <25% when averaging 2 results from images from the same site, and 50% when using an average of 3. The authors recommend that, where possible measurement precision should be optimised by using 3 measurements of both the image and the analysis aspects before averaging the results (Koppenhaver et al., 2009). It is important to consider that this methodology is primarily applicable to research, whereas a clinical setting is often limited by time constraints. Whilst there is almost certainly a benefit to following the Koppenhaver averaging method, single image measurements have been found to compare favourably to averaged measurements when time constraints prevent the Koppenhaver methods from being followed (Wilson et al., 2016). These studies seem to confirm that ultrasound imaging can reliability capture images of the lower back by both experienced and novice raters alike, with an overall agreement within the literature that USI can be used effectively and reliably (Cross-sectional area ICC=0.86, Thickness change ICC=0.76) to examine the muscles and connective tissues of the lower back. Specific research into the reliability of both experienced and novice raters at capturing and analysing ultrasound images of the thoracolumbar fascia is now needed to fill the gap in the literature for this particular area of connective tissue. It is important, given the emerging research establishing the potential role of the thoracolumbar fascia in LBP, that reliability studies include participants both with and without LBP to accurately measure the efficacy of USI. The inclusion of healthy populations will act as a control group and investigate whether any adaptation observed or measured are not caused by biological variance, and to quantify any differences in thickness or echogenicity between the two groups. There are multiple research variables with regards to the ultrasound of the thoracolumbar fascia. Indeed, Langevin and colleagues (2009) published a pioneering research study which examined the maladaptations in connective tissue found in those with chronic LBP. The authors found changes within the thoracolumbar fascia with regards to echogenicity and thickness of the connective tissue layers. Whilst clinically significant, no formal classification of the thoracolumbar fascia has been established. An ultrasound-based inter-rater reliability study by De Coninck et al. (2018) established good to excellent reliability of thoracolumbar fascia variation. Ultrasound images were grouped into 4 groups ranging from very organised to very disorganised. However, the authors acknowledged further analysis is required before formal classification criteria can be made. As such, the importance of each aspect of the thoracolumbar fascia requires a reliable method of measurement under ultrasound. The purpose of this study is to quantify the inter- and intra-rater reliability novice and experienced raters of thoracolumbar fascia ultrasound image capture and image analysis.

5.2 Methodology.

5.2.1 Participants.

Participants were recruited through the University of Kent's Graduate and Researcher College email, personal social media channels and via opportunistic sampling. Participation was voluntary with no financial or other reimbursement given. A total of 27 healthy male (n=15) and female (n=12) adults aged between 18 and 70 were recruited, 16 participants reported having LBP. Participant demographics can be found below in table 5.1. Prior to data collection, written informed consent was obtained from all participants. The inclusion criteria required the participant to be a healthy adult, aged between 18-70 years of age, with or without lower back pain. To the be included in the study, participants had to be free from any underlying connective tissue disorders (such as, rheumatoid arthritis and hypermobility), record a BMI reading within the range of 16.5-39.9 and have no lymphoedema present. Prospective participants were excluded if they met any of the following criteria: history of previous spine, hip or knee surgery in the past 12 months, unusual curvature of the spine (such as scoliosis, lordosis and/or kyphosis), a displaced vertebrae (e.g.: spondylolisthesis), spondylosis/parsa defect, a history of corticosteroid injections in the lower back, trunk or near the spine, previous surgical interventions including pins and plates near the spine, diabetes, pregnancy and current smokers. Participants were recruited via posters at the University of Kent and opportunistic sampling. The study was approved by the University of Kent's School of Sport and Exercise Sciences Research Ethics Advisory Group (Ref 44_2019_20) and conducted in compliance with the Helsinki Declaration.

Table 5.1: Participant demographics.

Variables	Participants (N=27)	Significance value
Age (y)	42.00 ± 13.93	0.40
Female / Male	12 / 15	0.54
LBP / No LBP	16 / 11	0.54
Height (cm)	174.85 ± 8.18	0.01
Weight (kg)	75.52 ± 16.11	0.59
BMI (kg/m^2)	24.64 ± 4.97	0.54

Significance values are shown as comparisons between pain and no pain groups.

5.2.2 Data Collection

Participants visited the laboratory at the University of Kent on two occasions 7 days apart. The data acquisition and image analysis procedure for the ultrasound methodology are described in chapter 3. Three zones were identified upon USI analysis, the subcutaneous zone (AT1 and NE1), the combined zone (AT2 and NE2) and the perimuscular zone (AT3 and NE3), these zones can be seen below in figure 5.1.

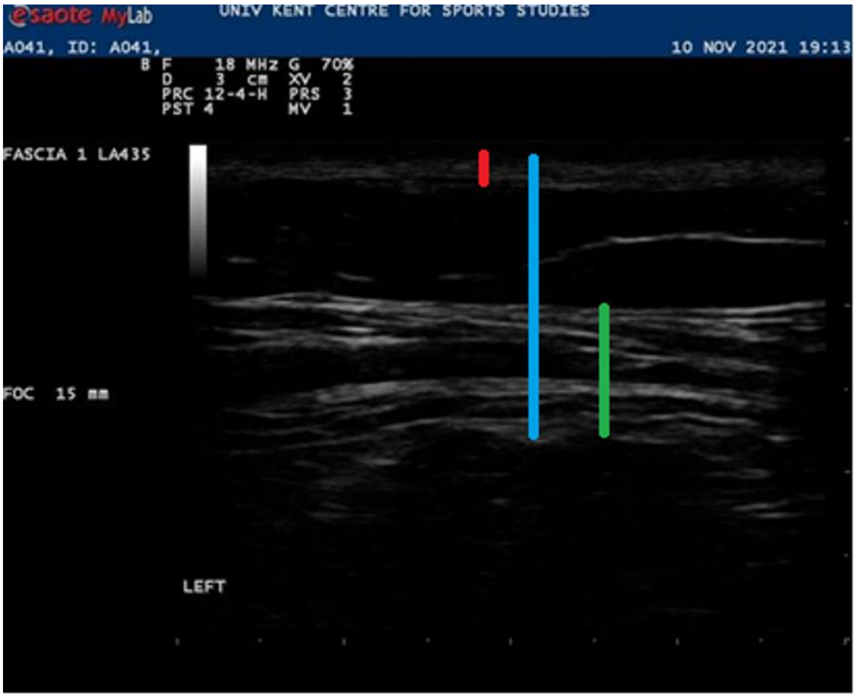


Figure 5.1. Ultrasound image depicting the three thoracolumbar fascia zones.

Red represents the subcutaneous zone, blue the combined zone and green the perimuscular zone.

5.2.3 Ultrasound image capture

For this study a total of 2 raters were used, 1 novice and one expert, for each participant both raters were randomised in terms of order of image capture and analysis and were fully blinded to previous images and findings. Intra- rater repeat images were taken by one of the raters within 10 days of the initial visit for intra-rater analysis. The trained rater qualified in musculoskeletal ultrasound at the

Centre for Ultrasound Studies Anglo-European Chiropractic College, the course included 250 hours of supervised scanning and is accredited by the Consortium for Accreditation of Sonographic Education (CASE). The novice rater was given one-to-one training by the trained rater on 6 occasions at the University of Kent, Canterbury Campus. Figures 5.2 and 5.3 below detail the methodology for both the intra- and inter- rater aspects of the study.

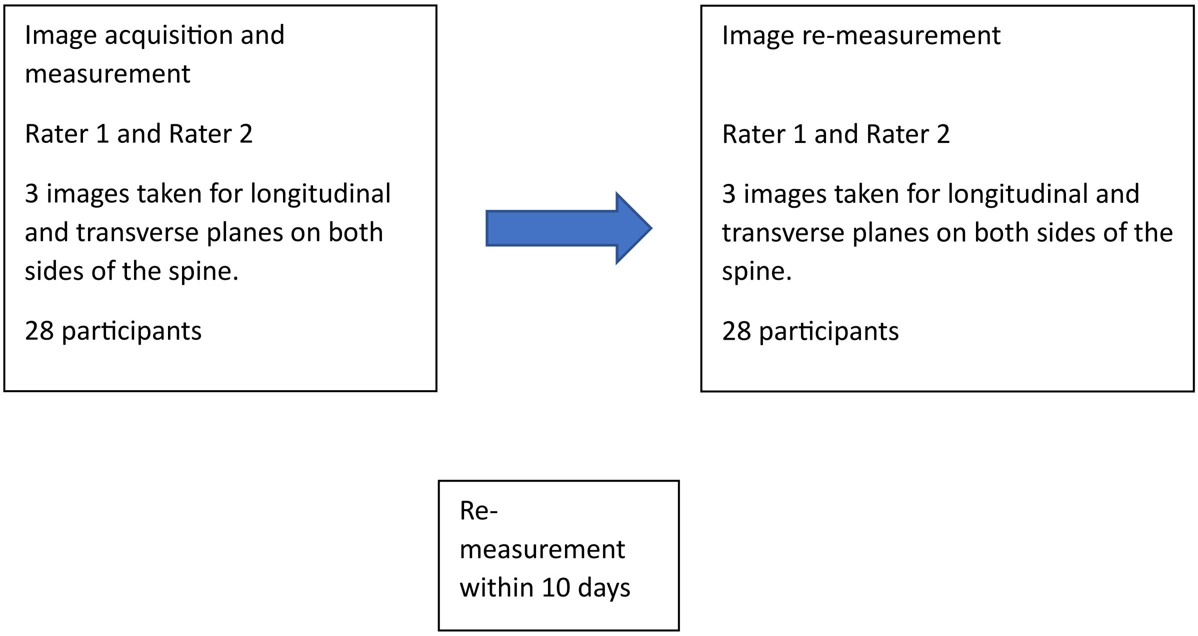


Image acquisition and measurement

Rater 1 and Rater 2

3 images taken for longitudinal and transverse planes on both sides of the spine.

28 participants

Image re-measurement

Rater 1 and Rater 2

3 images taken for longitudinal and transverse planes on both sides of the spine.

28 participants

Re-measurement within 10 days

Figure 5.2 Intra-image reliability methodology: Ultrasound image capture and analysis.

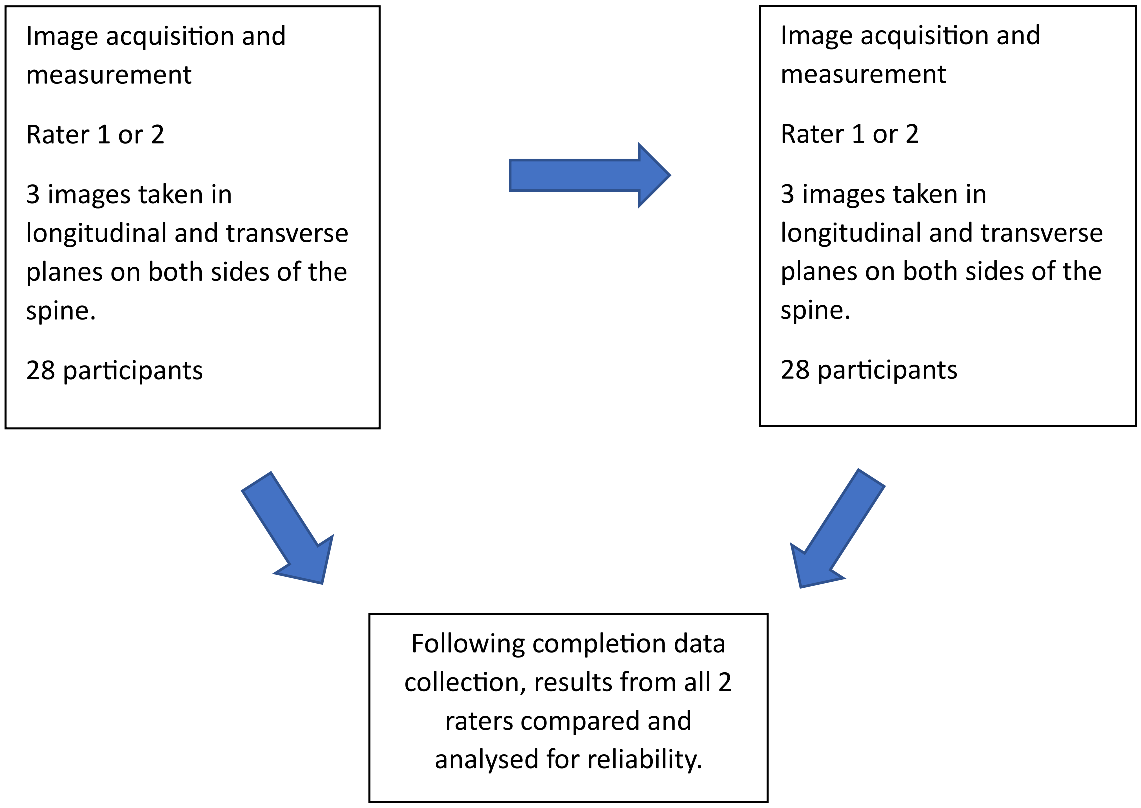


Figure 5.3: Inter-image reliability methodology: Ultrasound image capture and analysis.

5.2.4 Lower back pain status.

To classify lower back pain status, a modified Dionne LBP questionnaire (see appendix 1.2) which groups cases into the following categories: Acute lower back pain defined as experiencing pain for less than 3 months, and chronic low back pain for pain of 3 months or more. Participants without lower back pain are classified as those with an absence of LBP in the last 12 months. (Dionne et al., 2008). The LBP questionnaire was completed prior to the participant's first visit to the laboratory, as such raters were not blinded to the participant's lower back pain status. This was considered suitable for this study as the purpose of this study is to compare and analyse the reliability between 2 raters rather than a LBP specific focused study.

5.2.5 Statistical analysis.

All data analysis was completed using IBM SPSS statistics 27 (IBM SPSS Statistics v.5, SPSS Inc., Chicago:IL). For inter- reliability Intraclass correlation coefficient (ICC) with a 95% confidence interval (CI) were calculated. ICC results between >0.40 -<0.75 were treated as fair-good and any results above >0.75 as excellent. For intra- rater reliability a test-retest analysis was performed using the Pearson's Correlation coefficient to determine reliability between one rater across two visits with results between >0.4 -<0.79 treated as moderate, between 0.6-<0.79 as high and above 0.8 as very high.

In addition to reliability analysis, standard error measurements (SEM) across and between raters was measured to examine consistency. SEM was calculated by pooling the standard deviation multiplied but the square root of the ICC (SD pooled x √(1-ICC)).

For inter-rater reliability Bland Altman plots were also used. To prepare these the difference between the measurements of scans from the expert and novice rater were calculated and plotted against the mean. The limits of agreement (LOA) were defined as the mean bias plus or minus 1.96 times its standard deviation (SD) (Bland & Altman., 1986).

5.3 Results.

5.3.1 Intra- rater reliability.

Intra- rater reliability for the novice rater was classified as very high for the subcutaneous r_s= 0.95, p = <0.05, and combined thickness zones r_s 0.93, p = <0.05, and moderate for the perimuscular zone r_s =0.59, p = <0.05. Likewise, reliability for the echogenicity values was high with r_s = 0.85, p = <0.05, for the subcutaneous zone, r_s = 0.76, p = <0.05, for the combined and r_s = 0.75, p = <0.05, for the perimuscular zone. Table 5.2 below depicts the intra-rater reliability results for the novice rater.

Table 5.2 Novice intra-rater reliability of thickness and echogenicity values

Thoracolumbar zone? Measurement	Visit 1 Mean (mm) (SD)	Visit 2 Mean (mm) (SD)	Difference Mean	Visit 1 SEM	Visit 2 SEM	Pearson's Correlation
Sub. thickness	2.54 ± 2.34	2.51 ± 2.52	0.03	0.40	0.43	0.95
Comb. thickness	5.18 ± 3.61	5.07 ± 3.18	0.10	0.61	0.54	0.93
Peri. thickness	2.64 ± 1.70	2.56 ± 0.92	0.08	0.29	0.16	0.59
Sub. echogenicity	0.37 ± 0.12	0.37 ± 0.12	0.01	0.02	0.02	0.85
Comb. echogenicity	0.10 ± 0.06	0.11 ± 0.09	0.01	0.01	0.02	0.76
Peri. echogenicity	0.60 ± 0.12	0.57 ± 0.09	0.03	0.02	0.02	0.75

Mean values, standard deviation (SD) and standard error measurements (SEM) are in millimetres for thickness values and as a normalised greyscale value from 0-1 for echogenicity. Sub. refers to the subcutaneous zone, Comb. to the combined zone and Peri. to the perimuscular zone.

Intra-rater reliability for the expert rater was classified as very high for the subcutaneous zone $r_s = 0.85$, $p = <0.05$, high for the combined zone $r_s = 0.78$, $p = <0.05$ and high for the perimuscular zone $r_s = 0.77$, $p = <0.05$. Likewise, reliability for the echogenicity values was high for the subcutaneous zone with $r_s = 0.77$, $p = <0.05$, high for the combined zone with $r_s = 0.71$, $p = <0.05$, and moderate for the perimuscular zone with $r_s = 0.75$, $p = <0.05$. Table 5.3 below depicts the intra-rater reliability results for the expert rater.

Table 5.3 Expert intra-rater reliability of thickness and echogenicity values

Thoracolumbar Measurement	Visit 1 Mean (SD)	Visit 2 Mean (SD)	Difference Mean	Visit 1 SEM	Visit 2 SEM	Pearson's Correlation
Sub. thickness	2.32 ± 2.25	2.28 ± 2.43	0.04	0.43	0.47	0.85
Comb. thickness	4.49 ± 2.81	4.51 ± 2.95	0.02	0.54	0.57	0.78
Peri. thickness	2.18 ± 0.91	3.64 ± 2.55	1.47	0.18	0.49	0.77
Sub. echogenicity	0.38 ± 0.12	0.38 ± 0.12	0.00	0.02	0.02	0.77
Comb. echogenicity	0.13 ± 0.07	0.14 ± 0.08	0.01	0.01	0.02	0.71
Peri. echogenicity	0.62 ± 0.02	0.59 ± 0.09	0.03	0.02	0.02	0.75

Mean values, standard deviation (SD) and standard error measurements (SEM) are in millimetres for thickness values and as a normalised greyscale value from 0-1 for echogenicity. Sub. refers to the subcutaneous zone, Comb. to the combined zone and Peri. to the perimuscular zone.

5.3.2 Inter-rater reliability.

The ICC for inter-rater reliability for the thoracolumbar fascia thickness measurements between the novice and expert raters were very high for all measurements. For subcutaneous thickness, the average ICC measurement was 0.992 with a 95% confidence interval from 0.985-0.996, $p < 0.05$. For Combined thickness the average ICC measurement was 0.989 with a 95% confidence interval from 0.980-0.994, $p < 0.05$. Lastly, for perimuscular thickness, the average ICC measurement was 0.912 with a 95% confidence interval from 0.831-0.954, $p < 0.05$.

The ICC for inter-rater reliability for the thoracolumbar fascia echogenicity measurements between the novice and expert raters were very high for all measurements. For normalised subcutaneous echogenicity, the average ICC measurement was 0.993 with a 95% confidence interval from 0.986-0.996, $p < 0.05$. For normalised combined echogenicity, the average ICC measurement was 0.963 with a 95% confidence interval from 0.901-0.984, $p<0.05$. Lastly, for normalised perimuscular echogenicity, the average ICC measurement was 0.924 with a 95% confidence interval of 0.855-0.961, $p < 0.05$. Table 5.4 below depicts the inter-reliability values of both thickness and echogenicity between both raters.

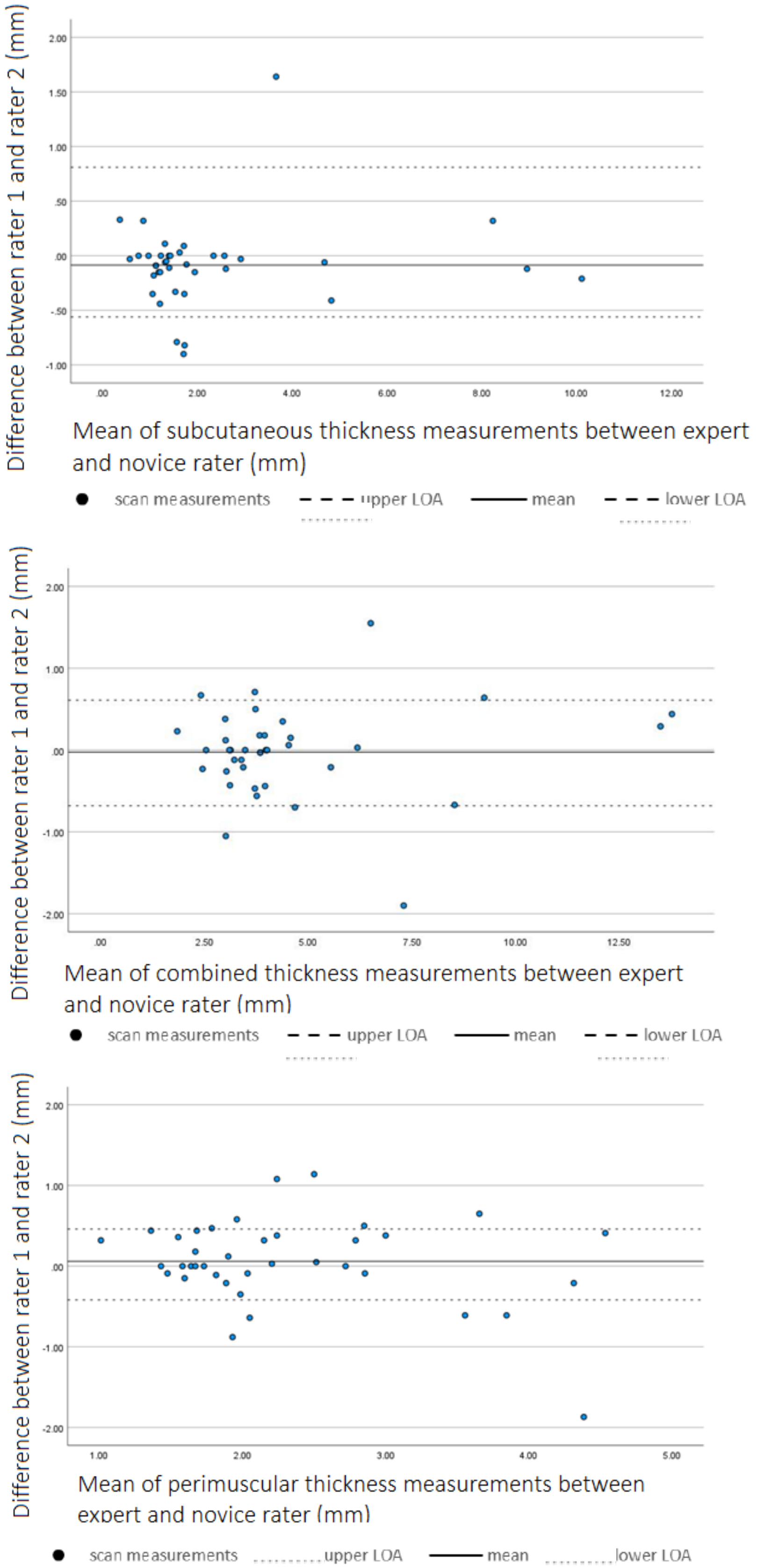
Table 5.4 Inter-rater reliability for thickness and echogenicity values between the novice and expert raters.

Thoracolumbar Measurement	Novice rater Mean (SD)	Expert Rater Mean (SD)	Difference Mean	Novice rater SEM	Expert rater SEM	ICC
AT1 thickness	2.25 ± 2.25	2.34 ± 2.21	0.08	0.36	0.36	0.99
AT2 thickness	4.60 ± 2.68	4.62 ± 2.63	0.03	0.43	0.43	0.99
AT3 thickness	2.35 ± 0.85	2.29 ± 0.99	0.06	0.14	0.16	0.91
NE1 echogenicity	0.38 ± 0.13	0.38 ± 0.13	0.01	0.02	0.02	0.99
NE2 echogenicity	0.11 ± 0.09	0.13 ± 0.10	0.02	0.01	0.02	0.96
NE3 echogenicity	0.60 ± 0.12	0.61 ± 0.12	0.01	0.02	0.02	0.92

Mean values, standard deviation (SD) and standard error measurements (SEM) are in millimetres for thickness values and as a normalised greyscale value from 0-1 for echogenicity. AT1 and NE1 refers to the subcutaneous zone, AT2 and NE2 combined and AT3 and NE3 perimuscular.

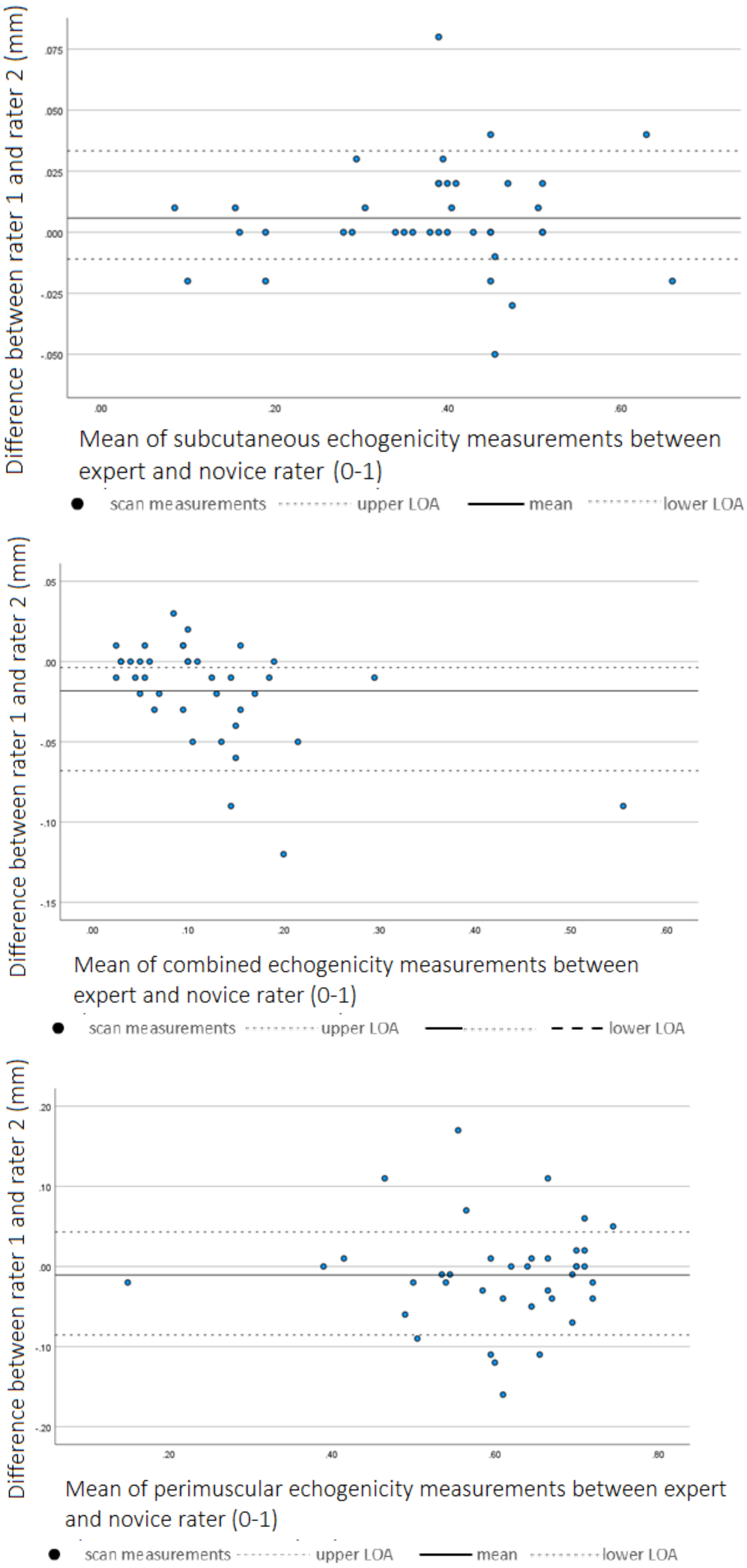
5.3.3 Analysis of Bland-Altman plots

Bland-Altman plots were created for the inter-rater reliability of all thickness and echogenicity measurements, shown below in figures 5.4 and 5.5. Inspection of Bland-Altman plots revealed no systematic pattern of variability in measurement across all three thoracolumbar fascia zones, between the two raters (Bland and Altman., 1986).



LOA: Limits of agreement, calculated as mean bias ± 1.96 times its standard deviation.

Figure 5.4: Bland Altman plots for inter-rater reliability of thickness



LOA: Limits of agreement, calculated as mean bias ± 1.96 times its standard deviation.

<u>Figure 5.5: Bland Altman plots for inter-rater reliability of echogenicity</u>

5.4 Discussion.

5.4.1 Inter-Rater Reliability.

Results from this study indicate very high inter-rater reliability measurements of the thoracolumbar fascia thickness and echogenicity with ICCs ranging from 0.91-0.99 coupled with small SEMs ranging from 0.01-0.02 for echogenicity and 0.14-0.43 mm for thickness measurements.

ICC scores for the perimuscular zone in respect of both thickness (ICC 0.91, SEM 0.14 and 0.16) and echogenicity (ICC 0.92, SEM 0.02) were marginally lower than the subcutaneous zone (Thickness: ICC 0.99, SEM 0.36 and 0.36. Echogenicity: ICC 0.99, SEM 0.02 and 0.02) and combined zone (Thickness: ICC 0.99, SEM 0.43 and 0.43. Echogenicity: ICC 0.96, SEM 0.01 and 0.02). However, all scores for inter-rater reliability were very high, with the lowest reading as 0.92. Moreover, the overall ICC scores are in agreement with previous USI inter-rater reliability studies (Sions et al., 2014, Teyhen et al., 2011 and Wilson et al., 2016) which all report ICC values of above 0.87.

The inter-rater reliability between trained and untrained clinicians on the ability to agree on morphological features of the thoracolumbar fascia has been investigated (De Coninck et al., 2018). The study recruited 30 trained clinicians, with n=12 self-reporting experience and training in USI, and n=17 reporting no training (n=1 did not report their experience level). In this study, thirty pre-selected images of the thoracolumbar fascia were chosen by a focus group with the participants then required to grade the images according to organisation rather than measuring and analysing the raw scans themselves. Reliability between the trained and untrained raters was measured using Cronbach's alpha with excellent/very high results for both groups (Experienced 0.96, Novice 0.95 respectively). Whilst this study differs in terms of the type of analysis, the inter-rater reliability between novice and expert individuals is in line with those found in the present study and further supports and extends the consensus that novice raters can reliability scan and analyse the thoracolumbar fascia using USI.

The Inter-rater reliability scores in the present study are higher than those in similar studies investigating using USI of the muscles of the trunk and specifically, lower back. Two key studies (Teyhen et al., 2011, and Wilson et al., 2016) have included measurement and analysis of the lumbar multifidus at a similar area to the methodology used in this thesis (2cm laterally to the interdisc space between L2-L3). Teyhen and colleagues (2011) analysed the inter-rater reliability of novice raters of individuals without LBP. Twenty-one young adults were recruited with a mean age of 21.5 ± 4.4 (5 female, 17 male). Inter-rater reliability was measured on several trunk muscles, for the lumbar multifidus ICC was scored at 0.87 with a 95% confidence interval between 0.68-0.95. The age range in the Teyhen study is smaller and younger than that used in the present study, with the mean age of participants reported as 42.00 ± 13.9. Wilson et al., (2016) recruited 92 older adults with a mean age of 75.9 ± 6.9 with 18% of participants self-reporting with LBP. Inter-rater reliability for the lumbar multifidus showed an ICC of 0.86 with a 95% confidence interval of 0.75-0.92. The reliability of both the Teyhen & Wilson studies can be described as high-to-very high but are still lower than those included in this study with 0.91-0.99 ICC reports across all thoracolumbar fascia measurements.

5.4.2 Intra-Rater Reliability.

Intra-rater reliability for the novice rater was reported as very high for the subcutaneous and combined thoracolumbar fascia thickness and moderate for the perimuscular thickness. For echogenicity intra-rater reliability was reported a high for all zones. ICC scores ranged from 0.59-0.95 for thickness measures with SEMs between 0.16-0.54, for echogenicity values ICC ranged from 0.75-0.85 with SEMs of 0.02 across all zones.

Intra-rater reliability for the expert rater was reported as very high for the subcutaneous thickness zone, and high for the combined and peri-muscular zones. Likewise, reliability for echogenicity values was high for all zones. ICC scores ranging from 0.77-0.85 with SEM ranging from 0.47-0.57 for thickness measurements and ICC scores ranging from 0.71-0.77 with SEMs of 0.02 across all three zones.

At present, no intra-rater reliability has been completed investigating imaging and analysis of the thoracolumbar fascia of either expert or novice raters. Intra- rater reliability has however been completed investigating USI of the trunk muscles. Sions and colleagues (2014) completed an inter- and intra- rater reliability investigation into lumbar multifidus muscles thickness of younger and older adults. A total of 61 participants were recruited, with 31 aged 18-40 and classified as "younger adults", and 30 participants aged 60-85 who were classed as "older adults". Two raters, one expert and one novice scanned and analysed each image with an intra-rater ICC of 0.85 (0.69-0.93) for younger adults and 0.92 (0.83-0.96) for older adults recorded. The ranges here are in line with the ICC thickness results from both the novice (0.75-0.85) and expert (0.77-0.85) raters in the present study. Interestingly, in the Sion study reliability was higher in the older adult population, for fascia morphological changes have been reported in aging populations which may impact the reliability of USI and analysis (Wilke et al.,2018). You would expect morphological adaptations of fascia to reduce the reliability of USI, however the Sion study seems to show the opposite, suggesting instead that the aging process may improve reliability. Whilst we did not compare the differences between the different age groups due the limitations with the sampling size within this study, we did find similar levels of reliability with the group overall. Future studies should seek to investigate the intra- rater reliability on the thoracolumbar fascia of two populations, younger and older adults, to investigate how the aging process may impact the reliability of ultrasound imaging capture on the thoracolumbar fascia.

Despite the limited number of USI reliability studies on the thoracolumbar fascia, a higher number of USI reliability studies are published on trunk muscles in populations with and without LBP. With the limited research here, it is important to understand the reliability of the surrounding muscle so that we can see if ultrasound can be used to measure both structures reliably. Wallwork et al., (2007) recruited 10 healthy participants with a mean age of 30.8 ± 18.1 and analysed the intra- rater reliability of novice and expert raters on the lumbar multifidus at L2-3 and L4-5 vertebral level. At L2-L3 (i.e., the same as the current study) intra rater reliability showed an ICC of 0.89 (95% confidence interval range of 0.72-0.97) for the novice rater and 0.94 with a small 95% confidence interval range of 0.86-0.99 for the expert rater. For a population with LBP, lumbar multifidus intra- rater reliability measured at a slightly lower L3-L4 level was reported as 0.81 with a much wider 95% confidence interval range of 0.47-0.94 (Wong et al., 2013). Wong and colleagues' (2013) study included 27 participants aged 32.7 ± 12.2, 14 of which self-reported with LBP. Importantly, the study also included a no-pain group of 13 participants (aged 26.2 ± 5.5), and the intra-rater reliability for this group was found to be higher than the pain group, with an ICC of 0.98 and a 95% confidence interval of 0.93-0.99). The three studies (Sions et al., 2014, Wallwork et al., 2007., and Wong et al., 2013) show that whilst the reliability of measurement for the trunk muscles is still classed as high in LBP populations, the results are lower than the very high ICC values seen in healthy populations. It is possible that this marginal reduction in reliability of pain groups could be replicated in the analysis of the thoracolumbar fascia.

5.5 Conclusion.

This study has demonstrated the USI of thoracolumbar fascia is a reliable method to analyse thickness and echogenicity of three zones: the subcutaneous zone, the combined zone and the perimuscular zone. This study found that the inter-rater reliability between a novice rater and an experienced rater is high, both can capture and analyse images of the thoracolumbar fascia with high reliability. Likewise, intra-rater reliability has proven to be between moderate and high for both novice and expert raters alike. These findings are comparable to those seen in studies investigating the reliability of ultrasound images of the trunk muscles and lower back, and thoracolumbar fascia reliability studies investigating organisation. Future studies should seek to investigate the reliability in distinct populations, such younger adults, and older adults. This study has shown that ultrasound imaging is a reliable method to image and analyse the thoracolumbar fascia by both a novice and expert rater, the next area of interest will be to see whether morphological differences can be seen in those with and without LBP.

Chapter 6. Altered morphology of the thoracolumbar fascia in those with lower back pain: An observational ultrasound study.

6.1 Background.

Lower back pain (LBP) is the leading cause of disability-adjusted life years with an estimated worldwide prevalence of 84%, effecting over 560 million individuals (Chen et al., 2022). Classified as one of the most taxing musculoskeletal disorders, LBP impacts mobility (Lee et al., 2015), independence, quality of life (O'Sullivan and Lin., 2014), and ability to work (Ozgular et al., 2000). Less than 15% of all chronic LBP cases are caused by a specific underlying pathological cause, with the remainder classified as non-specific (Russo et al., 2018). Altered morphology of the thoracolumbar fascia has been found in those with LBP (Bishop et al., 2016., and Langevin et al., 2011). Identifying the aetiology behind chronic non-specific LBP is still under investigation within the literature, with ultrasound imaging increasingly being used in musculoskeletal pathologies (Allegri et al., 2016, and Zugel et al., 2018). Langevin and colleagues (2007, 2009 and 2011) identified that ultrasound imaging could be successfully used to identify and measure the thoracolumbar fascia in populations with and without LBP. Further research into this area has continued to find ultrasound imaging as a safe, effective, and reliable method to analyse the thoracolumbar fascia without the need for invasive biopsies (De Coninck et al., 2018, Langevin et al., 2009, Wilke & Tenberg., 2020, and Whittaker & Stokes., 2011).

Structurally, the thoracolumbar fascia is made up of sheath-like layers of densely packed collagen fibres, dispersed with layers of loose connective tissue consisting of a ground substance fluid with hyaluronic acid being one of the main components (Benetazzo et al., 2011). In a healthy body, throughout our lifespan these collagen fibres are remodeled to maintain their elasticity and prevent injury (Kjaer et al., 2009). The morphological makeup varies from person to person with differing thickness, echogenicity, organization, and shear strain seen in both healthy populations and those with chronic pain (Almazan-Polo et al. 2009, De Coninck et al., 2018, Langevin et al., 2009 and 2011, Larivere et al., 2020).

Early ultrasound findings by Langevin and colleagues (2011), found that the thoracolumbar fascia in those with LBP can be up to 25% thicker and brighter (measured by echogenicity) than their pain free counterparts. The study included 107 participants, of which 60 self-reported with chronic non-specific LBP. Habitual exercise habits varied within the population, with 90% of the groups classified as moderately or highly active, and >10% of participants classified as sedentary. Ultrasound imaging of the perimuscular thoracolumbar fascia measured 2 cm laterally at the L2-L3 interspinal disc space found a ~25% increase in thickness and echogenicity when adjusted for BMI. However, when correlated to age there were no significant findings for thickness or echogenicity. This study has acted as a reference point for others since its publication, with many studies including those in this thesis applying its methodology. More recently, a study by Lariviere and colleagues (2020) investigated perimuscular thickness of the thoracolumbar fascia within a healthy and LBP population. The authors recruited 64 participants, 30 healthy and 34 with LBP (35% of which self-certified as physically active), and like earlier studies, the authors suggested a trend towards increased thoracolumbar fascia thickness in the LBP group of 18%, however these results were statistically insignificant (p=0.09). The authors went on to compare morphological differences between their male and female participants with non-significant (p=0.07) findings. Research into thickness and echogenicity differences in those with and without LBP is limited and equivocal in the existing literature. Currently there is no firm consensus on the differences seen in the thoracolumbar fascia and how they relate to LBP. Moreover, at present there is no gold standard for ultrasound image analysis for the thoracolumbar fascia, or any fascia.

Despite the uncertain evidence of an increased thickness in the thoracolumbar fascia in LBP, these specialised connective tissues continue to attract attention within the literature. Early research into the organisation of the thoracolumbar fascia found that different medical practitioners (both with and without MSK ultrasound experience) agreed on organisation grouping with inter-rater reliability with modest agreement (Krippendorf's alpha, 0.61) and with excellent consistency between observers (Cronbach's alpha, 0.98) (De Coninck et al., 2018). De Coninck and colleagues introduced 4 sub-groups for thoracolumbar fascia morphology: Group 1 = very disorganised, 2= Somewhat disorganised, 3 = somewhat organised and group 4 = very organised. Using this grouping, an ultrasound study by Almazan-Polo and colleagues (2020) investigated the thoracolumbar fascia and multifidus muscle in semi-professional athletes. Thirty male participants took part in the study, 15 with LBP and 15 healthy counterparts who all completed a minimum of 1500 metabolic equivalent minutes per week of physical activity (classified as moderate-vigorous physical activity level). The authors did not find significant differences in thoracolumbar fascia thickness of the LBP cohort but significant differences in the organisation of the thoracolumbar fascia in the LBP group (p = 0.011). Interestingly, in the LBP group thoracolumbar fascia was classified as “somewhat disorganised” for 46.7% of images of the right side of the thoracolumbar fascia and 25.7% for the left side of the thoracolumbar fascia. Unfortunately, the study did not specify LBP location as to sides of the spine, however it is likely that the pain can be attributed to the side of the spine with the higher levels of disorganisation. In the healthy control group, 0% of images for both left and right sides were classified as disorganised with most images classified as very organised >60% (Almazan-Polo et al., 2020).

Shear strain was introduced as a further measure of thoracolumbar fascia morphology by Langevin and colleagues in 2011. The layers of the thoracolumbar fascia’s connective tissue independently glide between each other as they are pulled in different directions according to the aponeuroses of neighbouring muscle. This gliding or shear strain occurs in both longitudinal (due to pulls from the erector spinae, latissimus dorsi and serratus posterior) and transverse (due to the internal and external obliques and the latissimus dorsi) directions (Benjamin., 2009). The first investigation into thoracolumbar shear strain included the analysis of 121 participants, 71 with LBP and 50 healthy control counterparts (Langevin et al., 2011). The LBP group elicited a significantly lower (p=0.01) mean shear strain capabilities (56.4% ± 3.1%) than their healthy counterparts who displayed 13.8%

higher level of gliding (70.2% ± 3.6%) following a standardised passive flexion movement. Moreover, significant correlations between male participants were found between shear strain and perimuscular thickness ($p=0.001$), shear strain and echogenicity ($p=0.05$) as well as other range of motion tests. There were no significant correlations found within the female participants. Vining et al., (2022) corroborated these sex differences in a recent pilot study, with men having a 9% reduction in shear strain capabilities compared to female participants with LBP (Females = 77% maximum shear strain, Males = 68% maximum shear strain) during passive spinal flexion. Whilst equivocal in the literature, it is thought that shear strain reductions in LBP populations are likely due to impairments in neuromuscular control and recruitment patterns of the adjoining trunk muscles to the thoracolumbar fascia (Langevin et al., 2011).

At this stage, the literature is still unclear about the relationship between differences in thoracolumbar fascia morphology and LBP. Research has speculated that LBP will be more commonly seen in those with adaptations or alterations in fascia morphology, resulting in worsening of LBP caused by maladaptive movement strategies due to pain (Langevin & Sherman., 2007). This theory is supported by evidence of connective tissue remodeling following repetitive stressors (E.g., activities of daily living, general ambulation, and exercise loading) in individuals both with and without tissue injury (Sahrmann et al., 2017). The majority of evidence for differences seen within thoracolumbar fascia morphology have been researched in active populations (Almazan-Polo et al., 2020., and

Langevin et al., 2011). Therefore, this study seeks to investigate thoracolumbar fascia thickness and echogenicity measurements in a physically inactive population both with and without LBP.

6.2 Methodology.

6.2.1 Participants.

Participants were recruited through the University of Kent's Graduate and Researcher College email, personal social media channels and via opportunistic sampling. Consent was given for anonymised ultrasound scans to be used for secondary analysis and publication. Participation was voluntary with no financial or other reimbursement given. The study was approved by the University of Kent's School of Sport and Exercise Sciences Research Ethics Advisory Group and conducted in compliance with the Helsinki Declaration (Ref 44_2019_20).

A total of 33 healthy male (n=18) and female (n=15) adults aged between 18 and 70 were recruited, 17 participants self-reported having LBP. Participant demographics can be found below in table 6.1. Prior to data collection written informed consent was obtained from all participants. The inclusion criteria required the participant to be a healthy adult, aged between 18-70 years of age, with or without lower back pain. To the be included in the study, participants had to be free from any underlying connective tissue disorders (such as, rheumatoid arthritis and hypermobility), record a BMI reading within the range of 16.5-39.9

and have no lymphoedema present. Prospective participants were excluded if they met any of the following criteria: history of previous lower back, hip or knee surgery in the past 12 months, unusual curvature of the spine (such as scoliosis, lordosis and/or kyphosis), a displaced vertebrae (e.g.: spondylolisthesis), spondylosis/pars defect, a history of corticosteroid injections in the lower back, trunk or near the spine, previous surgical interventions including pins and plates near the spine, diabetes, pregnancy and participants that are a current smoke. Likewise, participants were asked to self-report physical activity levels, the inclusion and exclusion criteria limited participants to be those completing less than 150 minutes moderate and/or <75 minutes of vigorous physical activity per week.

Table 6.1: Participant characteristics.

	Total (N=33)	No LBP (n=16)	LBP (n=17)
Mean age (years) ± SD	39.4 ± 13.38	42.5 ± 12.29	42.0 ± 19.23
Gender (n) Male/Female	18 / 15	11 / 5	7 / 10
Height (cm)	172.67 ± 8.81	175.08 ± 8.26	170.27 ± 9.18
Weight (kg)	77.78 ± 15.87	73.37 ± 16.08	82.20 ± 14.20
BMI (kg/m^2)	28.57 ± 5.71	23.85 ± 4.54	28.57 ± 5.89

Values represent mean +- standard deviation unless otherwise indicated.

6.2.2 Lower back pain status

To classify lower back pain status, a modified Dionne questionnaire (see appendix 1.2) was completed using an online MS form which groups LBP into the following categories: Acute lower back pain defined as experiencing pain for less than 3 months, and chronic low back pain for pain of 3 months or more. Participants without lower back pain were classified as those with an absence of low back pain in the last 12 months (Dionne et al., 2008). The LBP questionnaire was completed prior to the participant's first visit to the laboratory, as such the researcher was not blind to the participant's lower back pain status. This was considered suitable for this study as the purpose of this study was to compare and analyse the observational differences under ultrasound between individuals with and without LBP.

6.2.3 Data Collection protocol

Participants visited the laboratory at the University of Kent on one occasion for a total of 30-minutes. The data acquisition and image analysis procedure for the ultrasound methodology are described in chapter 3.

6.3 Results

6.3.1 Statistical analysis

Statistical analysis was performed using IBM SPSS statistics 24 (IBM SPSS Statistics v.5, SPSS Inc., Chicago:IL). No significant differences were found between left and right scans, so side-average measurements were used in all statistical analysis. Results are shown as mean ± standard deviation unless otherwise stated. The study included 17 participants with LBP and 16 without.

A Spearman's rank-order correlation was run to assess the relationship between BMI and each group (LBP and no pain). Preliminary analysis showed the relationship to be monotonic, as assessed by visual inspection of a scatterplot.

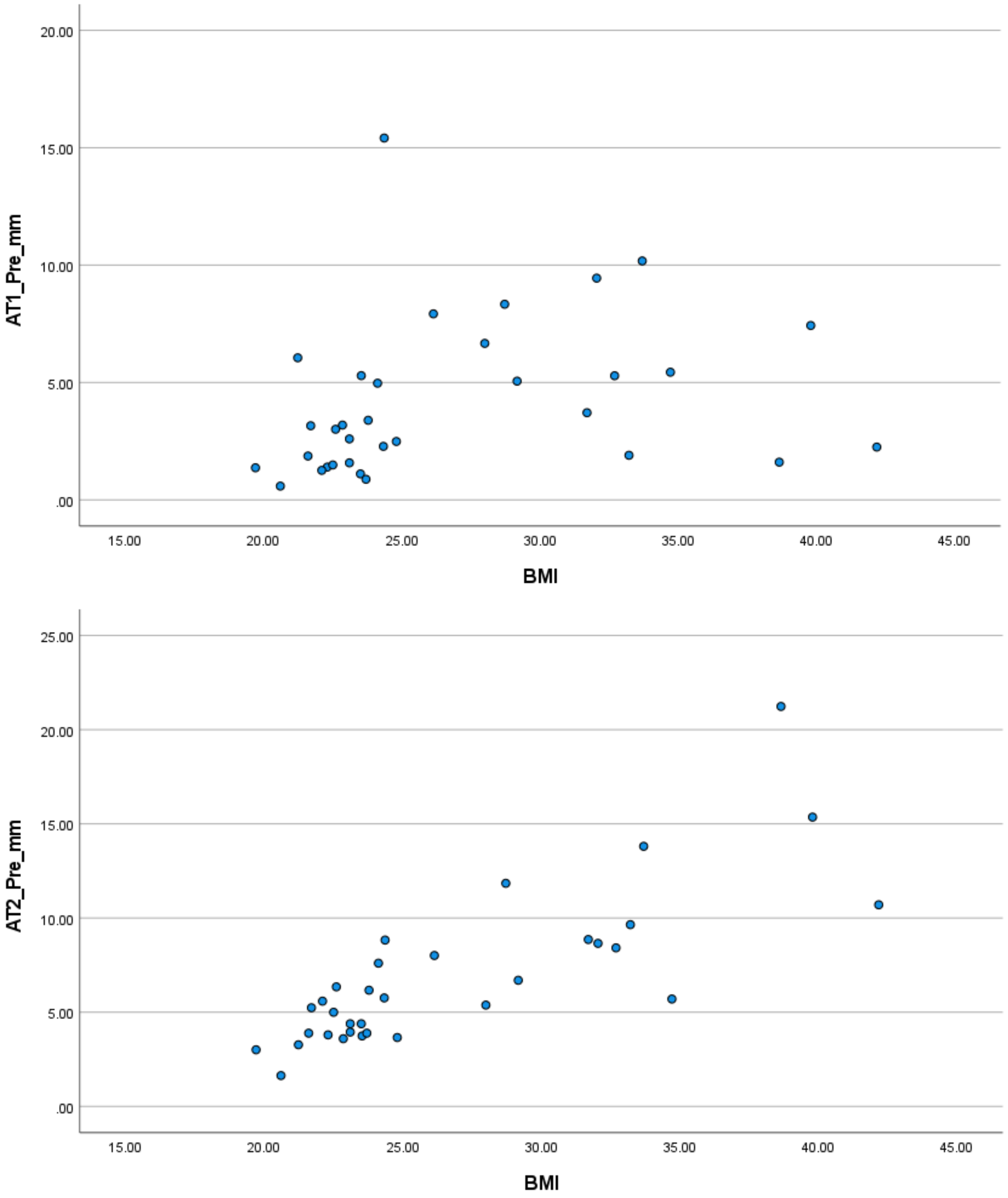
Thickness and echogenicity scores for each level were normally distributed, as assessed by Shapiro-Wilk's test (p=>0.05). There was homogeneity of variances for combined thickness (p=0.051), perimuscular thickness (p=0.922), normalised subcutaneous echogenicity (p=0.644) and normalised perimuscular echogenicity (p=0.644), as assessed by Levene's test for equality of variances. An independent-samples T-test was run to determine if there were any differences in thickness and normalised echogenicity between each group at the combined, subcutaneous, and perimuscular layers of the thoracolumbar fascia.

A Welch T-test was run to determine any differences for subcutaneous thickness ($p=0.017$) and normalised combined echogenicity ($p=0.021$) as homogeneity was violated, as assessed by Levene's test for equality of variances. There were no outliers in the data, as assessed by inspection of a boxplot of subcutaneous thickness and normalised combined echogenicity values, and values for each both LBP and no pain groups were normally distributed, as assessed by Shapiro-Wilk's test ($p=>0.05$).

6.3.2 BMI correlations

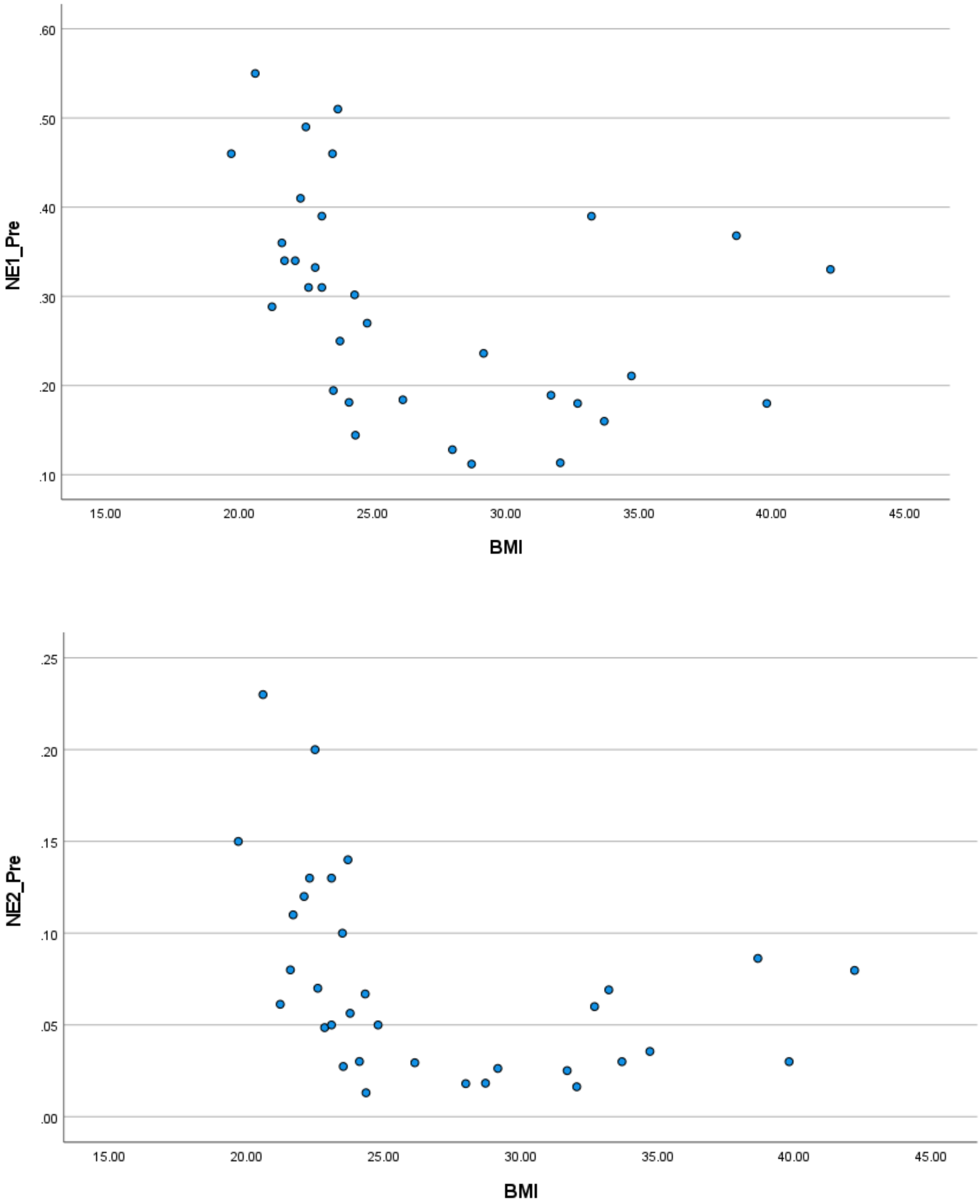
A Spearman's rank-order correlation between the LBP and no-pain group found that there was a statistically significant, moderate negative correlation with BMI, $r_s(98) = -0.509$, $p= <0.05$. . For thickness measurements, there was a statistically significant, moderate positive correlation between subcutaneous thoracolumbar fascia thickness and BMI, $r_s(98) = 0.453$, $p <0.05$ and a strong positive correlation between combined thoracolumbar fascia thickness and BMI , $r_s(98) = 0.761$, $p <0.05$. There was no statistically significant correlation between the perimuscular thoracolumbar fascia thickness and BMI, $r_s(98) = 0.674$, $p = 0.08$. Figure 6.1 below depict the significant correlations between BMI and subcutaneous thickness and combined thickness thoracolumbar fascia layers. For normalised echogenicity measurements there was a statistically significant, moderate negative corelation between subcutaneous normalised thoracolumbar fascia echogenicity and BMI, $r_s(98) = -0.468$, $p <0.05$, and a moderate negative correlation between combined normalised thoracolumbar fascia echogenicity and BMI, $r_s(98) = -0.477$, $p <0.05$.

There was no statistically significant correlation between the normalised perimuscular thoracolumbar fascia echogenicity and BMI, $r_s(98) = -0.279$ $p = 0.14$. Figure 6.2 below depict the significant correlations between BMI and subcutaneous and combined normalised echogenicity thoracolumbar fascia layers.



AT1 represents the subcutaneous zone, AT2 represents the combined zone.

Figure 6.1 Significant correlations for BMI and thoracolumbar fascia thickness



NE1 represents the subcutaneous zone, NE2 represents the combined zone.

Figure 6.2 Significant correlations for BMI and thoracolumbar fascia normalised echogenicity

6.3.3 Thoracolumbar fascia thickness and normalised echogenicity

Mean and standard deviations of all thickness and normalised echogenicity measurements are reported in Table 6.2.

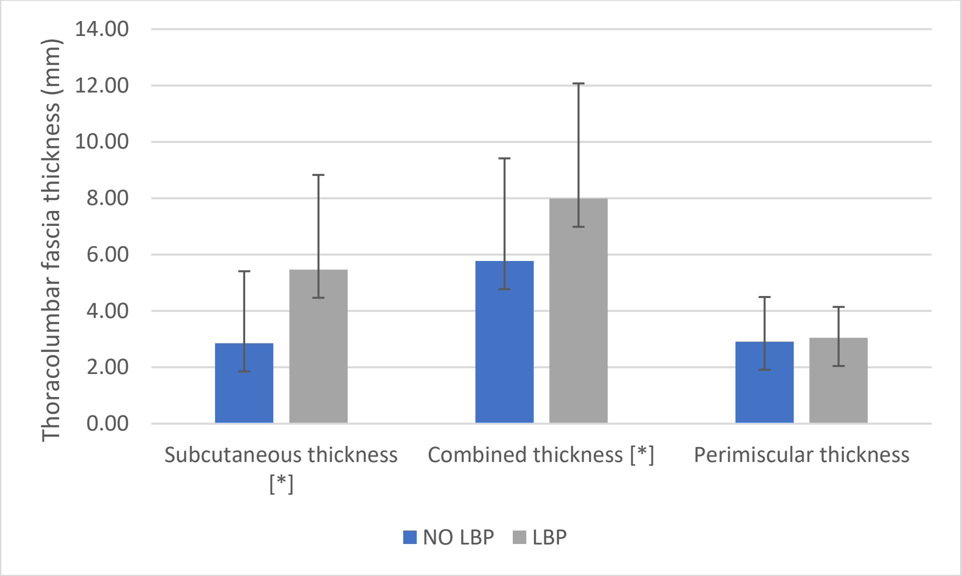
Table 6.2 Mean and standard deviation thoracolumbar fascia thickness and normalised echogenicity measurements.

Ultrasound measurement	LBP (n=17)	No LBP (n=16)
Subcutaneous thickness*	5.47 ± 3.36	2.86 ± 2.55
Combined thickness*	7.99 ± 4.09	5.77 ± 3.64
Perimuscular thickness	3.05 ± 1.10	2.92 ± 1.58
Normalised subcutaneous echogenicity*	0.36 ± 0.12	0.23 ± 0.09
Normalised combined echogenicity*	0.11 ± 0.06	0.04 ± 0.02
Normalised perimuscular echogenicity	0.59 ± 0.12	0.53 ± 0.02

Values represent mean ± standard deviation unless otherwise indicated. Thickness measured in mm. Normalised echogenicity measured on a scale from 0-1, with 0 representing black and 1 representing white on a greyscale. * represent statistically significant difference between groups p=<0.001.

6.3.4 Thoracolumbar fascia thickness.

Thoracolumbar fascia mean thickness values and standard deviation between the two groups can be seen below in figure 6.3.



[*] represents statistically significant findings.

Figure 6.3 Thoracolumbar fascia thickness values for the LBP and no LBP group.

Subcutaneous thickness layer.

There was a statistically significant difference in the mean subcutaneous thickness between the LBP and no pain group, with the LBP exhibiting thickness values 2.84 ± 0.69 mm (95% CI, 1.42 to 4.26) higher than the no LBP mean thickness, t(22.9)=4.14), p=<0.001. Subcutaneous thickness was on average 62.7% and 2.29mm thicker than the healthy control group.

Combined thickness layer.

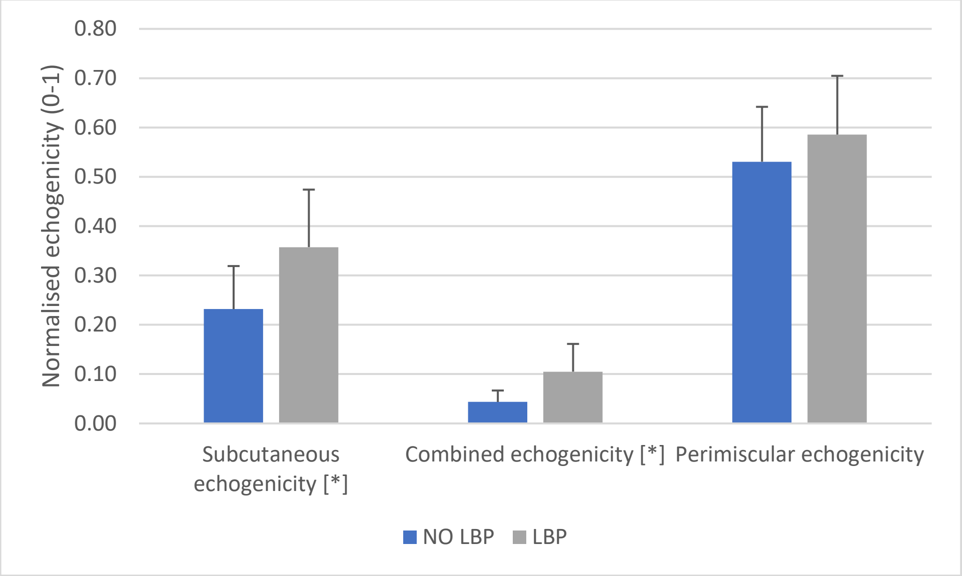
There was a statistically significant difference in the mean combined layer thickness between the LBP and no pain group, with the LBP exhibiting thickness values 3.42 ± 1.23 mm (95% CI, 0.90 to 5.94) higher than the no LBP mean thickness, t(28)=2.78), p=0.010. Combined thickness was on average 32.3% and 1.85mm thicker than the healthy control group.

Perimuscular thickness layer.

Mean perimuscular thickness for the LBP group was 0.37 ± 0.34 mm (95% CI, -0.33 to 1.06) higher than the no LBP mean thickness, this was not statistically significant, t(28)=1.08), p=0.290. Perimuscular thickness was on average 4.4% and 0.13mm thicker than the healthy control group.

5.3.5 Thoracolumbar fascia echogenicity.

Thoracolumbar fascia mean normalised echogenicity values and standard deviation between the two groups can be seen below in figure 6.4.



[*] represents statistically significant findings.

Figure 6.4 Thoracolumbar fascia normalised echogenicity values for the LBP and no LBP group.

Normalised Subcutaneous echogenicity layer.

There was a statistically significant difference in the mean normalised subcutaneous echogenicity between the LBP and no pain group, with the LBP exhibiting echogenicity values -0.15 ± 0.35 (95% CI, -0.22 to 0.07) higher than the no LBP mean echogenicity, t(28)=-4.18), p=0.0001. Normalised subcutaneous echogenicity was on average 83.3% and 0.2 units brighter than the healthy control group.

Normalised combined echogenicity layer.

There was a statistically significant difference in the mean normalised combined echogenicity between the LBP and no pain group, with the LBP exhibiting echogenicity values -0.07 ± 0.15 (95% CI, -0.11 to 0.40) higher than the no LBP mean echogenicity, t(17.2)=-4.65), p=0.0001. Normalised combined echogenicity was on average 54.5% and 0.04 units brighter than the healthy control group.

Normalised perimuscular echogenicity layer.

Mean normalised perimuscular echogenicity between the LBP and no pain group, with the LBP exhibiting echogenicity values -0.07 ± 0.42 (95% CI, -0.16 to 0.01) higher than the no LBP mean echogenicity, this was not statistically significant, t(28)=-1.76), p=0.090. Normalised perimuscular echogenicity was on average 10.7% and 0.5 units brighter than the healthy control group.

6.4 Discussion.

This study found significant differences between the thickness and normalised echogenicity for both the subcutaneous and combined zones when comparing individuals with and without LBP. However, no significant differences were found in the perimuscular zone for both thickness and echogenicity values. Of interest to this thesis is the perimuscular zone which includes the connective tissue layers of the thoracolumbar fascia and excludes the subcutaneous zone. BMI was significantly correlated with both the subcutaneous and combined zone for the thickness and echogenicity values, but there was no significant correlation for the perimuscular zone. Figure 6.5 displays a representative image of the thoracolumbar fascia in a participant with LBP whilst figure 6.6 is a representative ultrasound image of the thoracolumbar fascia in a participant without LBP. The red bar depicts the subcutaneous zone, the blue depicts the combined zone, and the green depicts the perimuscular zone. Visually, the two images are distinctly different, with the LBP scan (figure 6.5) covering a much deeper area with some visual differences in terms of the layout and structure of the perimuscular layer in particular.

Figure 6.5. Ultrasound imaging of the thoracolumbar fascia of an individual with LBP.

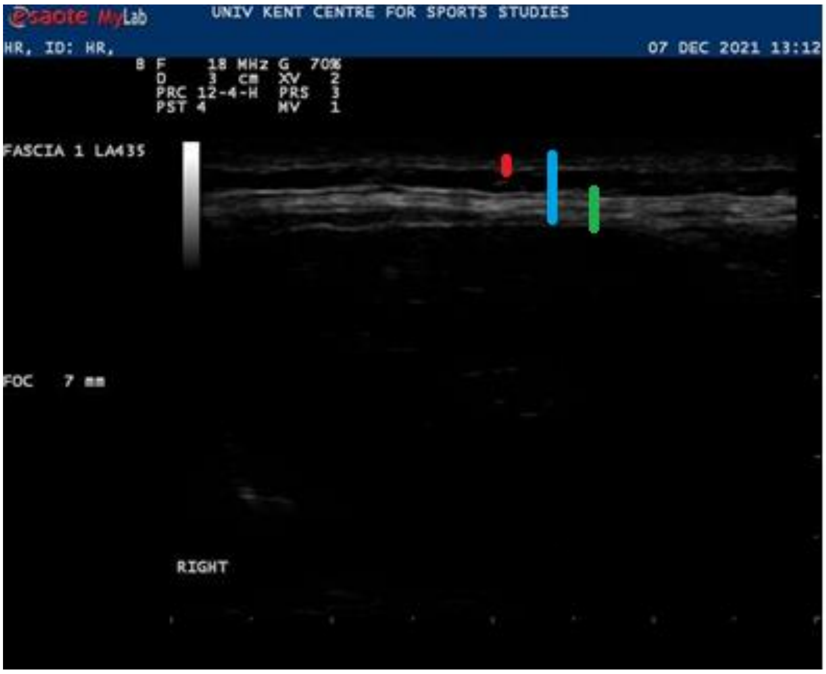


Figure 6.6. Ultrasound imaging of the thoracolumbar fascia of an individual without LBP.

6.4.1 Thoracolumbar fascia thickness

The present study found no statistically significant differences in the thoracolumbar fascia thickness of the perimuscular zone of people with and without LBP. In those with LBP, there was a non-significant trend towards an increased thickness in those with LBP. For example, perimuscular thickness was on 4.4% and 0.13mm thicker than the no-pain counterpart (LBP = 3.05mm ± 1.10mm, No pain = 2.92mm ± 1.58mm). Thickness at this level was not correlated with BMI. The findings of this chapter partially support previous ultrasound evaluations of the thoracolumbar fascia but disagree with key studies from Langevin and colleagues (2009) which found significant perimuscular thickness differences between LBP and no pain groups.

In the pioneering study Langevin and colleagues (2009), the LBP cohort exhibited an average perimuscular thickness of 4.2mm compared to 3.5mm in the no pain group. The difference of 0.7mm here showing as a significant increase in thickness and meaningful change to thoracolumbar fascia morphology. The average thickness in the present study is moderately different from that seen in the Langevin study, this could be attributed to pain levels of the participants. For this study, LBP was self-reported using a modified Dionne questionnaire with participants exhibiting low levels of pain. It is possible that to truly compare morphological differences in LBP and no-pain populations a higher pain level and for a longer duration is required. Moreover, all participants in the present study were classified as physically inactive (as reported by completing less than 150 minutes of moderate physical activity or 75 vigorous physical activity per week). Langevin's (2009) study consisted primarily of physically active individuals, with 62% of the LBP cohort and 67% of the no pain group partaking in over 3 hours of physical activity per week and just 9% (LBP) and 8% (no pain) participants classified as physically inactive. The impact of physical activity on the thickness of the thoracolumbar fascia is not yet known but given the differences between the thickness values of the present study and the Langevin study, physical activity levels could contribute to differences in thoracolumbar fascia thickness.

The thickness values in our study more closely align with those in the Whittaker and colleagues (2013). The authors found that average perimuscular thickness measured of 2.9mm in a LBP cohort and 2.3mm in a no pain group. Whittaker's findings attributed the significant 0.6mm difference to depict meaningful change. It should be noted that there are some differences in the ultrasound imaging capture in this thesis and the methods used by Whittaker study, which placed emphasis on the abdominal muscles and connective tissues by the authors recording images 3cm laterally to the spinous process, 1cm further than used in the present study. It is unlikely, however that this will make for major differences in results compared to the methodology used in this chapter as the thoracolumbar fascia will have the same function at both levels. The Whittaker study excluded those taking part in high levels of physical activity but did not specify the levels of physical activity in their participant demographics. It is therefore difficult to directly compare results of the inactive population in the present study. However, in comparison to this chapter, Whittaker and colleagues included a BMI range of 17-31 kg/m^2 which is closer to that of the present study. In the Whittaker study, the LBP cohort had reported an average BMI of 23.5 ± 2.5 in the LBP group and 24.0 ± 3.5 in the no pain group. Whilst marginally lower than the current study (28.57 ± 5.89 LBP and 23.85 ± 4.54 no pain respectively) the average participant for both groups in both studies were classified as overweight according to the BMI classification (Aronne., 2012). This classification is representative of the typical population with LBP with evidence supporting that an increase in LBP cases in those who are overweight or obese (Chin et al., 2020). Globally, LBP is the 6th leading cause of an individual (male or female) having a BMI of above 25.0 kg/m^2

(Dai et al., 2020). It is thought that higher BMI values are correlated with LBP and other musculoskeletal conditions due to a reduction in physical activity - both planned exercise and activities of daily living (Paraschiv-Ionescu et al., 2016). The findings in this chapter support the link between higher BMI and pain, as we found significant moderate negative correlation between BMI and LBP suggesting that those with higher BMI could be more likely to report LBP.

6.4.2 Thoracolumbar fascia echogenicity

The present study did not find significant differences in the echogenicity of the perimuscular zone. At present there is only one prior study (Langevin et al., 2009) that has investigated echogenicity differences between LBP and healthy populations in those with LBP. Perimuscular echogenicity was on average 10.7% and 0.5 units brighter than the no-pain counterpart (LBP = 0.59 ± 0.12, No pain = 0.53 ± 0.02) using a 0-1 greyscale. Echogenicity at this level was not correlated with BMI. Whilst research into the echogenicity of the thoracolumbar is sparse, the findings of this chapter do not support previous ultrasound evaluations of the thoracolumbar fascia which found significant perimuscular echogenicity differences between LBP and no pain groups.

The only study suitable for comparison is that from Langevin and colleagues (2009), who found a significant 25% increase in the brightness of the perimuscular thoracolumbar fascia layer when compared to a control group. The study included

60 participants with LBP and a no pain control group of 47 participants. As perimuscular echogenicity was highly correlated with BMI, analysis of covariance was performed finding a significant difference of p <0.01. The present study found no statistical differences between groups or correlations with BMI, despite a 10.7% increase in the LBP cohort. Langevin & Sherman (2007) previously hypothesised that differences in echogenicity would be seen due to the remodelling of the thoracolumbar fascia in response to pain and dysfunctional movement patterns, with follow up studies proposing that increases in echogenicity could be attributed to fibrosis of the collagen layers in fascia (Pavan et al., 2014). Langevin and colleague's (2009) study potentially included participants with a higher overall pain level than included in the current study. The 2009 study measured pain using a series of questionnaires including the McGill pain questionnaire, the Oswestry Disability scale and a custom designed questionnaire detailing current pain intensity, exacerbation of pain intensity, frequency and duration which provides a more robust categorisation compared to the self-reported modified Dionne questionnaire used in the current study. However, current pain intensity was measured at 3.2 ± 2.2 out of a scale of 10 in the Langevin study with the majority of the LBP group (67%) scoring as mild on the Oswestry disability questionnaire which is in line with the participants included in this study. The major difference between the participant demographics within Langevin study and this chapter are the physical activity levels described in the thickness discussion section. Increases in physical activity levels may play a role in the significance of echogenicity differences seen in LBP and no pain groups. Physical activity could act as a preventive measure and help

to reduce echogenicity of the thoracolumbar fascia in no pain groups, allowing for greater differences in echogenicity values.

6.4.3 Thoracolumbar fascia and BMI.

This study found a significant correlation between BMI and LBP, with the no pain group having a moderately lower BMI than those without pain. Likewise, when comparing the morphology of the subcutaneous zone and combined zone with BMI significant correlations were found for both thickness and echogenicity. In disagreement with early literature from Langevin et al., (2009), this study found a strong positive correlation between subcutaneous thickness and BMI and a moderate, positive correlation was found between combined thickness and BMI. Moreover, this pattern was similarly reflected in normalised echogenicity, with a moderate, negative correlation found between both subcutaneous and combined normalised echogenicity and BMI. The average participant BMI for the present study classify the pain group as “overweight” (28.57 ± 5.89) and the no pain group as “normal” (23.85 ± 4.54) according to the BMI classification (Aronne., 2012). Interestingly, the participants in the Langevin study (2009) also had an average BMI classification of “overweight”, (LBP group 25.9 ± 0.7, no pain group 25.7 ± 0.6). It is likely that the BMI range was lower than that of the present study which had a range of 21.23-42.19 for the LBP group, and 19.7-39.8 for the no pain group, including n=10 participants from the “obese” BMI classification. It is therefore probable that the greatest correlations between BMI and thoracolumbar fascia morphology are seen with participants with a BMI above 30.0 (the “obese” classification) and those with a “normal” BMI. Further investigation is needed to compare the thoracolumbar fascia morphology differences in high BMI populations with and without LBP. One limitation of this study was the increased difficulty of using ultrasound imaging on the participants with a BMI higher than 30.0. For those with above 30.0 a greater deep of adispose tissue was present, this meant that the area of interest on the ultrasound was only just visible using the scanning method. Future studies looking at those with a higher BMI should consider increasing the ultraound depth used from 3cm to 4cm or more to ensure the perimuscular layer is not cut off.

6.5 Conclusion.

This study found no significant differences in the perimuscular zone. Significant differences were found between the subcutaneous and combined thoracolumbar fascia layers for both thickness and normalised echogenicity values. Moreover, this study found a significant correlation between BMI and LBP, with the no pain group having a moderately lower BMI than those without pain. Whilst all participants in this study were classed as physically inactive, many of the no-LBP group came from an active background. Future studies should investigate the impact of exercise on the morphology of the thoracolumbar fascia and whether any changes can be seen following an increase in physical activity and potentially a reduction in BMI.

Chapter 7. The impact of group exercise and physical movement prompts on the thoracolumbar fascia in people with lower back pain.

7.1 Background.

The fibrous collagenous structure of fascia and all connective tissue types respond to physical stressors by stretching (Schleip et al., 2013), stiffening (Schleip et al., 2012) increasing in strength (Bond et al., 2019) and/or adapting its shear strain capabilities (Langevin et al., 2011). Research has yet to ascertain whether an increase in stimuli such as exercise and movement has a measurable impact on the morphology of the thoracolumbar fascia. However, exercise and movement have been shown to be beneficial for those with lower back pain (LBP) and is a common treatment option. Owen and colleagues (2020) completed a network meta-analysis to find the optimum exercise type for chronic, non-specific LBP, focusing on interventions lasting a minimum of 4-weeks up to a maximum of 17-weeks. Pilates, stabilisation/motor control exercise, resistance training and aerobic training were all beneficial for the treatment of LBP. In fact, only stretching and the McKenzie exercise training technique were seen to not improve LBP when compared to a control. The studies included ranged from 4-24 weeks in duration, with a dosage of 1-7 training sessions per week. Pilates-style exercise was found to induce the largest degree of pain reduction (surface under the cumulative ranking (SUCRA = 80%, pooled standardised mean difference (95% CI): −1.86 (–2.54 to –1.19)). Whereas neuromuscular/motor control exercises elicited the largest reduction in disability levels according to the Oswestry disability index (SUCRA = 80%, pooled standardised mean difference (95% CI): −1.13 (–1.53 to –0.74)), resistance and aerobic exercise interventions proved best for managing the psychological impact of LBP (SUCRA) = 100%, pooled standardised mean difference (95% CI): −1.14 (–1.71 to –0.56)) (Owen et al., 2020). The authors commented that it is unlikely that there is one single best exercise type for the management of LBP and that instead, exercises which actively encourage and guide an individual to move through a progressive physical activity approach are the most effective. Whilst exercise interventions have been researched extensively for LBP participants (Buchbinder et al., 2020, Gladwell et al., 2006, Gordan and Bloxham., 2016, Hayden et al., 2005, Maher et al., 2017, and van Middlekoop et al., 2010), little research has quantified the potential impact of morphological changes to the thoracolumbar fascia and whether this could be responsible for reductions in pain intensity and recurrence.

The structure and organisation of connective tissue, and importantly fascia, have been shown to adapt in chronic pain conditions such as LBP (Bishop et al., 2016, Langevin et al., 2011.). In a healthy body, collagen fibrils (a component of connective tissue) have been shown to replace 50% of their total number every 6-months demonstrating the capability of collagenous tissue remodelling (Neuberger et al., 1953). This remodelling process is thought to occur to maintain the elasticity of fascia and act as an injury prevention mechanism (Kjaer et al., 2009). Research in animal models has shown that immobilisation of tendons leads to a deterioration in biomechanical function of both skeletal muscle and connective tissue (Jarvinen et al., 2002). As we age, structural changes to connective tissue have been shown to result in the decline of both the strength and elasticity and this process is accelerated by physical inactivity (Reeves et al., 2006). Importantly, one short study found that exercise loading has been shown to reverse connective tissue decline by inducing an increase in the undulations of collagen fibres and significantly increasing elastic storage availability. A 14-week resistance training programme comparing 18 older adults (Training group, n=9 aged 74.3 ±3.5 years, Control group n=9 aged 67.1 ± 2 years). Over the 14 weeks, the training group completed a programme of leg extension and leg press exercises working at 80% of their 5- rep max at a dosage of 3 x week. An 11% increase in tensile fascial force and fascial length of the perimysium in the vastus lateralis was found in the training group. (Reeves et al., 2004). Whilst the study was supported by randomised grouping and an even mix of male and female participants, overall participant numbers remain low with just n=9 in each group. Moreover, participants in this study were all recreationally active and free of LBP, it is unknown whether chronic pain and/or sedentary behaviour would impact the ability of exercise loading to revise connective tissue decline. Pilates, developed from Joseph Pilates' principles and teachings, a form of exercise originally developed as a rehabilitation tool for dancers based (Pilates & Willer., 1945 and Schleip and Wilke., 2021). Pilates includes whole body movements focused on: breathing, centering, concentration, control, flowing movement, and precision with each aimed at reducing pain and aiding rehabilitation of injury (Kamioka et al., 2016). This form of exercise has found to be a valid treatment for the management of chronic non-specific LBP in all age groups (Miyamoto et al., 2013, Donzelli et al., 2006, and Wajswelner et al., 2012). Despite this evidence, exactly how changes in fascia morphology are part of a pain reduction mechanism remains poorly understood. Pilates is thought to stimulate large areas of the fascial network due to the whole-body approach and the multi-directional flowing movement (Schleip et al., 2012, and Kordosi et al., 2022). One hypothesis is that multi-directional dynamic movements such as Pilates contribute to fascia remodelling, aided by fibroblasts, healthy undulations of the collagen fibres and their elastic storage capacity are thought to increase in response to exercise (Jarniven et al., 2002, and Kjaer et al., 2009). Schleip and Muller (2013) published a book on the training principles for fascia, investigating the impact of different exercise and movement modalities on connective tissue. One movement type recommended by the authors is dynamic stretching and recoil-based movements, specifically stretching including alternative limbs. These dynamic stretching movements are also commonly used in Pilates, for example: alternative arm and leg raise and/or dead bug. The authors hypothesise that incorporating opposing limb movements, engages the movement-specific fascial layer, challenging the shear strain capabilities of fascia (Schleip & Muller., 2013). To support this hypothesis, further research is needed to quantify the impact on shear strain during dynamic, opposing limb movement compared to other dynamic movements and stretches. Research investigating the shear strain capabilities of fascia in those with LBP have found that this ability can be impaired by up to 25% (Langevin et al., 2011). Importantly, static stretching and pausing at end of range movements has been shown to have an anti-inflammatory and analgesic effect in connective tissue inflammatory conditions in rats (Corey et al.,2012), although these effects remain to be seen in humans.

Low habitual physical activity levels (such as activities of daily living) and sedentary behaviour have been shown to increase both the likelihood and severity of LBP in both men and women (Chen et al., 2009). However, a key limitation on measuring physical activity in clinical population is the self-reporting of physical activity levels. Self-reporting has been shown to be unreliable, with research showing that over-reporting is common due to the difficulty in recalling activity habits and unconscious bias from social desirability concerns (Sallis & Saelens, 2015). As such, the use of physical activity monitoring equipment and apps are recommended to increase reliability. One way to measure activity levels are to measure daily sitting time is using a Fibion activity tracker which records data that distinguishes between sitting, standing, and walking as well as the difference between moderate and vigorous intensity exercise. Previous studies have investigated the validity and accuracy of the Fibion tracker have found that the device is able to reliably track sitting time, standing time, different physical activity types and energy expenditure with an ICC rating between 0.69-0.81 (Yang et al., 2018).

Research evidence supporting the use of exercise for LBP are varied and lack consensus, as such there is no agreed single exercise or group of movements that is most effective at treating LBP. However, most exercise and movement has been shown to be beneficial in reducing pain symptoms and increasing quality of life. Whilst many LBP and group exercise studies have focused on aerobic exercise (Sculco et al., 2001), strength & resistance training (Cortell-Tormo et al., 2018 and Jackson et al., 2011) or flexibility-based training (such as yoga (Wieland et al.,

2013) and Pilates (Gladwell et al., 2006), there has been little research comparing the impact of group exercise and an increase in movement on the thoracolumbar fascia. This study sought to investigate the impact of a 6-month group exercise and movement interventions on the thoracolumbar fascia in those with LBP. The study aims to understand whether exercise can alter thickness and increase the echogenicity of the thoracolumbar fascia and whether this is related to a reduction in LBP. As there were no significant observational differences seen between those with and without LBP in chapter 6, it is of interest to researchers whether changes in the morphological make-up of the thoracolumbar fascia can be impacted by a 6-month intervention.

7.2 Methodology.

7.2.1 Participants.

The study was approved by the University of Kent's School of Sport and Exercise Sciences Research Ethics Advisory Group (Ref. 13_20_21). Participants were recruited through the University of Kent's Graduate and Researcher College email, personal social media channels and via opportunistic sampling. Participation was voluntary with no financial or other reimbursement given. Participants were asked to partake in a 6-month intervention with the full duration of the study lasting a maximum of 8 months to include pre-and post- testing. Before taking part in the study, all participants were required to complete a participant readiness health questionnaire alongside questions about their LBP and physical activity levels. Inclusion criteria for all participants included being aged between 19-70, being classified as sedentary and physically inactive and with a history of self-disclosed chronic or recurrent LBP for a minimum of 6 months (Dionne et al., 2008). Chronic LBP was classified by pain present for at least 3-months during a 12-month period, whilst recurrent LBP was defined by multiple pain episodes over a 12-month period. Sedentary behaviour was defined as physical activity levels below the WHO recommended guidelines of 150 minutes of moderate intensity aerobic exercise or 75 minutes of vigorous intensity aerobic exercise per week (UK Chief Medical Officers' Physical Activity Guidelines., 2019). Exclusion criteria consisted of previous back, hip, or knee surgery, displaced, or injured vertebral discs and vertebrae (e.g., spondylolisthesis), previous corticosteroid injections near the spine. In addition, current smokers and participants who could be pregnant were also excluded. In the event any structural abnormalities included in the exclusion protocol were found during the screening process, the participants would be excluded from the study and instead informed and asked to seek medical guidance. Please see figure 7.1 below which depicts the participant inclusion and exclusion criteria for this study. A total of 68 participants were recruited for the study, 20 participants were excluded as they did not meet the inclusion criteria. Participants were randomly allocated by an external researcher to one of three groups: Exercise Group who completed two weekly remote exercise classes, Movement Group who received daily prompts to increase their movement and reduce sedentary time or the Control Group who were given no specific intervention. As both sedentary behaviour and physical inactivity have been classified as risk factors for the development of LBP (Mahdavi et al., 2021), this study included two intervention groups: Exercise and Movement. Two intervention groups were included to ascertain whether increased general ambulation and a reduction in sedentary time could be as effective in reducing LBP and targeting thoracolumbar fascia morphology compared to an exercise intervention. Three participants withdrew from the study prior to the commencement of the interventions (2 from the exercise group and 1 from the control group), these participants failed to attend the mid-point scanning appointment and did not respond to reminders.

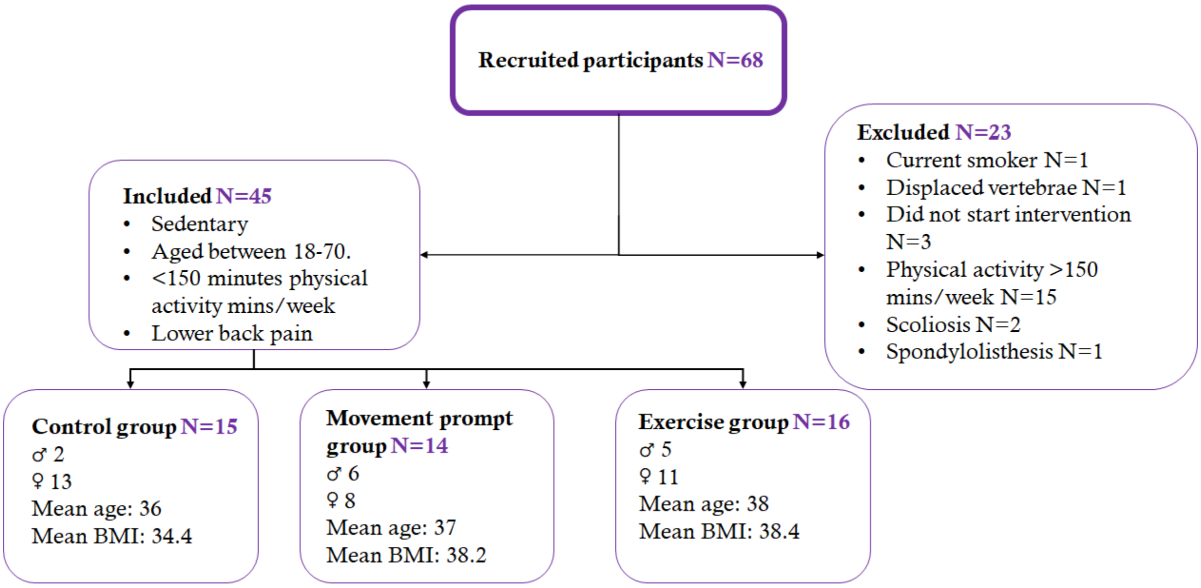


Figure 7.1. Participant inclusion and exclusion criteria and grouping flow chart.

Participants were asked to complete series of customised follow-up online questionnaires at the four data collection points throughout the 6-month intervention to monitor the qualitative aspects of LBP. Questionnaires included in this study were: The Dionne modified lower back pain questionnaire (Dionne et al., 2008), the Euroqol quality of life test (TEQ group., 1990), the patient specific functional scale (Horn et al., 2012), and the Roland-Morris disability questionnaire (Roland and Fairbank., 2000). The Euroquol Quality of Life Test (EQ-5D-5L) consists of 5 distinct categories, question 1 focuses on mobility, question 2 on self-care, question 3 on usual activities, question 4 on pain and discomfort and question 5 on anxiety and depression. Statistical analysis was completed separately on each question to look for any trends. The questionnaires were presented in an MS Forms document and emailed to the participant for completion.

Participant demographics are reported in table 7.1. Six participants had missing data for Fibion data collection due to a malfunction of the Fibion trackers. As such these participants were excluded from the sitting time analysis.

Table 7.1 Participant demographics for exercise, movement, and control groups.

	Exercise group n=14	Movement group n=16	Control group n=15
Gender (%) Male/Female	6 (42.9%)/ 8 (57.1%)	5 (31.3%) / 11 (68.7%)	2 (13.3%) / 13 (86.7%)
Age (Years)	37.71 ± 10.90	38.75 ± 12.46	36.6 ± 9.80
Height (cm)	170.42 ± 8.54	169.95 ± 8.47	168.2 ± 8.95
Weight (kg)	89.01 ± 17.60	79.20 ± 13.49	75.41 ± 12.73
BMI	38.43 ± 10.92	38.19 ±,12.26	34.4 ± 10.93
Sitting time (hours)*	8.82 ± 2.78	7.18 ± 1.59	7.83 ± 1.40

Values represent mean ± standard deviation unless otherwise indicated. *Sitting time measured via Fibion activity tracker over 2-consequtive days.

All participants (n=45) self-reported with LBP prior to taking part in the research study. LBP level was corroborated with a modified Dionne questionnaire (see Appendix 1.2). LBP levels are reported below in table 7.2.

Table 7.2 Participant Lower back pain levels.

	Exercise group (n=14)	Movement (n=15)	Control (n=16)
Lower back pain (%)	14 (100%)	15 (100%)	16 (100%)
A little pain (%)	21.4% n=3	18.8% n=3	40% n=6
Some pain (%)	64.3% n=9	50% n=8	33.3% n-=5
A lot of pain (%)	14.3% n=2	25% n=4	20% n=3
Worst pain (%)	0% n=0	6.2% n=1	6.7% n=1

LBP determined by results from Dionne questionnaire. Values represent mean unless otherwise indicated.

7.2.2 Study design.

A total of 45 participants passed the inclusion criteria search and were randomly allocated by an external researcher to one of three groups: Exercise Group (n=14), Movement Group (n=16) or Control Group (n=15). The Exercise Group consisted of two weekly remote online exercise classes lasting 55-minutes over the course of 6-months. Two-weekly sessions were prescribed to allow for an increase in physical activity towards the WHO guidelines but to allow for a progressive, approach due to the sedentary behavioural patterns of this population. The classes used a multi-modal exercise programme which included a mix of aerobic exercise, core strengthening exercises and Pilates style exercises. Each exercise class lasted 55-minutes and included a range of movements which were updated every 4-weeks. The Exercise group were split into two groups of 8 to take part in the Exercise classes to allow for the instructor to safely engage and monitor all participants. At the beginning of the class the instructor highlighted their own screen so that all participants would see a large video of just the instructor. Throughout each exercise class the participants were advised to keep their microphones on so that they would engage with the instructor and fellow participants. At the end of the class, 5-minutes were spent discussing how the group felt about the session and to allow for a social element to the group to add a sense of community to mimic a face-to-face exercise class and to aid retention. The Movement Group continued their usual daily activities whilst following prompts on their mobile phone to encourage movement to break up sitting time over the 6-month intervention, whilst the Control Group continued with their usual activities without any intervention. The timeline for the data collection stages of this study can be seen below in Figure 7.2.

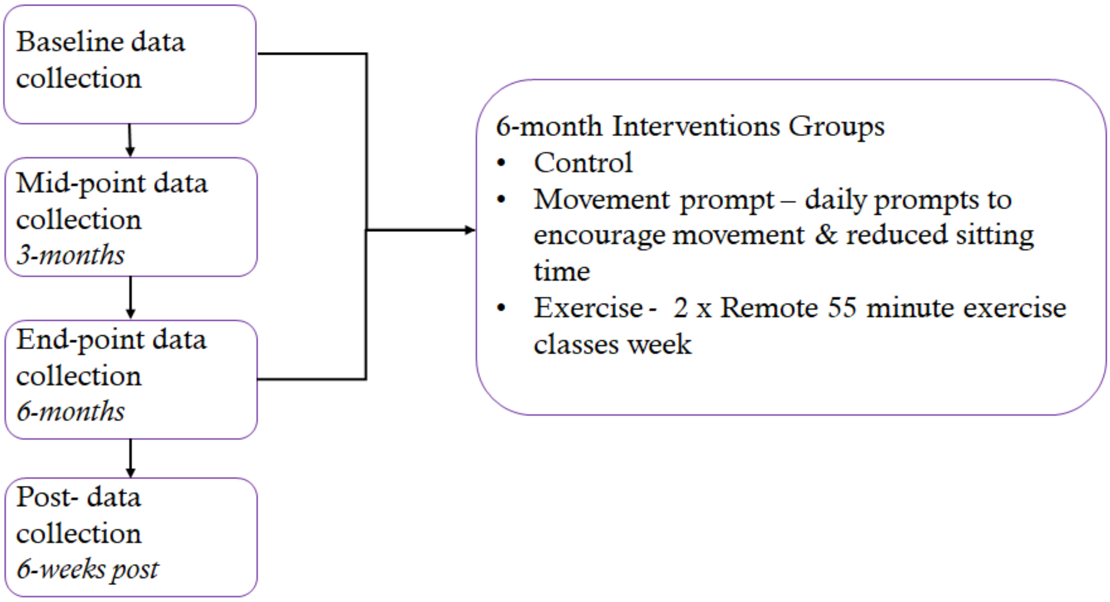


Figure 7.2. Data collection timeline for each of intervention groups.

7.2.3 Data collection protocol.

To assess the impact of the intervention, participants visited the laboratory at the University of Kent at four time points throughout the study, Pre (at sign up), Mid (3-months), End (6-months), and Post (6-weeks post cessation of the interventions). At each time point, ultrasound imaging was collected on site, questionnaires were sent electronically to be completed within the next 3-days, and each participant was given a Fibion activity tracker to wear for 2-consecutive days. The data acquisition and image analysis procedure for the ultrasound methodology are described in chapter 3.

7.2.4 Fibion activity tracker protocol.

Sedentary behaviour patterns for this study were reported using an accelerometer-based wearable called the Fibion (Fibion Inc, Jyväskylä, Finland). Fibion activity trackers use a three-axial accelerometer-based device to track orientation and movement of the thigh in relation to the body. Participants were asked to wear the Fibion tracker on their left thigh for two consecutive days, taken off only to shower or bathe and when sleeping. Tracking was recorded at the four data collection stages of the study to monitor any changes in sedentary behavioural patterns. Moreover, participants from all three groups were asked to track their daily step count using the Pacer pedometer and step tracker app (Pacer Health inc, California) on their mobile phone and catalogue the results in a personal MS office Excel sheet shared with the researcher so that physical activity levels could be monitored. The Fibion activity tracker data for sitting time, standing time, and physical activity times were anonymised and uploaded to Fibion for analysis on sedentary behaviour patterns before being extrapolated to an excel document ready for statistical analysis. After wearing the device for a minimum of 8-hours the report can be exported onto a PC and sent to Fibion remotely for a day-by-day breakdown of the activity levels, separated by duration (minutes) and prolonged periods (a numerical value for prolonged sitting/standing of 30-minutes or more).

7.2.5 Exercise group protocol.

Participants in the multi-modal Exercise Group were divided into two groups of 8 participants and were asked to partake in twice-weekly remote online group exercise classes for each week of the 6-month intervention. A 2-week break occurred over the Christmas period to account for recreational time and unavailability. Class plans were written by the lead researcher and approved by two external fitness professionals, a Level 4 Lower Back Pain & Exercise Referral Group Exercise instructor and a Musculoskeletal (MSK) physiotherapist. The class layouts followed a similar plan to that used by Mannion and colleagues (2001) and were broken down as follows. 20 minutes: Low impact aerobics warm-up and whole-body dynamic stretching. 20 minutes: Low impact core and muscular strength exercises. 15 minutes: Low impact cooldown, static stretching, and relaxation exercises. 5 minutes: Social discussion of the class including scoring of intensity levels, likes and dislikes and free, open discussion with peers. The exercise classes were delivered over MicroSoft (MS) Teams on Tuesday and Thursday evenings by the lead researcher (a qualified Level 4 Lower Back Pain & Exercise Referral Group Exercise instructor) and a second instructor with equivalent qualifications. Participants were asked to leave their cameras on throughout the exercise classes. At the beginning of the class the instructor muted all participants and highlighted their own screen so that each participant would see only the instructor. Participants were advised that should they need to gain the instructor's attention they were welcome to unmute their microphones at any time. Prior to the beginning of each class the instructor joined the MS Teams meeting 5-minutes early so that participants would have the opportunity to discuss any concerns with the intensity of their LBP on the day or anything else. Classes always began with verbal instruction from the instructor that all participants could choose lower intensity adaptations and take breaks whenever they see fit. The class structure remained constant throughout the 6-month duration, a maximum of 60-minutes was allocated to each class with an equal split of aerobic based movement, stabilisation, Pilates style core strengthening and whole-body muscular strength exercises and endurance movements. Table 7.3 below describes some of the exercises used in the classes. Full session plans can be found in appendix 1.5.

Table 7.3: Sample exercises.

Section	Sample Exercise	Adaptations and progressions
Aerobic warm up	Side-step	1) On the spot 2) On the with low arm swing 2) 2-steps right, 2 steps left 3) 2-steps with low arm swing 4) 2-steps with overhead arm raise
Aerobic warm up	Knee raise	1) On the spot, low raise 2) On the spot, high raise (to hips) 3) Moving forward and back
Core and Strength	Tabletop – Arm + Leg raise	1) Raise one arm at a time 2) Raise one leg at a time, tap down 3) Raise one leg at a time 4) Raise alternate arm and leg, tap down 5) Raise alternate arm and leg
Core and Strength	Side lying - Clams	1) Supporting arm down, half range 2) Supporting arm down, full range 3) Arm lifted, half range 4) Arm listed, full range
Stretch and Flexibility	Cat-Cow stretch	1) Breaks after each full cycle, half range on cat stretch 3) No breaks, half range 4) Breaks and full range 4) No breaks, full range
Stretch and Flexibility	Roll downs	1) Partial range, to thigh 2) Half range, to knees 3) Full range

Regular breaks, adaptations and alternative movements were given throughout each session to provide all participants with a variety of intensity options, with the intention of minimising pain and discomfort during the class. As the classes progressed, all participants were offered the option to increase the difficulty of the aerobic section of the class. This was managed by incorporating an increase in speed and range of motion. At the end of the exercise class, during the 5-minute social break, participants were asked to rate the intensity of the class with a score of 1-10, according to the rating of perceived exertion (RPE) scale (Foster et al., 2001). The instructor recorded these scores and if a participant's weekly score averaged 7 or above the intensity of the subsequent exercises and class would be reduced to standardise and monitor participant safety (Rowley et al., 2021). The exercises for the aerobic section of the classes remained constant throughout the 6-month duration of the class, with intensity gradually increased by the adaption of range of motion and tempo. The second half of the class was adapted monthly to incorporate new movements. Each month the class was recorded and added onto a private YouTube channel so that participants were able to take part in the class asynchronously should they need to miss the live session. A sample full session plan can be found in Appendix 1.5. At the end of the study the YouTube classes were made public and shared with all participants of the study for use as they wish.

7.2.6 Movement prompts protocol.

The Movement Group were asked to follow hourly movement prompts during their normal working hours to break up prolonged sitting time and increase daily movement. The movement prompts were delivered via either the participant's desktop computer or laptop, or their mobile phone. According to the participants preference one of the following apps was used. PC/Mac prompts were obtained using the "Awareness" app (Discover Yourself Inc, v.1.6.5, 2021, USA), IOS users were requested to use the "Move" app (Apple, v.3.3.1, 2021, USA) and Android users to use the "Randomly remindMe" app (James Morris Studios, v. 2.1.00, 2021, USA) to receive hourly prompts to increase their general movements and encourage a break from sitting time. Participants were prompted to stand and move around for a total of 4 hours over their usual 8-hour working day, aiming to avoid sedentary behaviour (Chastin and Granat., 2010). To monitor adherence to the movement prompts, participants were required to self-report how closely they followed the prompts on a Likert scale of 1-5 on a Microsoft Office Excel sheet. 1-not at all, 2- somewhat, 3-half the time, 4-most of the time, 5-all the time. Throughout the study, participants were also asked to track their steps using the Pacer pedometer app (free version). At the end of each day, participants were asked to input their total steps into the same document.

7.2.7 Control group protocol.

The Control Group were asked to continue with their usual physical activity and sitting time patterns without change. As the study spanned over a total of 6-months, the control group participants were asked to record any changes to their usual physical activity and movement habits. To confirm this, physical activity levels were self-reported at baseline and at 6-weeks post intervention, with responses verified verbally at the pre- and post- ultrasound scan appointments. Throughout the study participants were asked to record their daily step count using the Pacer pedometer app on their mobile phone and catalogue the results in a personal MS office Excel sheet shared with the researcher so that physical activity levels could be monitored.

7.3 Statistical analysis.

All data analysis was completed using IBM SPSS statistics 27 (IBM SPSS Statistics v.5, SPSS Inc., Chicago:IL) using a 3 x 4-way ANOVA.

Prior assumptions testing for 3x4 way ANOVA analysis of thickness measurements confirmed that homogeneity of covariance was found, as assessed by Levene's Test for Equality of Variances (combined thickness p=0.63; subcutaneous thickness p=0.11; perimuscular thickness p=0.88). There was homogeneity of regression slopes, as assessed by Levene's test of homogeneity, as the interaction term was not statistically significant.

Skewness of all variables was assessed by inspection of histograms and calculation of

z-score. Variables for all thickness measurements were found to be skewed, these were then log10 transformed prior to analysis, which resulted in a normal or near-normal distribution. Normal distribution was assessed by examination of Normal Q-Q Plots and found to be normal or near-normally distributed. All data points were assessed for outliers, by examination of studentised residuals for values greater than ±15.00mm. One outlier was found for subcutaneous thickness, with a studentised residual value of 16.76mm. This was not deemed to be the result of data entry error or measurement error. This value was removed from the analysis.

Prior assumptions testing for ANOVA analysis of normalised echogenicity measurements confirmed that homogeneity of covariance was found, as assessed by Levene's Test for Equality of Variances (combined thickness p=0.19; subcutaneous thickness p=0.87; perimuscular thickness p=0.66. There was homogeneity of regression slopes, as assessed by Levene's test of homogeneity, as the interaction term was not statistically significant.

Prior assumptions testing for the sitting time ANOVA were assessed by a positive homogeneity of covariance, and by Levene's Test for Equality of Variances (Pre p=0.45. Mid p=0.45, End p=0.47). There was homogeneity of regression slopes, as assessed by Levene's test of homogeneity, as the interaction term was not statistically significant.

Prior assumptions testing for a 3x4 way ANOVA analysis of the questionnaire measurements confirmed that homogeneity of covariance was found, as assessed by Levene's Test for Equality of Variances (Dionne LBP severity questionnaire p= 0.20, Euroqol p=0.97, Patient Specific Functional scale p=0.72, Roland Morris p=0.44). There was homogeneity of regression slopes, as assessed by Levene's test of homogeneity, as the interaction term was not statistically significant.

Results from each of the questionnaires were recorded and documented for comparisons for inter-person and within and against each group at each level of testing using IBM SPSS Statistics v27 (SPSS Inc., Chicago: IL).

7.4 Results.

7.4.1 Thickness measurements.

No significant differences were found between left and right scans, so side-average measurements were used in all statistical analyses. Mean and standard deviations of all thickness measurements are reported in Table 7.4.

Table 7.4 Mean and standard deviation thoracolumbar fascia thickness measurements.

	Pre- thickness	Mid-point thickness	End-point thickness	Post- thickness
Combined layer *				
Control	7.50 ± 4.68	7.28 ± 3.45	7.81 ± 4.28	7.59 ± 3.55
Movement	7.92 ± 2.95	8.28 ± 3.26	9.49 ± 4.84	8.71 ± 3.48
Exercise	9.61 ± 4.64	6.18 ± 1.93	6.75 ± 2.86	6.68 ± 2.53
Subcutaneous layer *				
Control	4.89 ± 4.22	3.94 ± 2.33	4.90 ± 3.61	5.22 ± 3.25
Movement	4.98 ± 2.58	5.42 ± 2.63	6.57 ± 4.20	6.24 ± 2.69
Exercise	6.44 ± 3.92	3.66 ± 1.69	4.02 ± 1.82	4.05 ± 1.92
Perimuscular layer				
Control	2.61 ± 0.80	3.34 ± 1.63	2.91 ± 1.09	2.37 ± 0.69
Movement	2.94 ± 1.06	2.86 ± 1.00	2.91 ± 1.44	2.47 ± 0.95
Exercise	3.16 ± 1.19	2.53 ± 0.59	2.74 ± 1.39	2.63 ± 0.85

Values represent mean ± standard deviation unless otherwise indicated. Thickness measured in millimetres. The * represents significant values at or below p=<0.05.

7.4.2 Combined thickness layer.

For the combined thoracolumbar fascia thickness layers there was a significant main effect of condition F=5.48, df=1, p=0.024, ETA^2 = 0.120. A paired sample T-test was completed which revealed the significance occurred between pre-mid (p= 0.002), mid- and end- (p=0.027) and mid- and post- (p=0.000) time points. There were no significant differences found for the main effect of time F=1.44, df=1, p=0.237, ETA^2 = 0.035. Nor the Interaction effect F=1.15, df=2, p=0.326, ETA^2 =

0.055. Changes over time for thoracolumbar fascia thickness at the combined layer between each group shown below in figure 7.3.

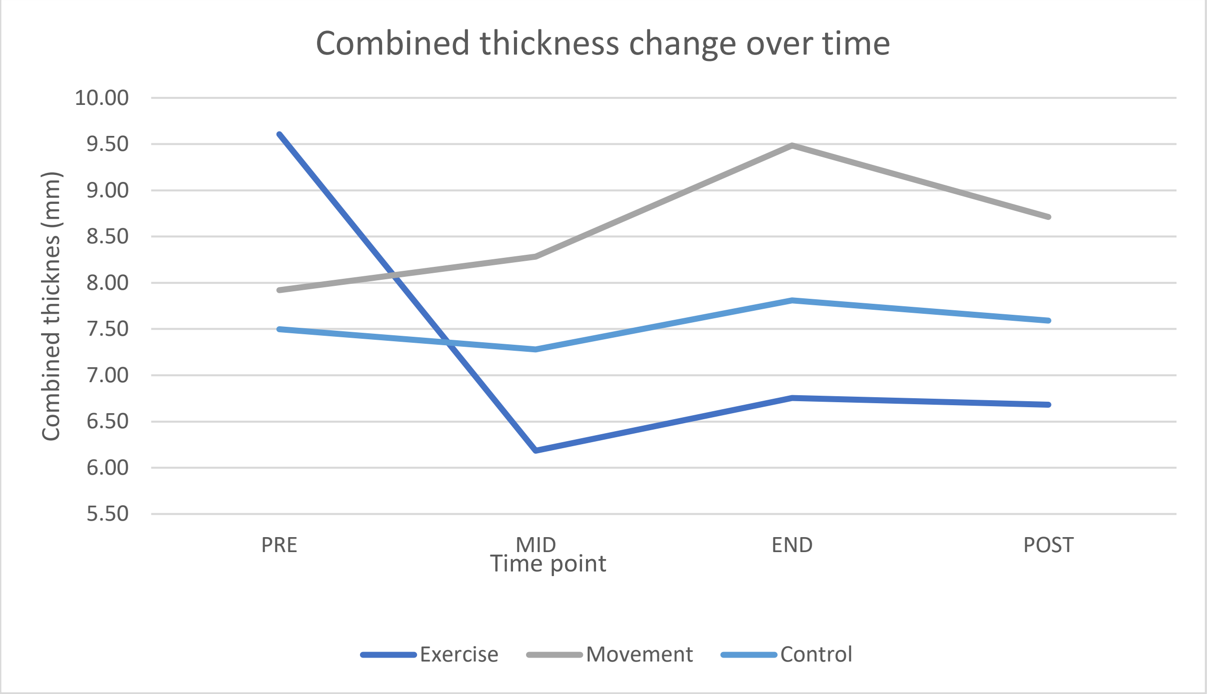


Figure 7.3 Combined thickness change over time in each intervention group.

7.4.3 Subcutaneous thickness layer.

For the subcutaneous thoracolumbar fascia thickness layers there was a significant main effect of condition F=7.77, df=1, p=0.08, ETA^2 = 0.163. A paired sample T-test was completed which revealed the significance occurred between pre-mid (p=0.002), mid- and end- (p=0.034) and mid- and post- (p=0.021) time points. There were no significant differences found for the main effect of time F=1.48, df=1, p=0.231, ETA^2 = 0.036. Nor Interaction effect F=0.531, df=2 , p=0.592, ETA^2 =

0.026. Changes over time for thoracolumbar fascia thickness at the subcutaneous layer between each group shown below in figure 7.4.

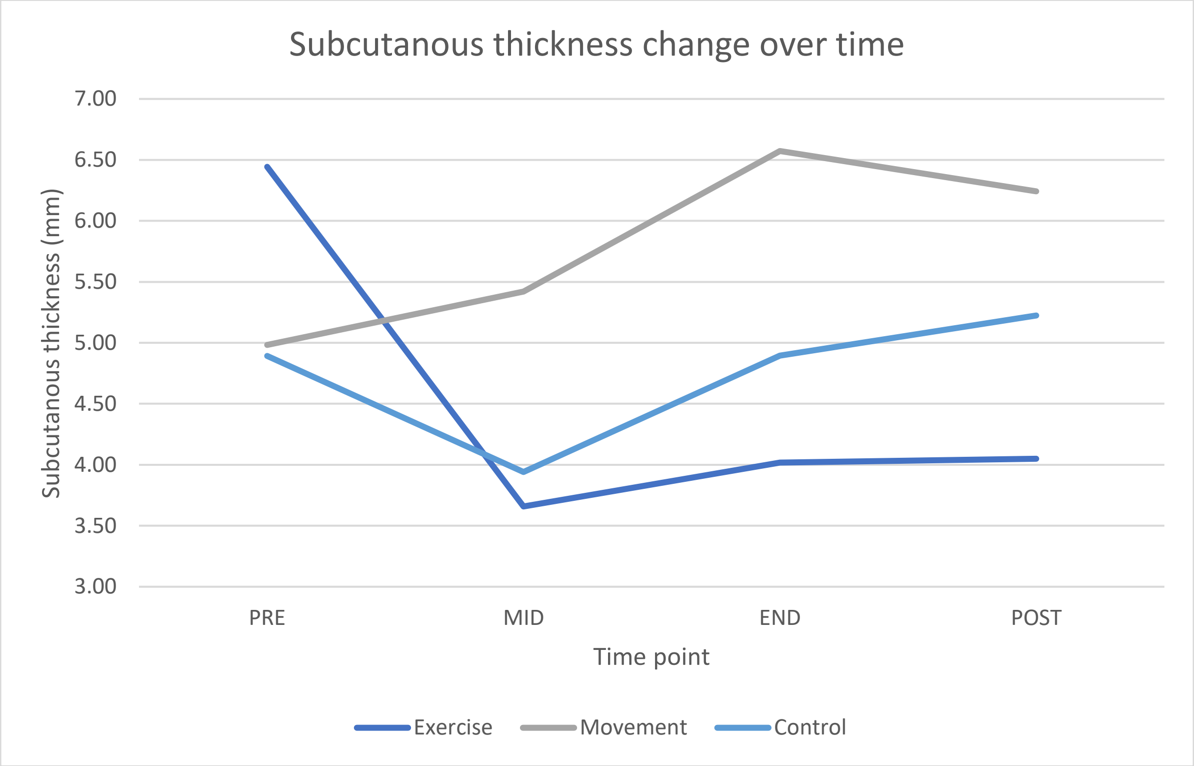


Figure 7.4 Subcutaneous thickness change over time in each intervention group.

7.4.4 Perimuscular thickness layer.

For the perimuscular thoracolumbar fascia thickness layers there were no significant main effect of condition F=1.165, df=1, p=0.287, ETA^2 = 0.0.28. No significant differences found for the main effect of time F=0.694, df=1, p=0.410, ETA^2 = 0.017. Interaction effect F=0.201, df=2, p=0.819, ETA^2 = 0.010. Changes over time for thoracolumbar fascia thickness at the perimuscular layer between each group shown below in figure 7.5.

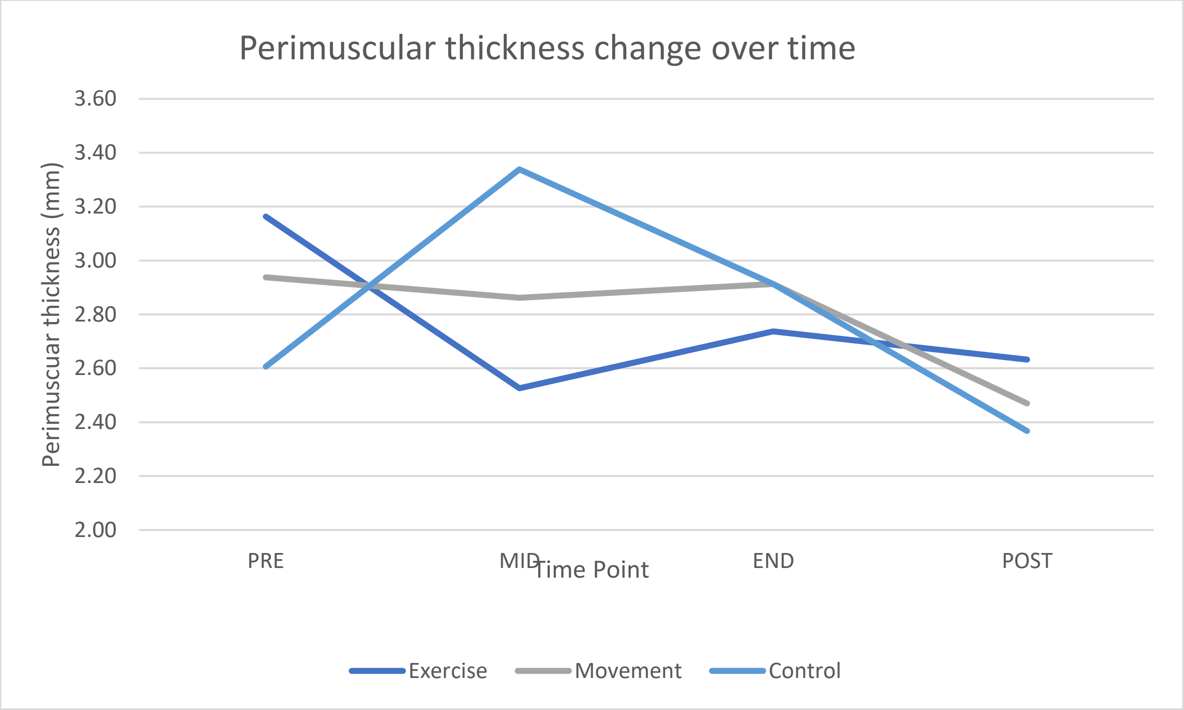


Figure 7.5 Perimuscular thickness change over time in each intervention group.

7.4.5 Normalised echogenicity measurements.

Mean and standard deviations of all normalised echogenicity measurements are reported in Table 7.4.

Table 7.4 Mean and standard deviation normalised echogenicity measurements.

	Baseline echogenicity	Mid Echogenicity	End Echogenicity	Post Echogenicity
Combined layer				
Control	0.53 ± 0.13	0.49 ± 0.12	0.53 ± 0.11	0.56 ± 0.09
Movement	0.04 ± 0.02	0.04 ± 0.03	0.04 ± 0.02	0.04 ± 0.01
Exercise	0.21 ± 0.69	0.20 ± 0.08	0.19 ± 0.08	0.18 ± 0.05
Subcutaneous layer				
Control	0.51 ± 0.11	0.54 ± 0.10	0.55 ± 0.08	0.59 ± 0.09
Movement	0.03 ± 0.02	0.05 ± 0.03	0.05 ± 0.02	0.05 ± 0.03
Exercise	0.20 ± 0.09	0.26 ± 0.09	0.26 ± 0.08	0.27 ± 0.08
Perimuscular layer				
Control	0.51 ± 0.11	0.48 ± 0.17	0.51 ± 0.10	0.56 ± 0.09
Movement	0.05 ± 0.03	0.05 ± 0.03	0.06 ± 0.05	0.06 ± 0.03
Exercise	0.23 ± 0.10	0.25 ± 0.10	0.24 ± 0.10	0.23 ± 0.09

Values represent mean +- standard deviation unless otherwise indicated. Normalised echogenicity measured as a greyscale value from 0-1.

7.4.6 Normalised combined echogenicity.

For the normalised echogenicity of the thoracolumbar fascia combined layers there were no significant main effect of condition F=2.08, df=1, p=0.157, ETA^2 = 0.051. No significant differences found for the main effect of time F=2.51, df=1, p=0.121, ETA^2 = 0.061. Nor the Interaction effect F=0.098, df=2, p=0.907, ETA^2 = 0.005. Changes over time of thoracolumbar fascia echogenicity at the combined layer between each group shown below in figure 7.6.

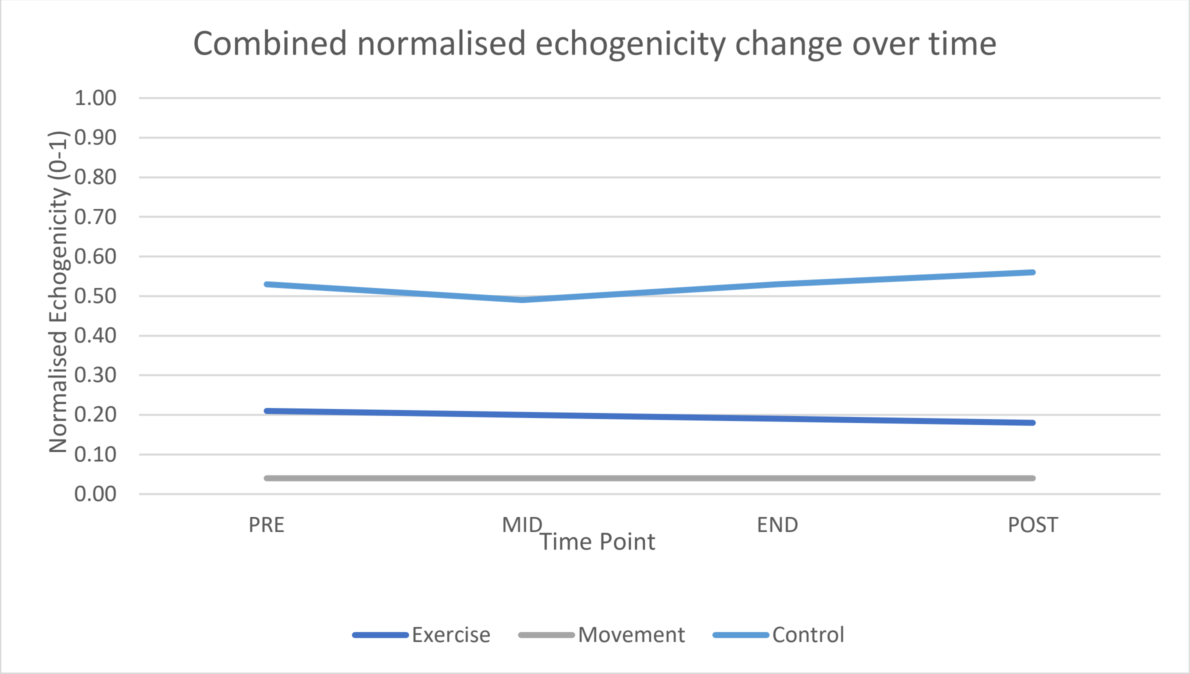


Figure 7.6 Combined Normalised Echogenicity change over time.

7.4.7 Normalised subcutaneous echogenicity.

For the normalised echogenicity of the thoracolumbar fascia subcutaneous layers there were no significant main effect of condition F=3.41, df=1, p=0.072, ETA^2 = 0.080. No significant differences found for the main effect of time F=2.93, df=1, p=0.095, ETA^2 = 0.070. Nor the Interaction effect F=0.088, df=2, p=0.916, ETA^2 = 0.004. Changes over time for thoracolumbar fascia echogenicity at the subcutaneous layer between each group shown below in figure 7.7.

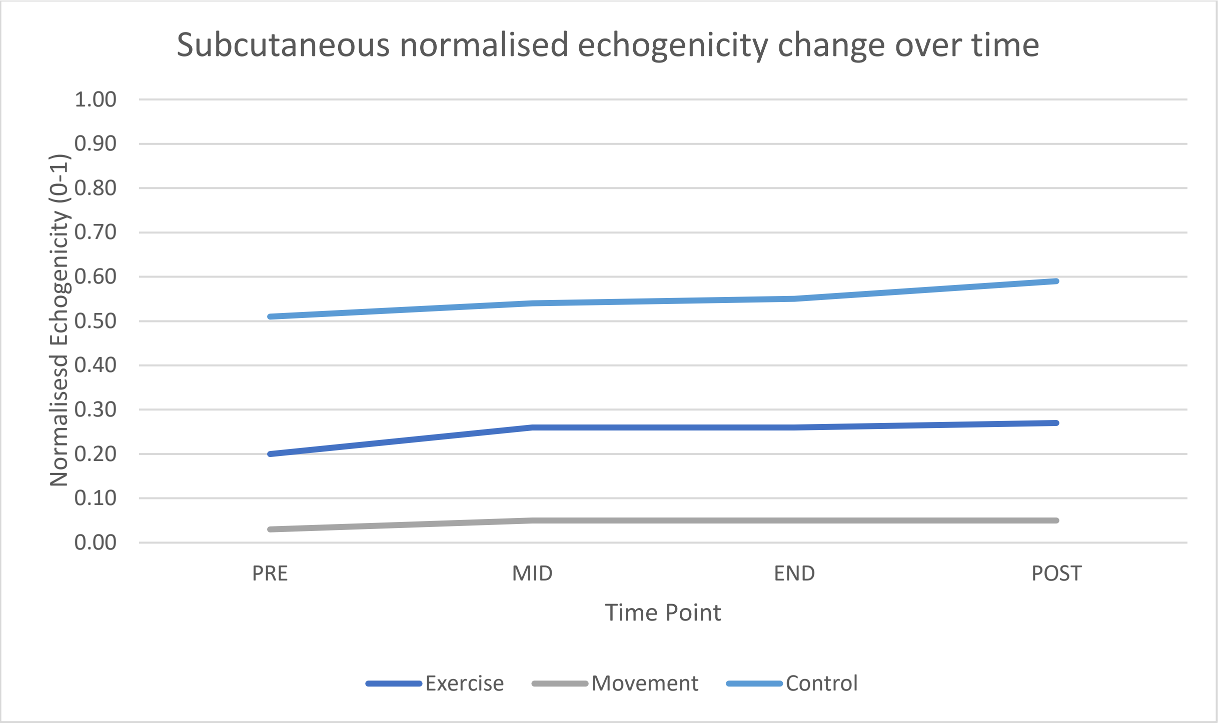


Figure 7.7 Subcutaneous Normalised Echogenicity change over time.

7.4.8 Normalised perimuscular echogenicity.

For the normalised echogenicity of the thoracolumbar fascia perimuscular layers there were no significant main effect of condition F=2.985, df=1, p=0.092, ETA^2 = 0.071. No significant differences found for the main effect of time F=3.855, df=1, p=0.057, ETA^2 = 0.090. Nor the Interaction effect F=0.524, df=2, p=0.597, ETA^2 = 0.026. Changes over time for thoracolumbar fascia echogenicity at the perimuscular layer between each group shown below in figure 7.8.

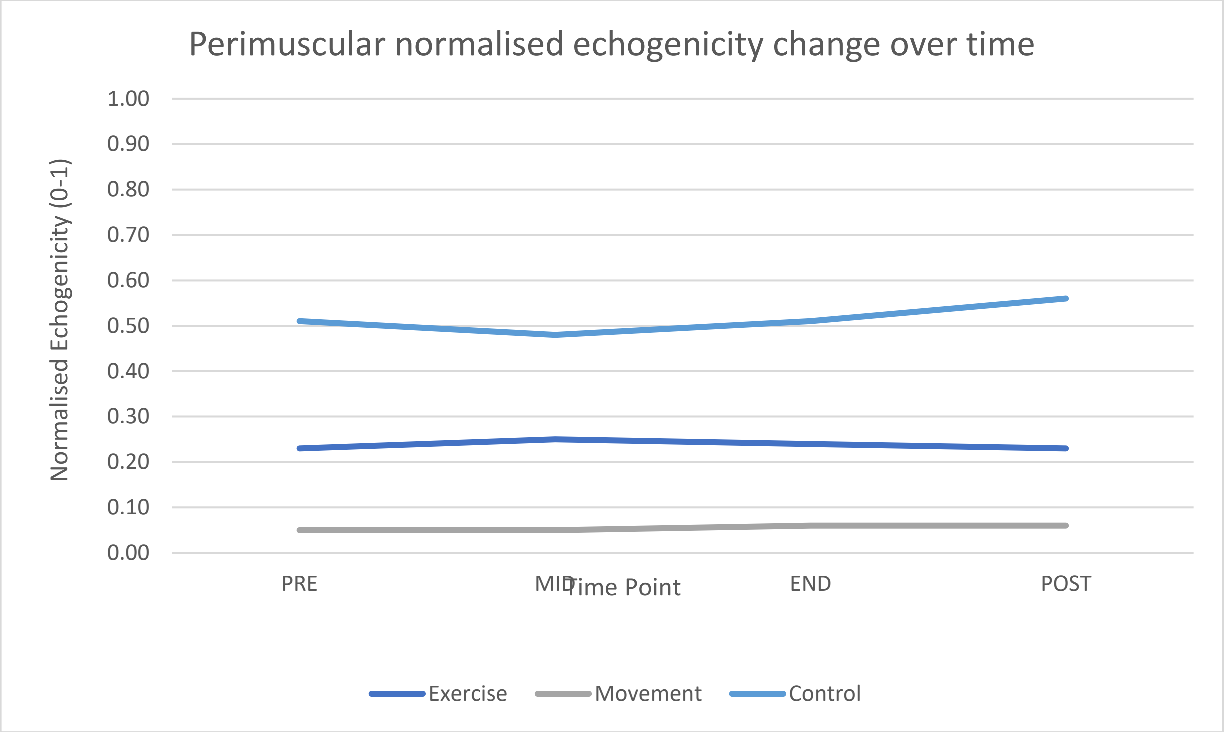


Figure 7.8 Perimuscular Normalised Echogenicity change over time.

7.4.9 Questionnaire measurements.

Mean and standard deviations of all pain and disability questionnaire scores are reported in Table 7.5 and Quality of life questionnaire scores are displayed in table 7.6.

Table 7.5 Mean and standard deviation for Pain and Disability questionnaire measurements.

	Baseline	Mid	End	Post
Dionne LBP questionnaire (0-4)*				
Control	1.73 ± 0.85	1.73 ± 0.68	2.07 ± 0.85	1.60 ± 0.88
Movement	2.19 ± 0.81	2.06 ± 0.75	1.63 ± 0.93	1.75 ± 0.90
Exercise	1.93 ± 0.59	1.79 ± 0.86	1.64 ± 1.11	1.36 ± 1.04
Patient Specific Functional Scale (1-20) △				
Control	8.04 ± 1.83	8.35 ± 1.63	8.25 ± 2.33	9.06 ± 1.21
Movement	8.04 ± 1.64	7.61 ± 2.05	8.13 ± 1.83	7.48 ± 2.22
Exercise	7.72 ± 2.18	7.94 ± 1.86	8.24 ± 1.84	8.08 ± 11.56
Control	3.33 ± 3.34	4.13 ± 4.81	3.87 ± 4.05	4.27 ± 5.58
Movement	3.50 ± 3.76	3.31 ± 4.55	2.94 ± 3.01	3.31 ± 4.22
Exercise	4.36 ± 4.57	2.93 ± 4.39	2.57 ± 3.28	2.71 ± 3.69
Roland Morris Disability Questionnaire (0-24) °				
Control	3.33 ± 3.34	4.13 ± 4.81	3.87 ± 4.05	4.27 ± 5.58
Movement	3.50 ± 3.76	3.31 ± 4.55	2.94 ± 3.01	3.31 ± 4.22
Exercise	4.36 ± 4.57	2.93 ± 4.39	2.57 ± 3.28	2.71 ± 3.69

Values represent mean +- standard deviation unless other indicated. *Dionne questionnaire measured from 0=no pain, 1= a little pain, 2= some pain, 3-a lot of pain, 4-worse pain. △Patient Specific Functional scale measured from 1-20, lowest number equated to worse functional ability. °Roland Morris Disability questionnaire measured from 0-24, highest number equated to worse disability.

Table 7.6 Mean and Standard deviation for Quality of Life questionnaire measurements.

	Baseline	Mid	End	Post
Control group				
Question 1	1.36 ± 0.72	1.43 ± 0.62	1.43 ± 0.73	1.50 ± 0.91
Question 2	1.29 ± 0.59	1.29 ± 0.59	1.43 ± 0.73	1.29 ± 0.70
Question 3	1.57 ± 1.05	1.50 ± 0.63	1.71 ± 0.70	1.43 ± 0.90
Question 4	2.00 ± 0.76	1.93 ± 0.46	1.93 ± 0.70	1.93 ± 0.80
Question 5	1.86 ± 1.06	1.86 ± 0.83	2.00 ± 1.07	1.57 ± 0.82
Movement				
Question 1	1.44 ± 0.70	1.56 ± 0.79	1.63 ± 1.11	1.63 ± 0.78
Question 2	1.25 ± 0.56	1.31 ± 0.58	1.56 ± 1.32	1.31 ± 0.58
Question 3	1.69 ± 0.98	1.75 ± 0.90	1.44 ± 0.61	1.50 ± 0.71
Question 4	2.25 ± 0.97	2.19 ± 1.01	1.81 ± 0.63	1.75 ± 0.75
Question 5	1.94 ± 0.75	2.06 ± 1.06	1.88 ± 0.86	1.75 ± 0.90
Exercise				
Question 1	1.40 ± 0.80	1.27 ± 0.44	1.27 ± 0.44	1.33 ± 0.60
Question 2	1.13 ± 0.50	1.07 ± 0.25	1.27 ± 0.47	1.27 ± 0.57
Question 3	1.60 ± 0.80	1.33 ± 0.47	1.33 ± 0.47	1.47 ± 0.62
Question 4	2.20 ± 0.83	2.00 ± 1.03	1.80 ± 0.40	1.93 ± 1.06
Question 5	1.80 ± 1.17	2.47 ± 1.45	2.00 ± 1.32	2.27 ± 1.29

Values represent mean +- standard deviation unless other indicated. Euroqol 5-point questionnaire rate from 0-5, highest number equated to lower quality of life. Questions depict selected areas of quality of life 1= mobility, 2= self-care, 3= usual activities, 4=pain or discomfort ,4 = anxiety or depression.

7.4.10 Dionne Lower back pain severity questionnaire.

There was no difference between the Dionne LBP severity questionnaire score, the movement group, exercise group and the control group and time, between pre-end intervention F=2.7, p=0.80. There was no difference between the groups, F=0.13, p=0.88.

7.4.11 Patient specific functional scale test.

There was no difference between the Patient specific functional scale test, the movement group, exercise group and the control group and time, between pre-end intervention F=0.88, p=0.92. There was no difference between the groups, F=0.47, p=0.95.

7.4.12 Euroqol quality of life test.

There was no difference between Euroqol quality of life test score for question 1, the movement group, exercise group and the control group and time, between pre-end intervention F=0.30, p=0.97. There was no difference between the groups, F=0.17, p=0.85.

There was no difference between Euroqol quality of life test score for question 2, the movement group, exercise group and the control group and time, between pre-end intervention F=0.02, p=0.99. There was no difference between the groups, F=0.13, p=0.88

There was no difference between Euroqol quality of life test score for question 3, the movement group, exercise group and the control group and time, between pre-end intervention F=0.87, p=0.43. There was no difference between the groups,F=0.74,p=0.93.

There was no difference between Euroqol quality of life test score for question 4, the movement group, exercise group and the control group and time, between pre-end intervention F=1.67, p=0.20. There was no difference between the groups, F=0.84, p=0.92.

There was no difference between Euroqol quality of life test score for question 5, the movement group, exercise group and the control group and time, between pre-end intervention F=0.28, p=0.76. There was no difference between the groups, F=0.39, p=0.68.

7.4.13 Roland Morris disability questionnaire.

There was no difference between the Roland Morris disability scores, the movement group, exercise group and the control group and time, between pre-end intervention F=1.46, p=0.24. There was no difference between the groups, F=0.36, p=0.97.

7.4.14 Fibion activity reports.

Mean and standard deviations for Fibion sitting time results are reported in Table 7.7.

Table 7.7 Mean and standard deviation for Fibion sitting time reports.

	Pre- Sitting time	Mid- Sitting time	End- Sitting time
Control	7.72 ± 2.07	7.45 ± 1.59	7.35 ± 2.26
Movement	7.52 ± 2.28	7.75 ± 52.78	7.14 ± 1.96
Exercise	8.31 ± 2.28	7.42 ± 1.94	7.16 ± 2.13

Values represent mean +- standard deviation unless other indicated. Sitting time values obtained by Fibion activity tracker worn over 2-consequtive days. Sitting time is calculated and measured in hours.

There was no difference between the sitting time, the movement group, exercise group and the control group and time, between pre-end intervention F=0.20, p=0.82. There was no difference between the groups, F=1.12, p=0.34.

7.5 Discussion.

This is the first study to evaluate the effect of both a 6-month remote multi-modal exercise programme and a movement prompt intervention on the thoracolumbar fascia in those with LBP. This study found that a 6-month remote multi-modal exercise programme and a movement prompt intervention had no significant effect on the thickness or echogenicity of the thoracolumbar fascia compared to a control group. However, the morphological adaptations seen in the present study are in line with prior studies investigating the thoracolumbar fascia thickness and echogenicity differences between adults with and without LBP (Langevin et al., 2009, Langevin et al., 2011, and Whittaker et al., 103). Our LBP population had a lower mean baseline thickness (-2.2mm) compared to the population in Langevin et al. (2009) earlier study. However, our demographic was in line with those used in the Whittaker et al., (2013) study (2.63 ± 0.81mm for Whittaker compared to 2.90 ± 3.16mm for the current study. Whilst not statistically significant, The thickness values of the exercise group reduced by 0.43mm (and a total reduction of 3.5%) whilst the movement group recorded a reduction of 0.34mm (a 1.16% reduction). Perhaps even more interesting is the difference in thoracolumbar fascia thickness in the exercise group seen when the cohort is split into two groups. The first, including participants who attended all of the live exercise classes (n=7), and the second who attended a minimum one class per week live (n=7). The group who regularly completed two exercise sessions per week (n=7) showed a thoracolumbar fascia thickness reduction of 19% (0.63mm), whilst the group who did not fully complete the intervention showed a smaller reduction of 6.7% (0.20mm) . This demonstrates that the number of exercise classes per week could be an important factor in thoracolumbar fascia adaptation over a longer duration. Our recorded reductions in thoracolumbar fascia thickness are comparable to values seen in healthy populations. Langevin and colleagues (2011) who found that individuals with LBP had a 20% increase in thoracolumbar fascia thickness compared to a control group without LBP. The primary hypothesized mechanism for an increased thoracolumbar fascia thickness in individuals with LBP is due to connective tissue remodelling following repetitive stresses created by maladaptive movement patterns, for example: fear avoidance movement strategies, poor posture and pain (Langevin & Sherman., 2007).

Echogenicity of the thoracolumbar fascia (the brightness of the ultrasound signal) seemed to show an increase in brightness over 6 months in both intervention groups, however this was not a statistically significant change. The greatest increase in echogenicity was seen in the exercise group, who at the 6-month mark exhibited a 15.10% increase in brightness of the perimuscular thoracolumbar fascia zone. Interestingly, the Movement group had the smallest increase brightness, averaging a 7.76% increase whilst the control group displayed a 13.70% increase. As no statistical differences were found between echogenicity values, our results suggest that echogenicity alone may not be a reliable measure to ascertain morphological adaptations to the thoracolumbar fascia in a population with LBP. Organisation of fascia has already been discussed in the literature (De Coninck et al., 2018), with clinicians able to distinguish between levels of disorganisation of the thoracolumbar fascia. Despite the lack of significant changes in the thickness or echogenicity of the thoracolumbar fascia over time, interesting trends and adaptations were seen in terms of organisation of fascia. Figure 7.9 below shows an example of exercise group participant's baseline scan and Figure 7.10 shows the same participant at the 6-month stage. In the baseline scan, you can clearly see large pockets of dark areas (the hyaluronan matrix), and the thoracolumbar fascia as a whole can be classified as quite disorganised in line with research from De Coninck et al., (2018). By the 6-month scan these pockets have reduced and instead the connective tissue is more organised and lined up. This thesis proposes that these changes could be due to changes in fluid levels rather than connective tissue changes themselves. Future ultrasound analysis should focus on measuring the organisation of fascia and note how changes in fluid levels are impacted by exercise and LBP levels.

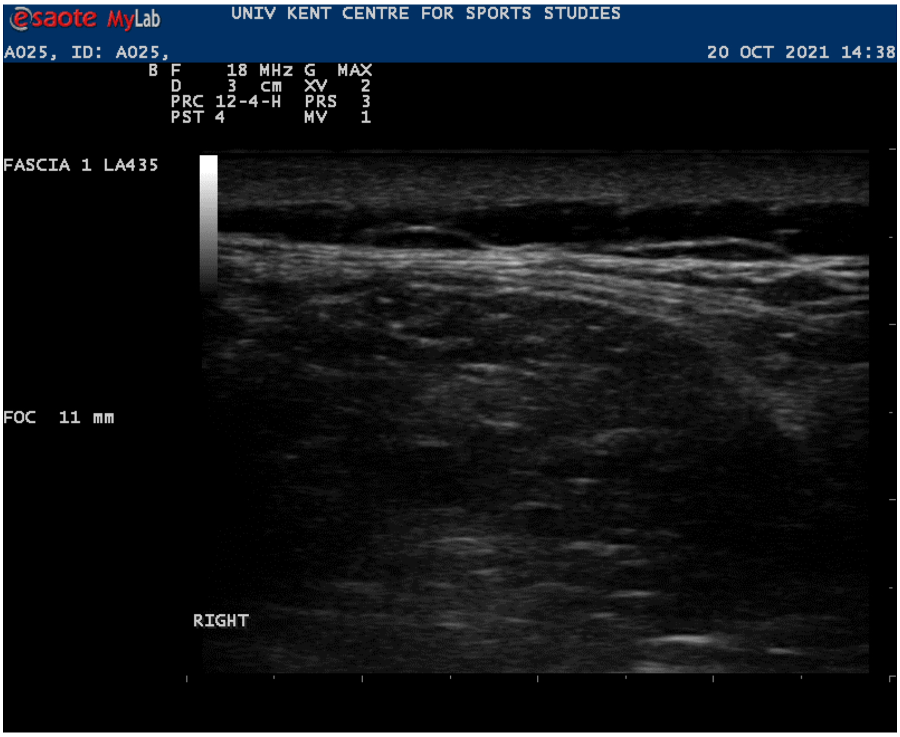


Figure 7.9 Baseline scan from Participant A025 prior to exercise intervention.

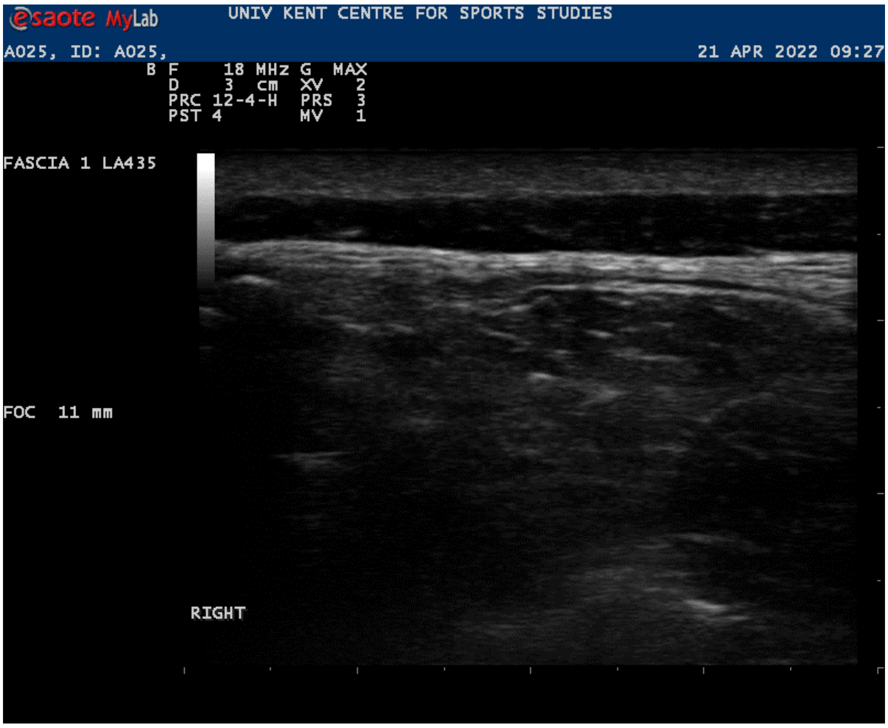


Figure 7.10 6-month scan from Participant A025 post 6-month exercise intervention.

Little is known about the effect of a movement prompt intervention whereby participants are encouraged to break up sitting time by getting up and engage in gentle physical movement, via the use of reminders through their phone. Equally there are few research studies investigating longitudinal multi-modal exercise programmes on the structure of the thoracolumbar fascia. Evidence has shown that the use of a range of exercise types is beneficial in LBP population (Owen et al., 2020). When investigating the morphological adaptations of thoracolumbar fascia in response to exercise in a population with LBP, it is important to incorporate a range of exercise training techniques to ascertain similarities and crossovers with prior research findings. Understanding the impact of a longitudinal multi-modal exercise programme will enable the development of effective training programmes targeting the thoracolumbar fascia for people with non-specific LBP. Likewise, developing a movement intervention that could be easily incorporated into everyday life could act as a simple, readily available, and low-cost method to reduce LBP in the community.

Our supplementary data for sitting time, quality of life, disability levels, functional capabilities and LBP levels were non-significant for each of the three intervention groups. Interestingly, pain and disability questionnaire results from the exercise group were non-significant with disability scores reducing by 41% and LBP scores reducing by 15%. Likewise, functional capabilities of the exercise group increased by 7% and overall sitting time reduced by 15% indicating an increase in daily activity levels. The overall consensus of a reduction of pain and disability levels alongside and increase in movement and functional capabilities were corroborated verbally at the post-intervention feedback with comments such as "the exercise group has hugely improved by back pain especially when walking". It could be suggested that whilst the findings of this study were statistically non-significant, the results for patients are clinically meaningful and require further exploration to corroborate the ideal intervention type and duration for the LBP. The movement prompt group also reported non-significant reductions in pain and disability, with scores from the Roland Morris disability questionnaire reducing by 16% and LBP scores 26% lower than baseline. However, functional movement and sitting time scores showed marginal changes of within 2% of baseline. In disagreement to existing literature, the lack of significant evidence from the movement prompt groups suggests that this form of intervention could be less suitable for LBP participants. Perhaps, differences between the movement and exercise groups could be in part due to a lack of engagement with the prompting software and the independent aspect of this group (Neff & Fry., 2009). Whilst the exercise group included a group environment to help encourage engagement and retention, motivation and empathy (McLean et al., 2010), the movement prompts were completed in isolation. Future studies could investigate the use of movement prompt interventions alongside a group dynamic, perhaps a combination of group exercise and movement prompts, or a movement prompt group which includes a group chat via social media channels to encourage discussion around following the intervention and/or total steps completed per day.

Another factor to consider when reviewing the results from the sitting time outcomes, are the Fibion activity trackers. Unfortunately, due to the duration and participant numbers involved in the study, data collection using the trackers was limited to 2-consequtive days at each time point. In an attempt to counter act this, all participants were asked to record their daily step count using a pedometer. However, adherence to this was very low and provided unusable data. This could have had a negative impact on the reliability of the sitting time values, future studies should incorporate 7-days of tracking at each stage to enable a more well-rounded picture of sedentary behaviour. Furthermore, daily activity levels could have been collected using data from a smart watch, such as a Garmin or Fitbit, in order to monitor habitual activity levels.

The outcomes from the interventions presented in this chapter found non-significant reductions in thickness and increases in the echogenicity of the thoracolumbar fascia, and it could be suggested that 6-month interventions are not long to observe significant anatomical adaptations to the thoracolumbar fascia for those with LBP. Indeed, Schleip & Müller (2012) suggest a 6–24-month duration of exercise training to enable modifications to fascia. Future studies should seek to investigate the effect of exercise and movement on the thoracolumbar fascia over a longer duration (for example: 12-months). Recruiting and retaining participants for a period of 12-months presents retention difficulties. To mitigate these issues, further studies should incorporate randomised controlled crossover design to encourage participant adherence (Frost et al., 2017). Given thoracolumbar fascia thickness reductions were reduced in participants not maintaining two exercise classes per week over the 6-month duration, there is scope for follow-up interventions of the same duration but with an increased frequency of exercise classes per week. By increasing the exercise intervention to 3 x 60-minute classes, the total load to the thoracolumbar fascia can be increased. As connective tissue, and in turn fascia, have been shown to adapt more slowly to exercise, increasing the total load per week could have a beneficial role in fascial tissue adaptation (Kjær et al., 2009, Schleip & Muller., 2009). Likewise, increasing to 3 x 60 -minute classes per week would enable physical activity levels to match the WHO guidelines for physical activity of 150-minutes of moderate intensity exercise per week recommended for those with chronic health conditions (WHO., 2009). This was unfortunately out of scope of this PhD study due to the time constraints caused by the COVID-19 pandemic, allowing for just 9-months to recruit, complete, analyse and write up this study.

Despite a variety of interventions to increase physical activity levels in the community many of the world's population remain physically inactive, this is particularly true in those with LBP (Lin et al., 2011). This chapter has sought to investigate changes to the morphology of the thoracolumbar fascia by increasing physical activity levels within this population using remote, telehealth interventions in a LBP population. Telehealth interventions and the use of video conferencing may help to mitigate the poor adherence rates to physical activity. Telehealth can be defined as the use of telecommunication techniques (such a video conferencing) for the purpose of providing medical and health education over a distance (Brown et al., 2022). Physical activity intervention studies using telehealth methodologies have begun to emerge in the literature (Lai et al., 2020 and Ptomey et al., 2019.). The group exercise intervention for this study incorporated live remote exercise classes and recordings available for participants to complete the classes in their own time. Within the exercise group, two of the participants used lower intensity options through the aerobic section of the class for the first 8-weeks, after which all participants were able to work to the standard intensity level. Allowing for the asynchronous completion of the exercise class increased the accessibility for participants who were caregivers and/or worked alternate shift schedules, however this of course impacted the percentage of participants that attended the live sessions. Attendance was limited to 50-60% of each exercise group during the 2 x weekly live sessions whilst the remainder of the participants used a mix of live and pre-recorded sessions to complete their intervention. Participants who completed the asynchronous classes were asked to report when they completed a class to ascertain engagement with the intervention. Whilst the participants using the asynchronous classes adhered to self-reporting their completion of the class, it is difficult to ascertain exactly how many completed the classes this way. Whilst this is a limitation to our current study, allowing for asynchronous delivery increased accessibility and contributed to a high level of retention in the study with only 3 participants (6.25%) dropping out from the start of the study. Prior review of exercise prescription in exercise referral schemes has shown that retention rates for group exercise programmes can be as low as 12% (Tobi et al., 2012). Our study experienced an overall retention rate of 93.75% across all three groups which is higher than previously reviewed in a report by Brown and colleagues (2022), who found that telehealth exercise interventions across 23 trials between 2016-2021 exhibited a retention rate as high as 70%.

The population demographics for our study included a high proportion of female participants (57.1%). Females are significantly underrepresented in all areas of sport and exercise research with the average percentages of female participants below 37% (Costello et al., 2014). Unsurprisingly, little to no research has investigated the physical activity levels of women with LBP. Craft & colleagues (2014) assessed gender differences in exercise habits of 108 women and 72 men aged between 18-25 years via a series of questionnaires and found that women reported significantly higher physical activity levels ($p <0.0125$) compared to their male counterparts. The exercise habits of these women favoured light-moderate intensity with an average of 6.0 increase in weekly metabolic equivalent of task levels (METs) from moderate activity, and an increase of 4.0 METs for light activity. However, physical activity levels have been shown to vary throughout life stages, with a progressive decline seen in both men and women as they age (Schutzer & Graves (2004). Importantly, when the authors analysed the physical activity habits of older women (aged >60), adherence to regular exercise is as low as 15% of the population. Another factor which can impact physical activity levels is pregnancy, one study surveyed 3482 pregnant women and found that just 14.6% followed current WHO exercise guidelines (Gjestland et al., 2012). Moreover, the authors found that exercising in line with WHO guidelines reduced the likelihood of reporting LBP (aOR: 0.80, 95% CI 0.66 to 0.97).

7.6 Conclusion.

The present study found no significant differences in thoracolumbar fascia thickness and echogenicity of those with chronic non-specific LBP after a 6-month remote exercise and movement prompt intervention. However, reductions in thickness and an increase in echogenicity were found which were clinically meaningful in the exercise group. The anatomical adaptations seen were correlated with a reduction in pain reduction and disability and an increase in functional ability and movement in the exercise intervention. Likewise, the movement prompt group exhibited a reduction in pain and disability following the 6-month intervention. Engagement and retention in the present study was recorded at 93.75% which is higher than that previously reported for exercise telehealth interventions, we suggest that this population is particularly suitable for remote exercise interventions and that incorporating a mix of synchronous and asynchronous delivery is suitable to encourage retention over longitudinal interventions. Future studies should investigate the impact of a 12-month intervention on the thoracolumbar fascia result in significant anatomical adaptations to the thoracolumbar fascia under ultrasound due to the slow adaptability of fascia to loading. Moreover, interventions to include a more social and collaborative approach to the movement prompt group could increase engagement and improve outcome measures. Moving forward, multi-modal group exercise has been shown to be a safe and effective way to target the thoracolumbar fascia and reduce pain and quality of life in a population with LBP.

Chapter 8. General Discussion.

8.1 Thesis Overview.

This thesis has contributed and built upon existing literature surrounding the thoracolumbar fascia and LBP. Primary data has been gathered which quantifies and confirms the observation that fascia is still largely unrecognised and a factor in LBP by the professions that work with and treat LBP patients. This suggests a need to increase the dissemination of research findings concerning fascia treatment as a means to manage LBP. This thesis has also shown that novice practitioners with a basic level of MSK ultrasound imaging training can accurately and reliably measure the thoracolumbar fascia in populations with and without pain. This is important, as it can support the implementation and use of ultrasound imaging amongst physical therapists in patients with non-specific LBP. No significant morphological adaptations were found in people with lower back pain, nor were any changes detected following a 6-month exercise intervention, this thesis provides evidence to suggest that the wrong fascia metric may have been previously used to evaluate fascia morphology in those with LBP with its inability to produce the significant morphological differences. Instead, it is possible thoracolumbar fascia organisation and shear strain capabilities could be used to measure thoracolumbar fascia adaptations more accurately between those with and without LBP (De Coninck et al., 2018(.

Despite global physical activity recommendations for both the prevention and management of chronic disease, an increasing number of the population are physically inactive. To manage this discrepancy, there have been a range of international public health initiatives and schemes (Rowley et al., 2018 and Salis 2009) which have been created to utilise existing health care systems to promote physical activity. However, despite this there few recommend physical activity as a primarily treatment and very little interdisciplinary work between health care practitioners and the fitness industry (U Din et al., 2014 and Craike et al., 2019). Moreover, with research evidence suggesting that the thoracolumbar fascia may be implemented in LBP it is essential we understand what treatment methodologies physical therapists (including chiropractors, massage therapists, osteopaths, physiotherapists, and sports therapists) and fitness professionals (including fitness instructors, group exercise instructors, personal trainers, Pilates, and yoga instructors) are using to treat patients with LBP. Chapter 4 in this thesis utilised a bespoke online questionnaire to reach n=112 professionals working in the industry. The questionnaire was split into three sections; the first to describe the participant, their profession, and time in practise, the second to identify the type of LBP management techniques they preferred to use, and finally identifying their pre-existing knowledge about the thoracolumbar fascia. Results showed that exercise recommendations are being communicated to patients in both profession groups, however the exact form this takes varies. Fitness professionals and physical therapists both commonly utilised one-to-one rehabilitation exercise, however whilst fitness professionals also incorporated group exercises for those with LBP, this was less common in the physical therapist group. Existing evidence identifies three key reasons for why this profession may be more hesitant to recommend exercise as treatment for LBP:

1. practitioner beliefs about LBP (Gardner et al., 2017)
2. a lack of training in the area (Cowell et al., 2018);
3. a lack of support from their respective professional bodies (Francke et al., 2008).

However, research has not yet uncovered why physical therapists may be hesitant to refer to fitness professionals as a way to promote and use exercise treatments more fully. Section 3 of the questionnaire uncovered some gaps in knowledge about the thoracolumbar fascia and LBP in both physical therapists and fitness professionals. Over 85% of participants expressed that fascia was not included in their initial anatomy training. This finding supports recent publications calling for a need to update anatomy curricula to include fascia in the initial training as well as the continuous professional development of medical and allied health professionals (Pratt., 2019., and Sharkey & Kirkness., 2021). This thesis not only supports these guidelines but also lends to the argument that fascia anatomy training is missing in vocational training for those in the health and fitness industry treating those with LBP. The study found that only n-16 (15.3%) of all participants confirmed that the thoracolumbar fascia was included in their initial training as a practitioner. This suggests a need for curriculum development and indeed a greater emphasis on research dissemination targeted towards practitioners. Practitioners are aware of the benefits of exercise for those with LBP, however given an apparent lack of knowledge of the thoracolumbar fascia perhaps they are unaware of why exercise is beneficial, in particular to those with non-specific LBP. Practitioners are currently unaware of the effect of exercise on the thoracolumbar fascia, as such the following chapters were developed to evaluate the morphological differences of the thoracolumbar fascia in participants with and without LBP and establish whether practitioners would be able to accurately measure this using ultrasound imaging. Further studies should explore this further and seek to ascertain why group exercise is less commonly used by physical therapists.

Existing literature has previously found ultrasound imaging to be an accurate and reliable method to measure the musculature of the lower back, with studies beginning to ascertain the reliability of using the same method for the thoracolumbar fascia (Langevin et al., 2009., Teyhen et al., 2011., and Wallwork, Gides & Stanton., 2007). Inter- and intra- rater reliability studies found high levels of agreement when scanning the lower back of younger and older adults alike (Sions., 2014), however little research has evaluated the reliability of untrained investigators. Chapter 5 sought to bridge this gap in the literature by analysing and comparing the reliability of a trained investigator, with over 250 hours of supervised musculoskeletal ultrasound scanning experience and formal accredited certification, to a novice investigator with no formal training of qualification nor experience. This study also served to confirm that the author of this thesis could accurately capture and reliably analyse the thoracolumbar fascia using ultrasound imaging. The novice rater was given a total of 6 training sessions by the expert investigator to teach the methodology required to capture images of the thoracolumbar fascia. Remarkably, a very-high level of reliability between 0.91-0.99 (reported by an inter-class correlation (ICC)), coupled with a small standard error measurement was found for both thoracolumbar fascia echogenicity (SEM between 0.01-0.02) and thickness (SEM between 0.14-0.43mm) measurements. This level of reliability supports the hypothesis that a novice rater can accurately, and reliability measure the thoracolumbar fascia in a population with or without LBP. Formal training is not required to allow for reliable image capture and analysis, however informal training, mentoring, and practice is necessary to allow for the appropriate ultrasound methodology to be developed. Likewise, intra-rater reliability for the novice was reported as high for all echogenicity measures (between 0.75-0.85, subcutaneous (r_s= 0.95) and combined (r_s= 0.96) thoracolumbar thickness measurements), with moderate reliability found for perimuscular thoracolumbar thickness (r_s= 0.59). For the expert rater, echogenicity values were reported as high for all zones (between 0.71-0.77), whereas thickness measures were found to be very high for the subcutaneous zone (r_s= 0.85) and high for the combined (r_s= 0.78) and peri-muscular zone (r_s= 0.77). The lower reliability found for perimuscular thoracolumbar fascia thickness compared to subcutaneous zone in both investigators is interesting, suggesting that this area of the thoracolumbar fascia is marginally more challenging to analyse and capture under ultrasound. One potential explanation for this is the increased level of disorganisation seen in previous thoracolumbar fascia ultrasound studies for those with LBP (De Coninck et al., 2018 and Almazan-Polo et al., 2020), it is probable that higher levels of disorganisation impact the repeatability of ultrasound imaging accuracy. However, even with the marginally lower accuracy of intra-rater reliability, ultrasound imaging was found to be a reliable method to measure all thoracolumbar fascia zones in populations both with and without LBP. The differences in reliability between zones, suggested further investigation into the morphological differences of thoracolumbar fascia in people with and without pain was needed. To further investigate this, a follow-up study evaluating observational differences between populations with and without LBP was completed.

With ultrasound imaging found to be a reliable method for a novice investigator to measure the thoracolumbar fascia, the same methodology was used to investigate any potential morphological differences seen in those with and without chronic non-specific LBP. Research has previously speculated that LBP would be more prominent in those with maladaptation’s to the thoracolumbar fascia, such as increased thickness and reduced shear strain (Langevin & Sherman., 2009). Research studies have found trends in thoracolumbar fascia to support this (Langevin et al., 2011., Almazan-Polo et al., 2020), however existing studies have been completed on primarily physically active populations. As such, the observational ultrasound imaging study in chapter 6 sought to ascertain any differences in the thickness and echogenicity of the thoracolumbar fascia in populations with and without LBP. A total of n=33 participants aged between 18-70 years were recruited for the study, with n=17 self-reporting with chronic non-specific LBP who all completed less than the recommended weekly physical activity levels (UK Chief Medical Officer’s physical activity guidelines., 2019). Interestingly, the observational study did not find significant differences for the thickness or echogenicity of the thoracolumbar fascia between the pain and no pain group. However, there was a trend towards an increase in thickness (LBP = 3.05mm ± 1.10mm, No pain = 2.92mm ± 1.58mm, F=1.165, df=1, p=0.287, ETA^2 = 0.0.28) and reduction in echogenicity (LBP = 0.59 ± 0.12, No pain = 0.53 ± 0.02, F=2.985, df=1, p=0.092, ETA^2 = 0.071) for those in the LBP group at the perimuscular zone. Interestingly, whilst the differences for thickness were below the minimal detectable change level (MDC), the difference in echogenicity between the pain and no pain groups are above the MDC of 0.35 units indicating a clinically meaningful change. Future ultrasound imaging studies on the thoracolumbar fascia should incorporate MDC to help ascertain whether morphological differences are clinically meaningful. Importantly, the observational study did find a significant correlation between Body Mass Index (BMI) and thoracolumbar fascia thickness and echogenicity, which is in disagreement with prior ultrasound imagine studies (Langevin et al., 2009). The average BMI for the LBP group in this study was 28.57 (± 5.89) placing participants in the overweight category, whilst the no pain group recorded an average BMI within the normal range of 23.85 (± 4.54). Importantly the ranges of BMI readings for both groups included classification into the obese category with a total of n=10 participants classified as obese according to BMI classification (Aronne., 2012). This suggests that future research should include individuals with a BMI above 30.0 to evaluate morphological differences to the thoracolumbar fascia. Equally, higher BMI readings are more common in physically inactive individuals, the incorporation of regular physical activity could potentially alter the thoracolumbar fascia in part due to a reduction in body fat mass.

The final and largest study chapter in this thesis was a 6-month exercise and movement prompt intervention, described in chapter 7. This study sought to fulfil the pre-existing gaps in the literature surrounding the impact of a 6-month multi-modal exercise and a reduction in sedentary behaviour on the thoracolumbar fascia in those with LBP. Previously, exercise loading has been shown to positive impact connective tissue by increasing tensile fascial force and fascial length (Reeves et al., 2004). Researchers had previously hypothesized that exercise may target fascia by increasing undulations in collagen fibres and their elastic storage capacity (Jarvinen et al., 2002). However, very few randomised controlled trials have reviewed the effect of exercise interventions targeting the thoracolumbar fascia in a population with chronic, non-specific LBP. Schleip & Muller., (2013), recommended Pilates style exercises for those with LBP, hypothesizing that the dynamic, opposing limb movements would target the shear strain capabilities of the thoracolumbar fascia. LBP specific exercise recommendations have supported the use of aerobic exercise (Sculco et al., 2001), strength & resistance training (Cortell-Tormo et al., 2018 and Jackson et al., 2011) and flexibility-based training (such as yoga (Wieland et al., 2013) and Pilates (Gladwell et al., 2006)) to improve LBP symptoms and quality of life. The intervention study presented in this thesis incorporated three participant groups of which n=45 participants were randomly allocated to. The first, a twice-weekly remote group exercise intervention, the second a movement prompt intervention, and the third a control group. For the exercise group, a bespoke exercise programme was created by the lead researcher and subsequently approved by two external fitness professionals. The exercise class was progressed every 4-weeks and followed a similar plan to previous LBP studies (Mannion et al., 2001). The movement prompt group received daily prompts to their mobile phone which recommended breaking up sitting time and general ambulation. Lastly, the control group were advised to continue with their usual habitual activity throughout the 6-month intervention. For each group a series of measurements were taken at baseline, during and after the intervention had ceased including ultrasound imaging of the thoracolumbar fascia, LBP, disability, and quality of life questionnaires a well as sitting time measurements taken with a Fibion wearable activity tracker. Whilst this study found no significant adaptations to the thoracolumbar fascia in either intervention group when compared to the control, a trend towards a reduction in thickness and echogenicity following an increase in physical activity and reduction in sitting time was seen. For thoracolumbar fascia thickness measurements of the perimuscular zone, the exercise group average thickness reduced by 0.43mm (a reduction of 3.5%) and the movement group recorded a reduction of 0.34mm (a 1.16% reduction). The control group, however, experienced a 0.30mm (and an 11.5%) increase in thoracolumbar fascia thickness. Likewise, for echogenicity a general trend for an increase following both intervention groups was seen. The greatest increase in echogenicity was seen in the exercise group with a 15.10% increase in brightness of the perimuscular thoracolumbar fascia zone. Whilst the movement group exhibited an average increase of 7.76% in echogenicity, this was lower than the increase seen in the control group (13.70% increase). As the increases in echogenicity were apparent in the control as well as the intervention group this puts into question the reliability of using echogenicity to monitor adaptations in the thoracolumbar fascia associated with LBP and/or exercise. Across all three ultrasound studies only one measurement recorded an observational difference above the Minimal Detectable Change, the perimuscular echogenicity between the pain and no pain groups seen in chapter 6. The supplementary measures for LBP, disability, quality of life and sitting time were also non-significant. However, a trend towards quality of life improvements and a reduction in pain were found in the exercise group, with a 41% reduction in disability, a 15% reduction in LBP and 15% decrease in daily sitting time. The trends seen in all measures indicate that the 6-month intervention may not have been not long enough to lead to significant changes to the thoracolumbar fascia, or indeed LBP.

8.2. Thesis Limitations.

There are a number of limitations and constraints to this thesis that could be improved upon for future research studies. The first, was identified in the Chapter 6 and corroborated in chapter 7 but it arguable relevant for all ultrasound chapters in this thesis. In both studies ultrasound imaging was used to measure the thickness and echogenicity of the thoracolumbar fascia. However, with no significant differences found between participants with or without LBP, nor significant adaptations found following a 6-month intervention it is possible that thoracolumbar fascia organisation and shear strain capabilities are more directly linked to LBP adaptations (Langevin et al., 2011). Recent studies have shown the organisation of the thoracolumbar fascia is more disorganised in those with LBP (Almazan-Polo et al., 2020). Likewise, shear strain has not only been shown to decrease in those with LBP (Brandl et al., 2022) but has also been shown to adapt to exercise therapy (Brandl et al., 2023, and Devantéry et al., 2023) and manual therapy (Vining et al., 2022). Moreover, the pain intensity and disability levels of the LBP populations in this study were classified as low, whilst this is indicative of the LBP globally. Whilst this has yet to be researched, it is possible that populations with higher pain levels and higher levels of disability, would exhibit greater morphological differences under ultrasound. It is difficult to ascertain the LBP intensity and pain levels of those included in prior literature, it is probable that those with significant observational differences included participants with a higher level of pain and disability than those used in this thesis (Langevin et al., 2009., Langevin et al., 2011). A limitation to chapter 7 is the duration of the intervention itself. Originally and prior to the COVID-19 pandemic the intervention was planned to continue for 12 rather than 6 months, allowing for a prolonged duration for the connective tissue in the lower back to adapt, and for the interventions themselves to become habitual practice for the participants. The reasoning for a 12-month duration study came from early guidelines by Schleip & Müller (2013) who hypothesized that fascia would take a minimum of 6-months to show significant morphological adaptations, and that indeed these adaptations could take up to 24 months to be seen. Unfortunately, due to the unforeseen lockdown period the study was reduced to a 6-months study.

8.3 Future Directions.

This thesis contributes to the existing literature base encompassing ultrasound imaging, the thoracolumbar fascia and exercise expanding previous knowledge from short-term interventions of 4-weeks. Moreover, this thesis lends support to recent discussion around the importance of including fascia anatomy training in higher education and vocational training courses for those working with LBP. The findings of this thesis are not conclusive, with difficulty finding significant observational differences in those with and without LBP and quantifying adaptations from exercise. With the prevalence of LBP remaining high and the role of the thoracolumbar fascia here still unknown further research studies are recommended to continue from this thesis and further advance the literature base of the thoracolumbar fascia.

The lack of knowledge around the thoracolumbar fascia and associated research connecting this area of connective tissue to LBP support publications from Pratt (2019) and Sharkey Kirkness (2021) who argue for higher education curriculum change in medical and allied health care professionals . The authors argue that with the growing interest in fascia and its link to pain (Fede et al., 2020), force transmission (Wilke et al., 2018) and communication (Wall et al., 2008) this is an essential area to include in anatomy training. Likewise, the findings of this chapter recommend that alongside higher education curriculum, vocational qualifications in the fitness industry would benefit from the inclusion of fascial anatomy. Whilst developing curriculums would indeed be beneficial for health and fitness professionals, this of course does little for those already working in the field. As such, future studies should seek to enhance the dissemination of fascial research within this field. This could be done with the development of infographics, similar to those used by NICE (2023) to recommend physical activity levels for the global population. Infographics have been found to be an effective tool for health and physical activity promotion, with recent studies finding that 83% of participants questioned would view information like this around these subjects (Coyne et al., 2021). Instead, new infographics could be created which aimed to target the key findings of fascia research and how this knowledge can be used to facilitate the rehabilitation of those with chronic LBP amongst other fascial conditions.

As highlighted above, due to the non-significant findings in chapter 6 and 7, future thoracolumbar fascia studies need to consider organisation and shear strain alongside thickness and echogenicity. Organisation could be measured using a scoring system from organised to disorganised as it being developed by De Coninck and colleagues (2018), this would be particularly beneficial in how to measure and analyse organisation and importantly to quantify each level. For shear strain measurements, existing literature has primarily measured this in unloaded tissues (Langevin et al., 2011), it would be of interest to researchers and practitioners for shear strain to be measured in loaded tissues for those with and without LBP to see if dysfunctional gliding patterns are more prominent during movement and physical loading. Shear strain dysfunctions of the thoracolumbar fascia has been investigated with significant reductions in gilding capability seen in both human (Langevin et al., 2011) and animal models (Bishop et al., 2016). Likewise, future studies should consider recruiting participants with higher levels of LBP. Future LBP classification should include a greater range of pain intensity, higher levels of disability, longer duration and recurrence of LBP to gain an understanding of how LBP severity impacts the morphological make-up of the thoracolumbar fascia.

Future exercise interventions would benefit from continuing the multi-modal exercise methodology over a duration of 12-months in line with previous recommendation (Schleip & Muller., 2013) to ascertain the impact of a sustained period of group exercise on the thoracolumbar fascia adaptations trends, observed in this thesis. Very little research has been completed to quantify this assumption which makes it difficult to truly understand the duration of exercise needed for fascia to adapt. Miller and colleagues (2005) completed labelling techniques on the achilles and patellar tendons showing remodelling rates of 1% per day. Moreover, the authors estimated that collagen tissues remodel at 2-3 times the rate of skeletal muscle, remodelling roughly every 12-18 weeks. However, such research has not yet been completed on fascia, future studies should investigate the remodelling capabilities of the thoracolumbar fascia to truly understand the duration of exercise interventions needed for remodellng.

Whilst research into the impact of the menstrual cycle and physical activity is growing (Bruinvels et al., 2021., Colenso-Sempole et al., 2023), there is a lack of research investigating how the thoracolumbar fascia fits into this and importantly, how the thoracolumbar fascia adapts to LBP at different stages of the hormone cycle and at each stage of development (from puberty to post-menopause). Studies have begun to investigate the impact of hormones on connective tissue and fascia (Fan et al., 2020, Herzberg et al., 2017, and Vita et al., 2019) but there is still much to investigate here. Additionally, another factor to consider is childbirth. Studies have found a significantly increased thickness of the rectus sheath in women who have experienced a caesarean section, compared to women who have undergone a vaginal birth or those without children (Fan et al., 2020). The authors commented how caesarean sections may be the greatest contributor to dysfunctional gliding within the fascia plane which could contribute to LBP cases, muscle deficits and muscle asymmetries. Interestingly, a contraceptive study by Vita and colleagues (2019) investigated the thickness and elasticity of fascia of women using hormonal contraceptives compared to a control group and found that, women without a history of hormonal contraceptive use have significantly stiffer thoracolumbar fascia and greater perimuscular thoracolumbar fascia thickness than those using hormonal contraceptives (Vita et al., 2019). These adaptations suggest that hormonal contraceptive use could play a key role in fascial gliding capabilities and perhaps contribute to pain symptoms. A limitation of this study is the omission of key data such as menstrual cycle, hormonal contraceptive use, or history of childbirth. Whilst researchers are now discussing lack of research surrounding female health in the literature (Cowley et al., 2021), research specifically addressing womens' facial health is also required. Future research studies around the impact of LBP on the thoracolumbar fascia, and equally subsequent exercise interventions, should specifically include female participants. Moreover, future studies investigating how the thoracolumbar fascia adapts during the female hormone cycle and indeed throughout the female lifespan would be of interest to researchers and clinicians globally. Research into the thoracolumbar fascia over the hormone cycle could be particularly interesting to women's health researchers and help to bridge existing gaps in the literature.

8.4 Thesis conclusion.

The perceptions of fitness professional and physical therapist study in this thesis lends support to the arguments from Pratt (2019) who strongly advocates for the inclusion of the fascia anatomy into curriculum of medical study and pushes further to recommend inclusion into the vocational training of those within the health and fitness industry. This thesis has advanced previous ultrasound reliability studies to show that novice investigators can accurately use ultrasound imaging to capture and measure the thoracolumbar fascia in those with and without LBP to a high level of accuracy. Furthermore, the studies in this thesis, expand on earlier in-vivo ultrasound studies investigating morphological differences in people with and without LBP and disagrees with findings that suggests the perimuscular zone is significant altered in those with LBP in terms of thickness and echogenicity. The exercise intervention study demonstrated a trend towards a reduction in thickness after 6-months of group exercise, however, was not able to show significant adaptations. Moreover, the exercise and movement prompt randomised controlled trial in this thesis is the first intervention of this type and duration to evaluate the impact on the thoracolumbar fascia in those with LBP. Though the findings were non-significant, this thesis has provided essential insights into the need for longitudinal exercise interventions, showing that studies of longer duration are warranted to fully understand the impact of exercise on the thoracolumbar fascia.

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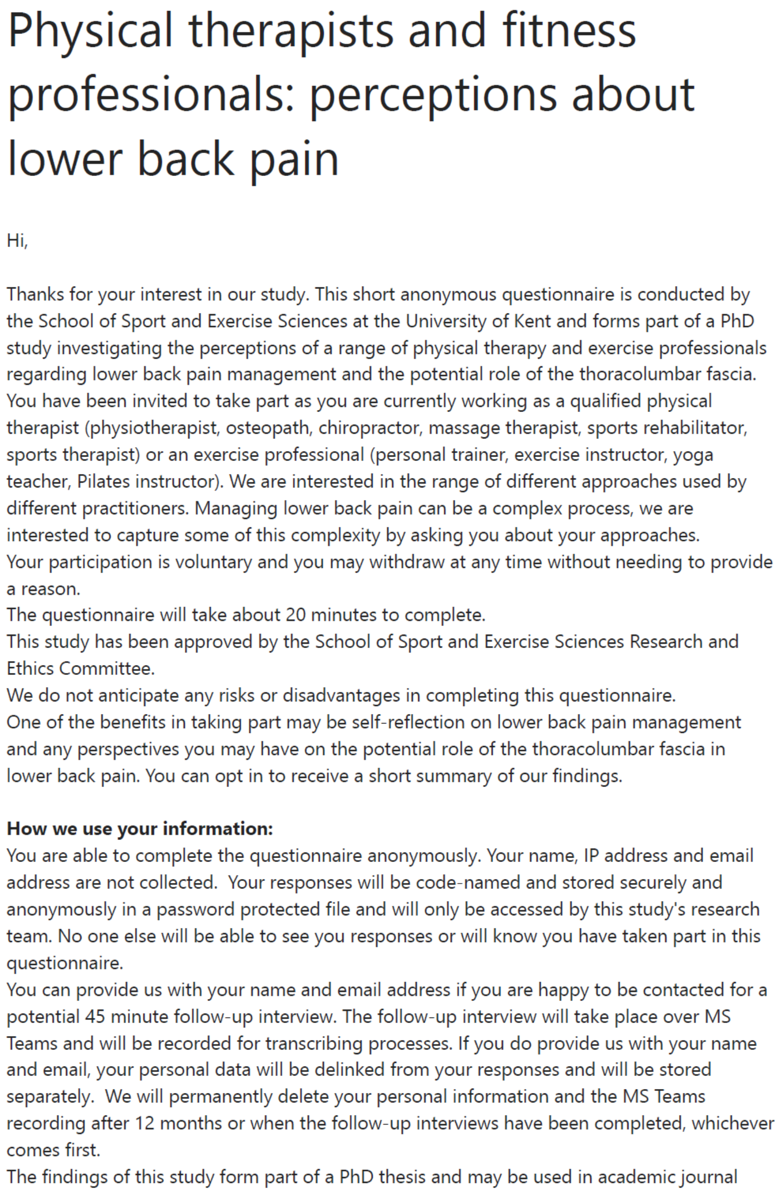
Appendices

Appendix 1.1 Perceptions questionnaire

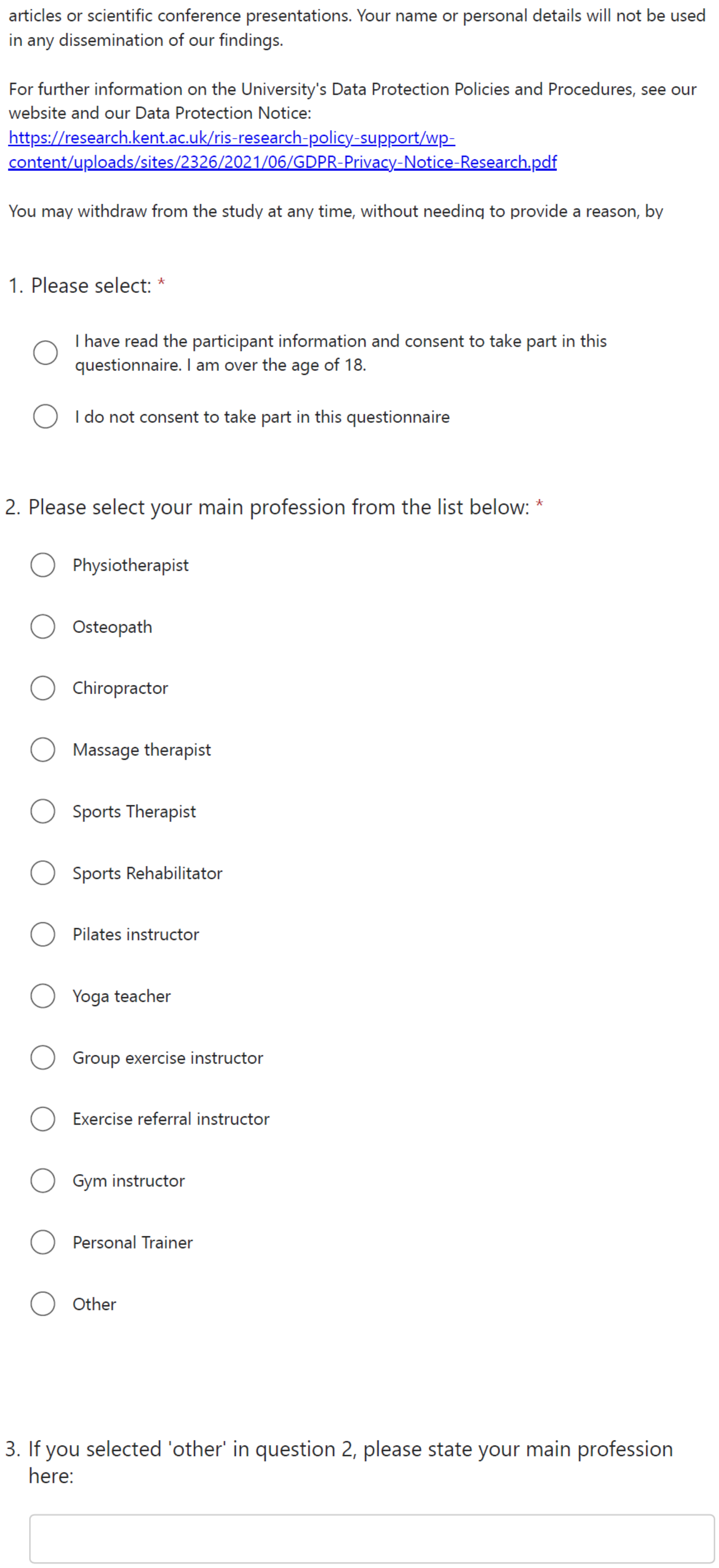


Physical therapists and fitness professionals: perceptions about lower back pain

Hi,

Thanks for your interest in our study. This short anonymous questionnaire is conducted by the School of Sport and Exercise Sciences at the University of Kent and forms part of a PhD study investigating the perceptions of a range of physical therapy and exercise professionals regarding lower back pain management and the potential role of the thoracolumbar fascia.
You have been invited to take part as you are currently working as a qualified physical therapist (physiotherapist, osteopath, chiropractor, massage therapist, sports rehabilitator, sports therapist) or an exercise professional (personal trainer, exercise instructor, yoga teacher, Pilates instructor). We are interested in the range of different approaches used by different practitioners. Managing lower back pain can be a complex process, we are interested to capture some of this complexity by asking you about your approaches.
Your participation is voluntary and you may withdraw at any time without needing to provide a reason.
The questionnaire will take about 20 minutes to complete.
This study has been approved by the School of Sport and Exercise Sciences Research and Ethics Committee.
We do not anticipate any risks or disadvantages in completing this questionnaire.
One of the benefits in taking part may be self-reflection on lower back pain management and any perspectives you may have on the potential role of the thoracolumbar fascia in lower back pain. You can opt in to receive a short summary of our findings.

How we use your information:
You are able to complete the questionnaire anonymously. Your name, IP address and email address are not collected. Your responses will be code-named and stored securely and anonymously in a password protected file and will only be accessed by this study's research team. No one else will be able to see you responses or will know you have taken part in this questionnaire.
You can provide us with your name and email address if you are happy to be contacted for a potential 45 minute follow-up interview. The follow-up interview will take place over MS Teams and will be recorded for transcribing processes. If you do provide us with your name and email, your personal data will be delinked from your responses and will be stored separately. We will permanently delete your personal information and the MS Teams recording after 12 months or when the follow-up interviews have been completed, whichever comes first.
The findings of this study form part of a PhD thesis and may be used in academic journal



articles or scientific conference presentations. Your name or personal details will not be used in any dissemination of our findings.

For further information on the University's Data Protection Policies and Procedures, see our website and our Data Protection Notice:
https://research.kent.ac.uk/ris-research-policy-support/wp-content/uploads/sites/2326/2021/06/GDPR-Privacy-Notice-Research.pdf

You may withdraw from the study at any time, without needing to provide a reason, by

1. Please select: *

○ I have read the participant information and consent to take part in this questionnaire. I am over the age of 18.

○ I do not consent to take part in this questionnaire

2. Please select your main profession from the list below: *

○ Physiotherapist

○ Osteopath

○ Chiropractor

○ Massage therapist

○ Sports Therapist

○ Sports Rehabilitator

○ Pilates instructor

○ Yoga teacher

○ Group exercise instructor

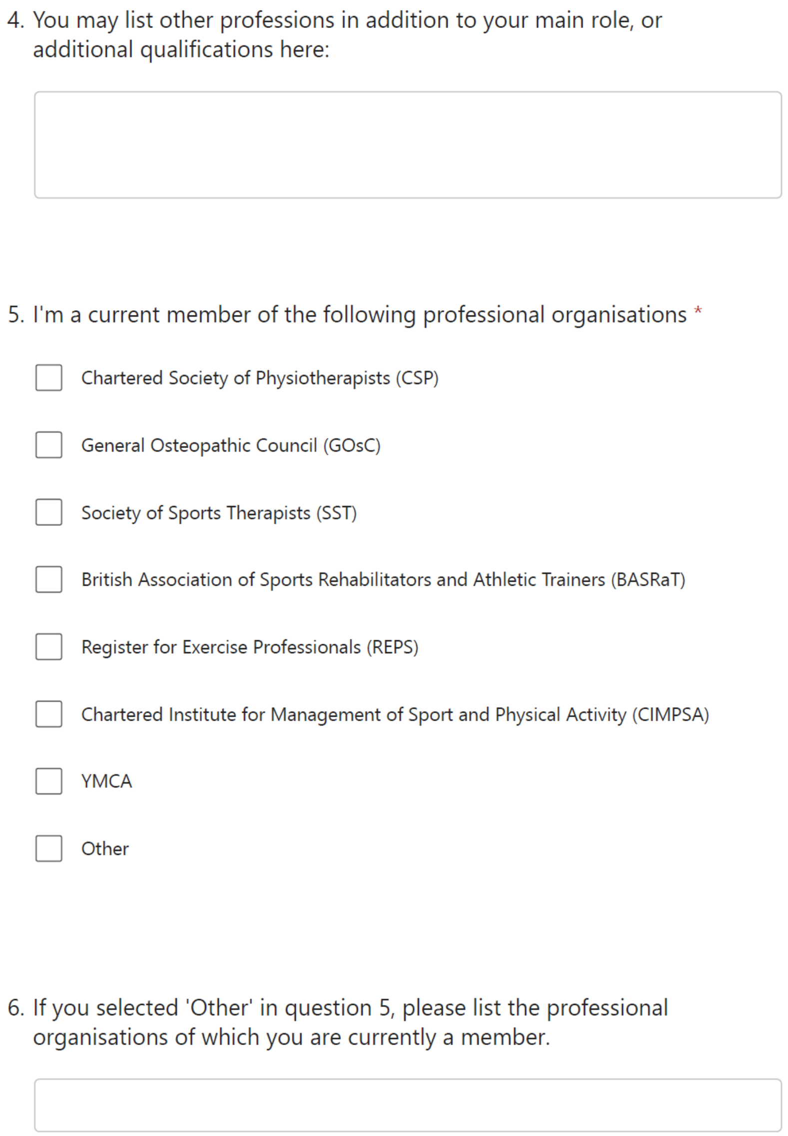
○ Exercise referral instructor

○ Gym instructor

○ Personal Trainer

○ Other

3. If you selected 'other' in question 2, please state your main profession here:

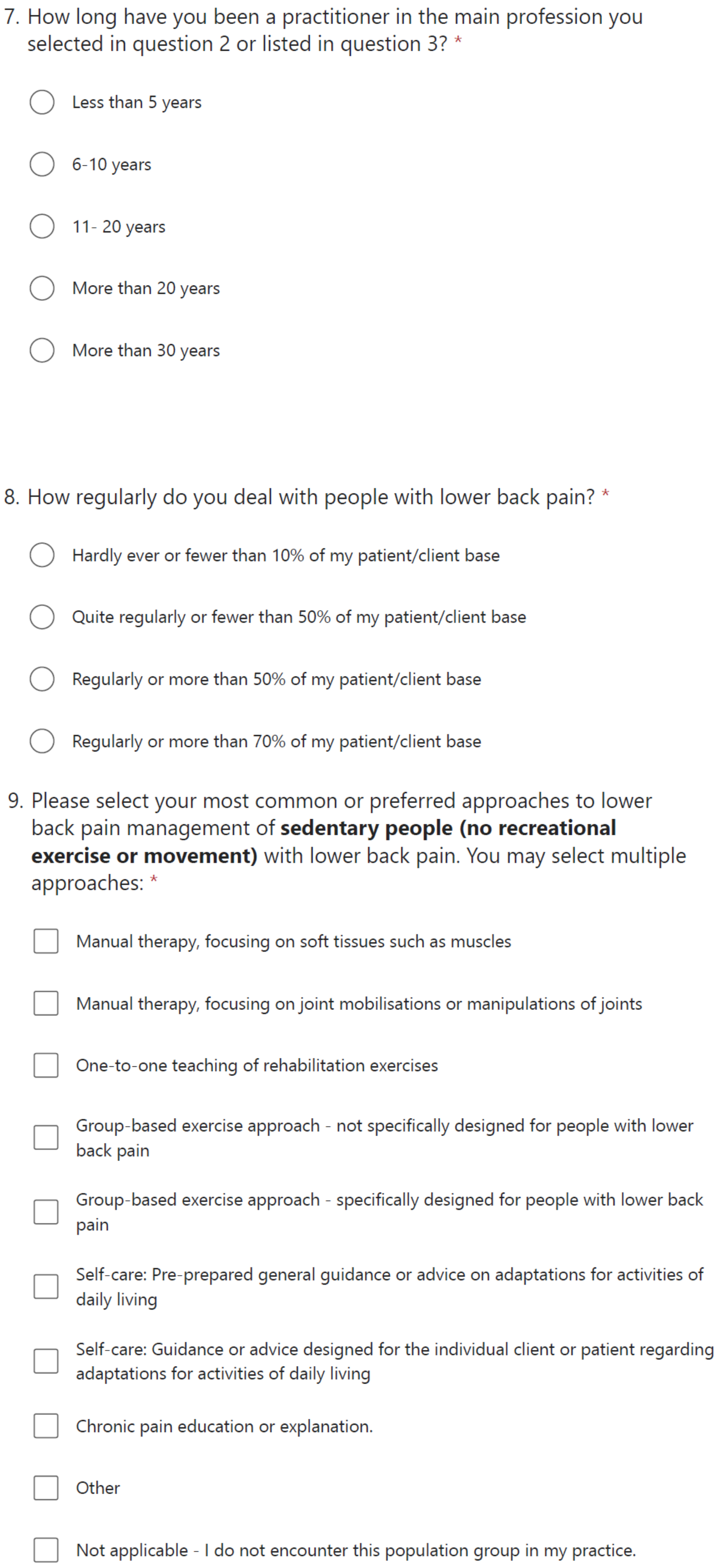


4. You may list other professions in addition to your main role, or additional qualifications here:

5. I'm a current member of the following professional organisations *

- ☐ Chartered Society of Physiotherapists (CSP)
- ☐ General Osteopathic Council (GOsC)
- ☐ Society of Sports Therapists (SST)
- ☐ British Association of Sports Rehabilitators and Athletic Trainers (BASRaT)
- ☐ Register for Exercise Professionals (REPS)
- ☐ Chartered Institute for Management of Sport and Physical Activity (CIMPSA)
- ☐ YMCA
- ☐ Other

6. If you selected 'Other' in question 5, please list the professional organisations of which you are currently a member.



7. How long have you been a practitioner in the main profession you selected in question 2 or listed in question 3? *

○ Less than 5 years

○ 6-10 years

○ 11- 20 years

○ More than 20 years

○ More than 30 years

8. How regularly do you deal with people with lower back pain? *

○ Hardly ever or fewer than 10% of my patient/client base

○ Quite regularly or fewer than 50% of my patient/client base

○ Regularly or more than 50% of my patient/client base

○ Regularly or more than 70% of my patient/client base

9. Please select your most common or preferred approaches to lower back pain management of **sedentary people (no recreational exercise or movement)** with lower back pain. You may select multiple approaches: *

☐ Manual therapy, focusing on soft tissues such as muscles

☐ Manual therapy, focusing on joint mobilisations or manipulations of joints

☐ One-to-one teaching of rehabilitation exercises

☐ Group-based exercise approach - not specifically designed for people with lower back pain

☐ Group-based exercise approach - specifically designed for people with lower back pain

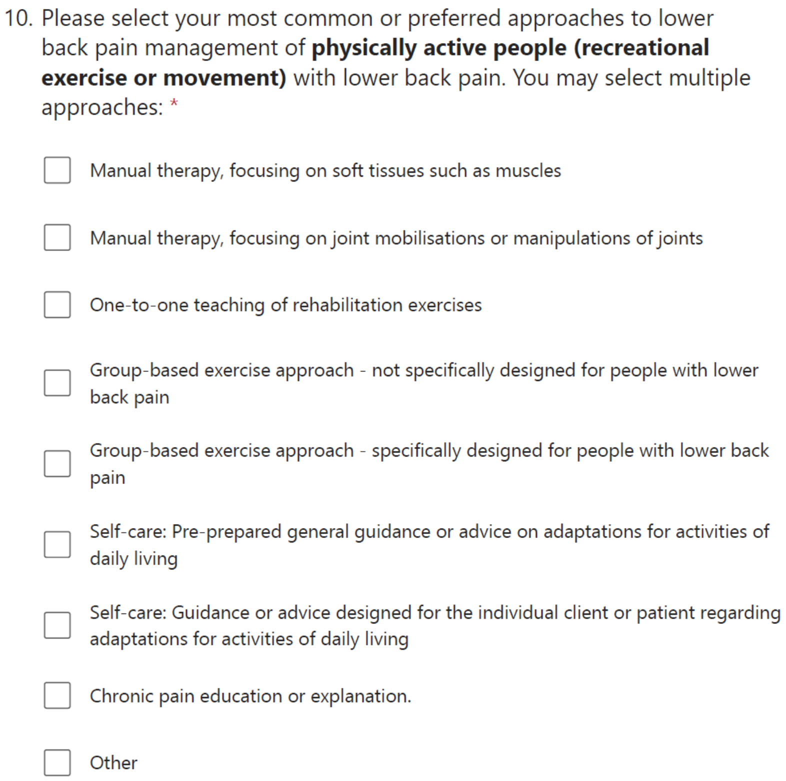
☐ Self-care: Pre-prepared general guidance or advice on adaptations for activities of daily living

☐ Self-care: Guidance or advice designed for the individual client or patient regarding adaptations for activities of daily living

☐ Chronic pain education or explanation.

☐ Other

☐ Not applicable - I do not encounter this population group in my practice.



10. Please select your most common or preferred approaches to lower back pain management of **physically active people (recreational exercise or movement)** with lower back pain. You may select multiple approaches: *

☐ Manual therapy, focusing on soft tissues such as muscles

☐ Manual therapy, focusing on joint mobilisations or manipulations of joints

☐ One-to-one teaching of rehabilitation exercises

☐ Group-based exercise approach - not specifically designed for people with lower back pain

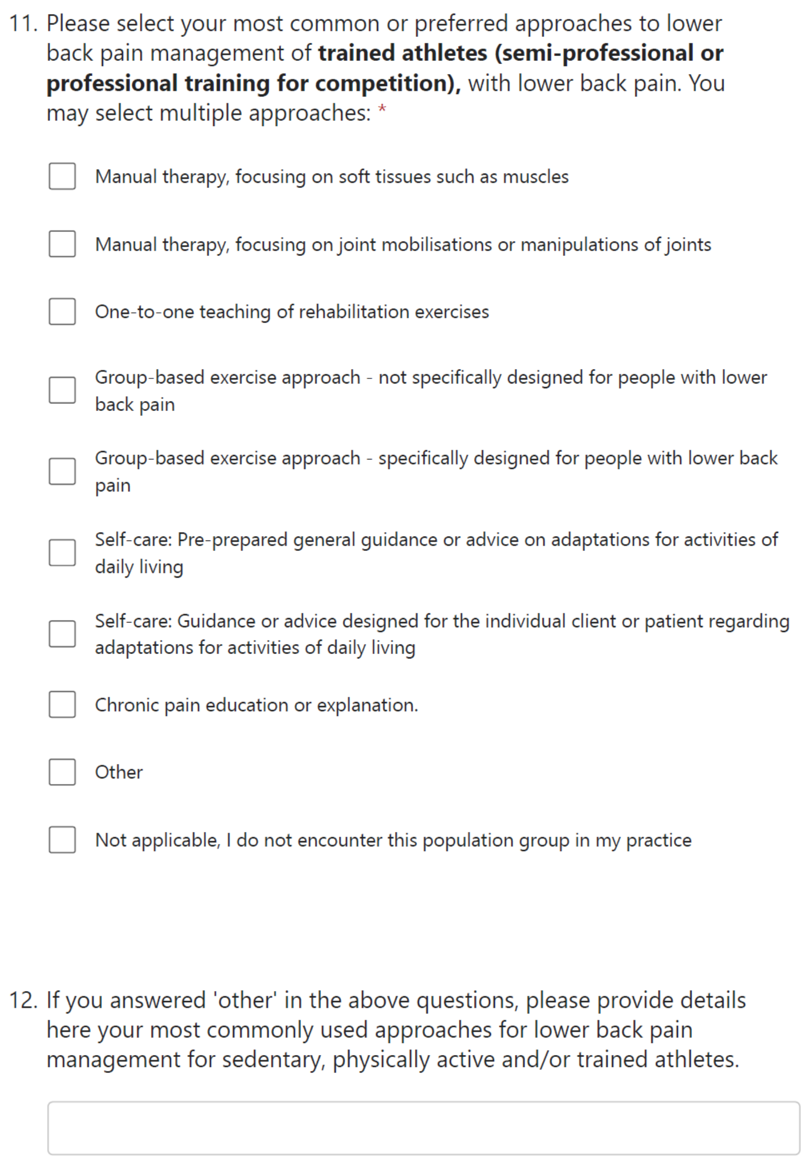
☐ Group-based exercise approach - specifically designed for people with lower back pain

☐ Self-care: Pre-prepared general guidance or advice on adaptations for activities of daily living

☐ Self-care: Guidance or advice designed for the individual client or patient regarding adaptations for activities of daily living

☐ Chronic pain education or explanation.

☐ Other



11. Please select your most common or preferred approaches to lower back pain management of **trained athletes (semi-professional or professional training for competition),** with lower back pain. You may select multiple approaches: *

☐ Manual therapy, focusing on soft tissues such as muscles

☐ Manual therapy, focusing on joint mobilisations or manipulations of joints

☐ One-to-one teaching of rehabilitation exercises

☐ Group-based exercise approach - not specifically designed for people with lower back pain

☐ Group-based exercise approach - specifically designed for people with lower back pain

☐ Self-care: Pre-prepared general guidance or advice on adaptations for activities of daily living

☐ Self-care: Guidance or advice designed for the individual client or patient regarding adaptations for activities of daily living

☐ Chronic pain education or explanation.

☐ Other

☐ Not applicable, I do not encounter this population group in my practice

12. If you answered 'other' in the above questions, please provide details here your most commonly used approaches for lower back pain management for sedentary, physically active and/or trained athletes.

13. Are you aware of connective tissue layers in the lower back called the thoracolumbar fascia? *

○ yes

○ no

○ not sure

14. Please select one option for each statement: *

	I agree	I somewhat agree	I somewhat disagree	I disagree
The thoracolumbar fascia does not have a specific function regarding the lower back, it is a passive structure.	○	○	○	○
The thoracolumbar fascia may have a functional role regarding the lower back, but I'm not sure what this could be	○	○	○	○
The thoracolumbar fascia has a specific functional role related to the lower back.	○	○	○	○

15. Please explain what you think the function of the thoracolumbar fascia is or could be:

16. Do you consider the thoracolumbar fascia to be a potential contributor or factor in lower back pain? *

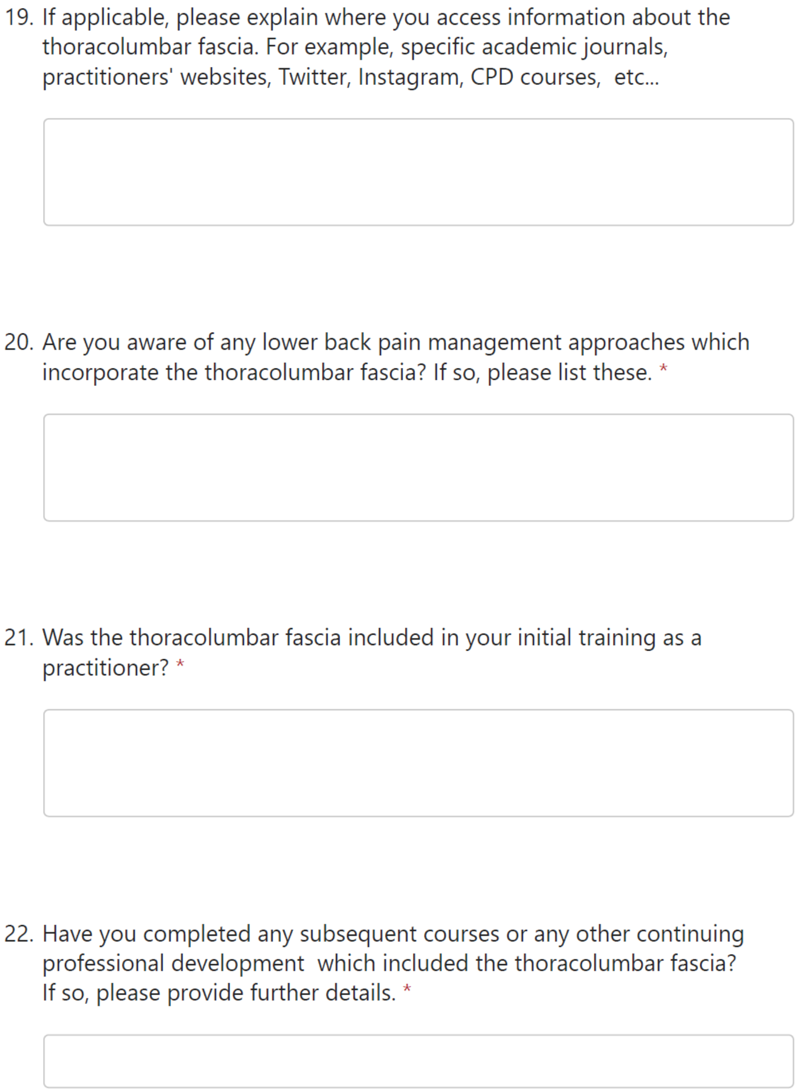
17. Are you aware of any research-based evidence related to the thoracolumbar fascia being a factor in lower back pain? *

○ No

○ Not sure

○ Yes

18. If you answered 'not sure' or 'yes' in the previous question, please provide further details of any research evidence of the potential role of thoracolumbar fascia regarding the lower back or lower back pain.

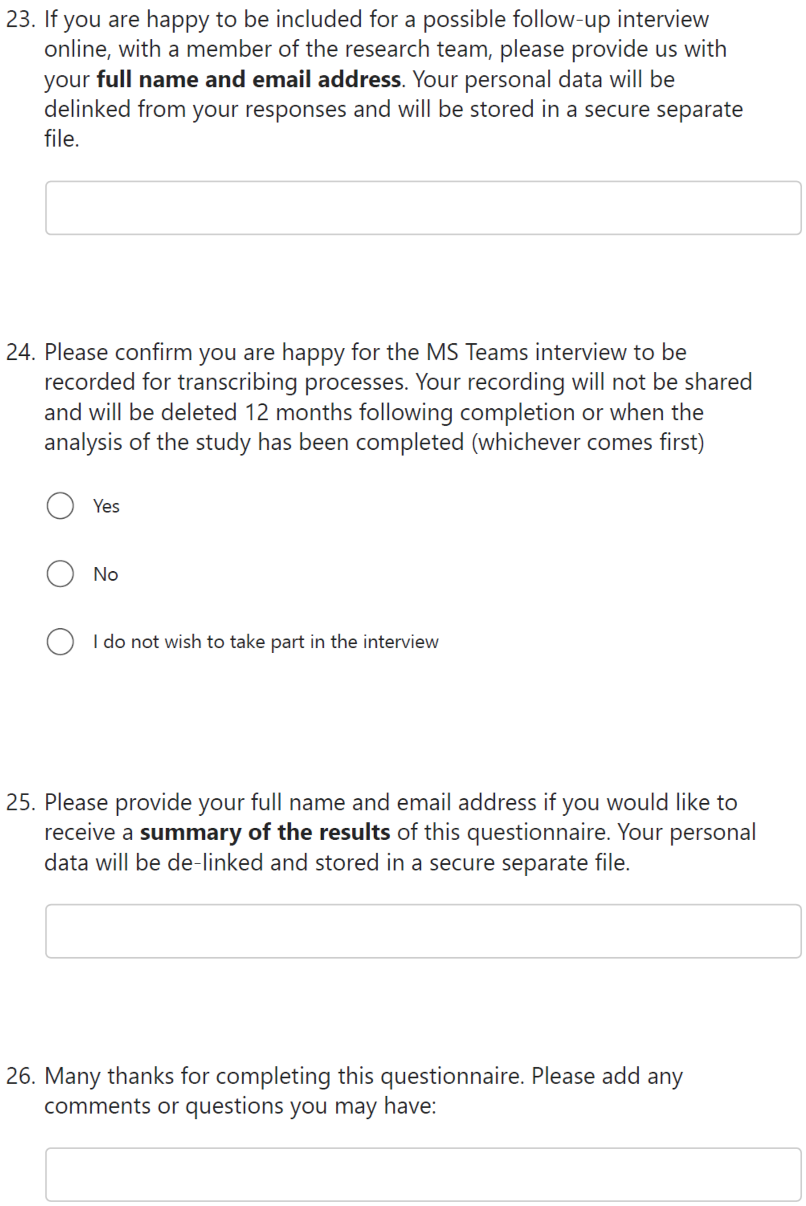


19. If applicable, please explain where you access information about the thoracolumbar fascia. For example, specific academic journals, practitioners' websites, Twitter, Instagram, CPD courses, etc...

20. Are you aware of any lower back pain management approaches which incorporate the thoracolumbar fascia? If so, please list these. *

21. Was the thoracolumbar fascia included in your initial training as a practitioner? *

22. Have you completed any subsequent courses or any other continuing professional development which included the thoracolumbar fascia? If so, please provide further details. *



23. If you are happy to be included for a possible follow-up interview online, with a member of the research team, please provide us with your **full name and email address**. Your personal data will be delinked from your responses and will be stored in a secure separate file.

24. Please confirm you are happy for the MS Teams interview to be recorded for transcribing processes. Your recording will not be shared and will be deleted 12 months following completion or when the analysis of the study has been completed (whichever comes first)

○ Yes

○ No

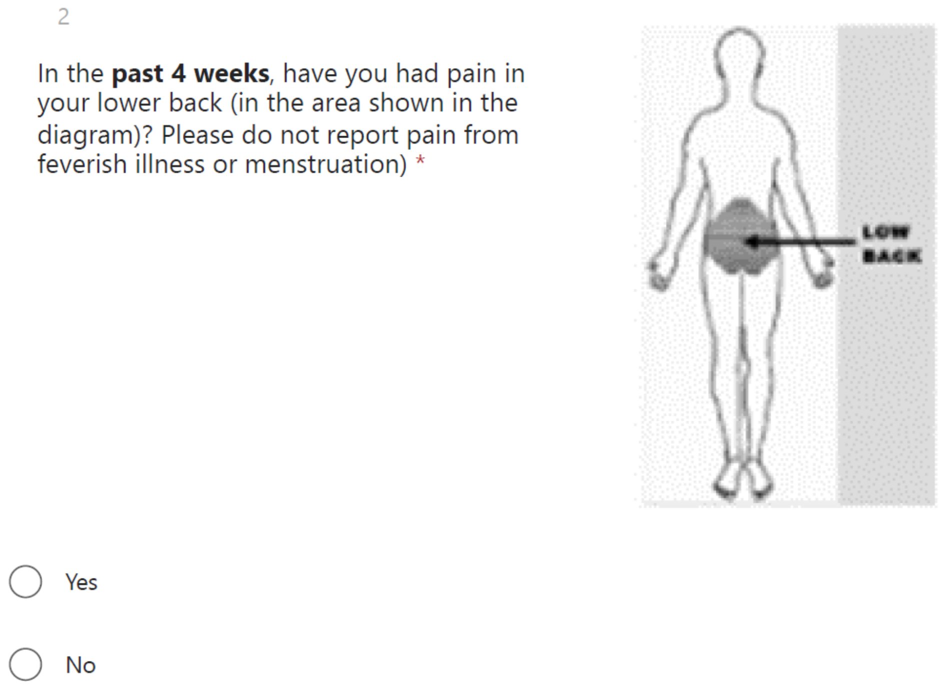
○ I do not wish to take part in the interview

25. Please provide your full name and email address if you would like to receive a **summary of the results** of this questionnaire. Your personal data will be de-linked and stored in a secure separate file.

26. Many thanks for completing this questionnaire. Please add any comments or questions you may have:

Appendix 1.2 Lower back pain questionnaires

Dionne questionnaire

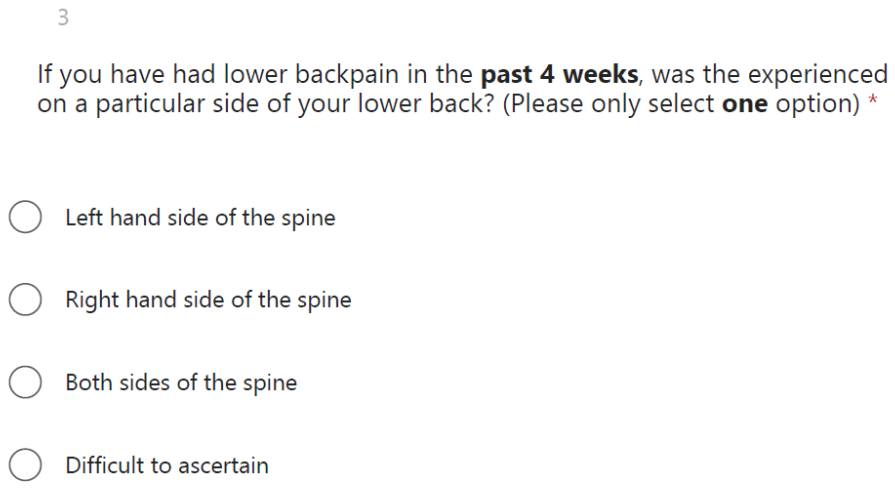


2

In the **past 4 weeks**, have you had pain in your lower back (in the area shown in the diagram)? Please do not report pain from feverish illness or menstruation) *

○ Yes

○ No



3

If you have had lower backpain in the **past 4 weeks**, was the experienced on a particular side of your lower back? (Please only select **one** option) *

○ Left hand side of the spine

○ Right hand side of the spine

○ Both sides of the spine

○ Difficult to ascertain

4

If you have had lower back pain in the **past 4 weeks**, was this pain bad enough to limit your usual activities or change your daily routine for more than one day? *

○ Yes

○ No

5

If you have had lower back pain in the **past 4 weeks**, how long has it been since you have had a whole month without any lower back pain? (Please select only **one** option) *

○ Less than 3 months

○ 3 months or more **but** less than 7 months

○ 7 months or more **but** less than 3 years

○ 3 years or more

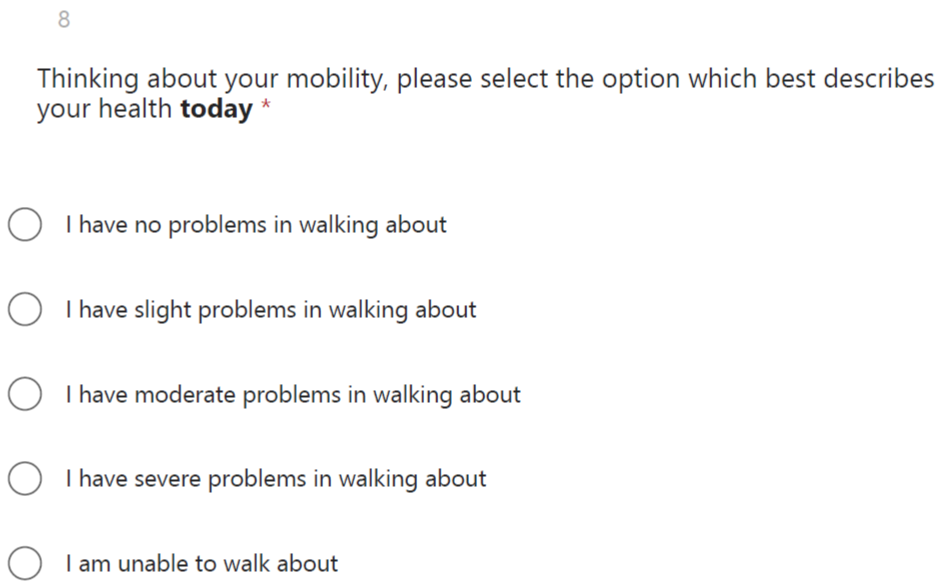
6

If you had lower back pain in the **past 4 weeks**, please indicate the usual intensity of your pain on a scale of "no pain at all" to “the worst pain imaginable”? (Please **select** your answer). *

	No pain at all	A little pain	Some pain	A lot of pain	Worst pain
Lower back pain intensity	○	○	○	○	○

Appendix 1.3 Quality of life questionnaires

Euroqol quality of life test



8

Thinking about your mobility, please select the option which best describes your health **today** *

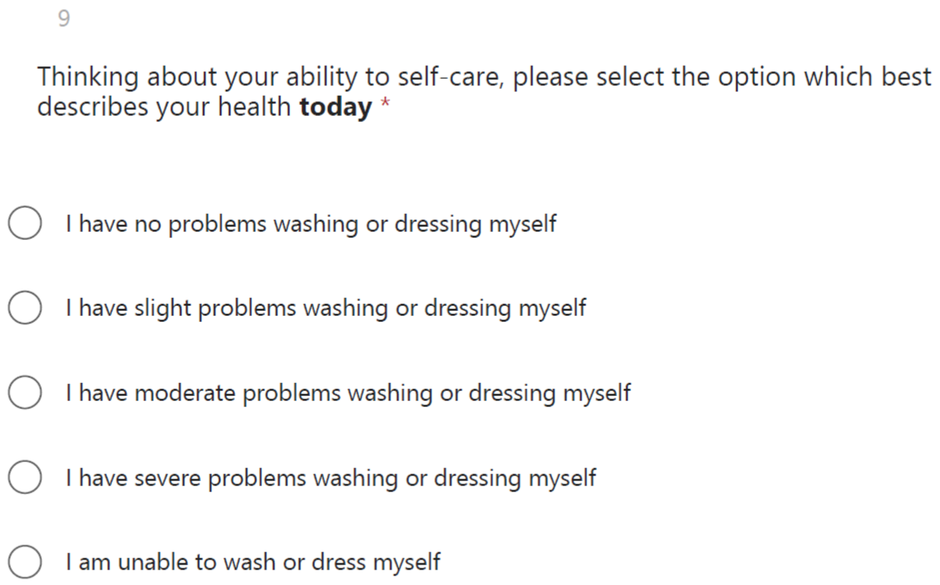
○ I have no problems in walking about

○ I have slight problems in walking about

○ I have moderate problems in walking about

○ I have severe problems in walking about

○ I am unable to walk about



9

Thinking about your ability to self-care, please select the option which best describes your health **today** *

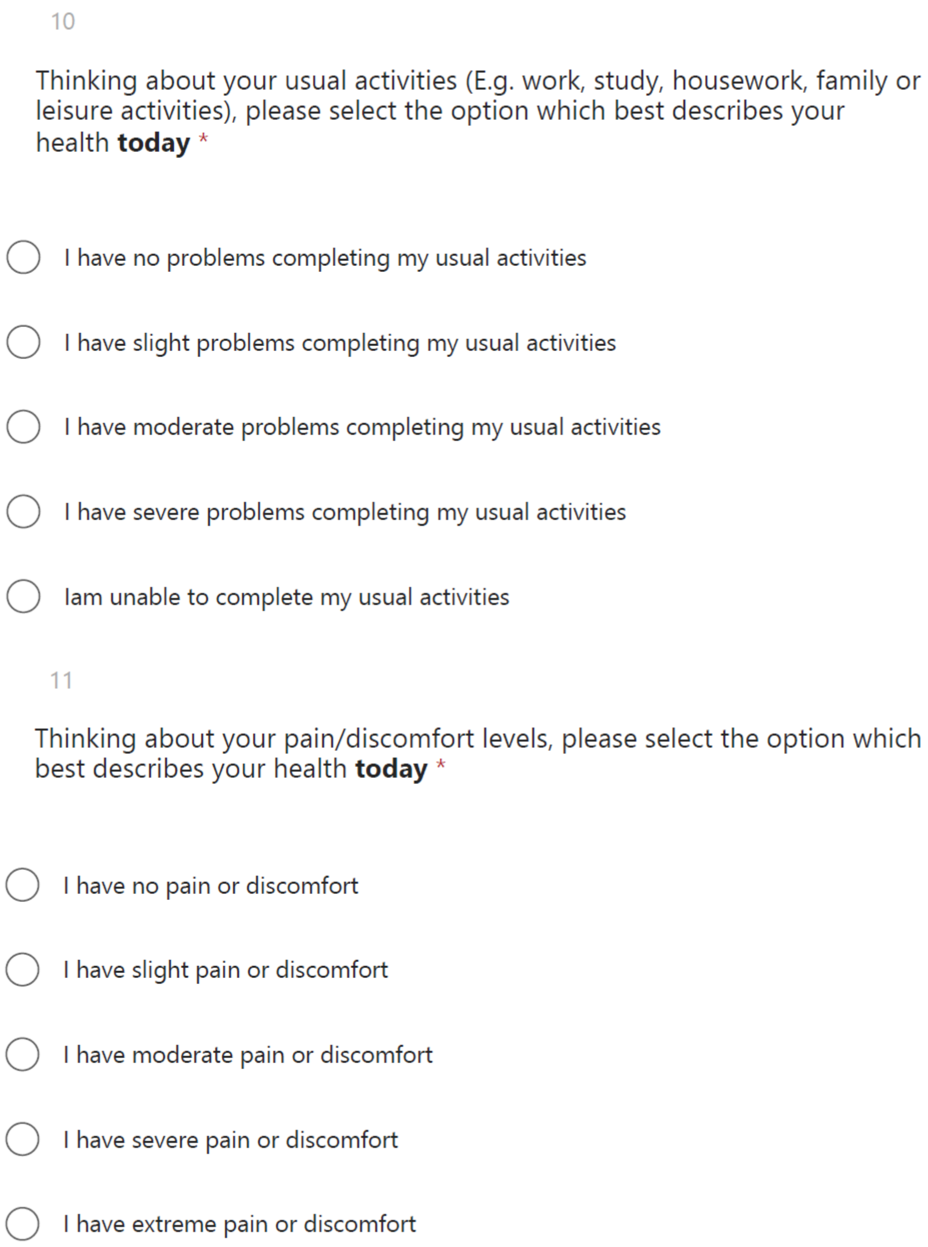
○ I have no problems washing or dressing myself

○ I have slight problems washing or dressing myself

○ I have moderate problems washing or dressing myself

○ I have severe problems washing or dressing myself

○ I am unable to wash or dress myself



10

Thinking about your usual activities (E.g. work, study, housework, family or leisure activities), please select the option which best describes your health **today** *

○ I have no problems completing my usual activities

○ I have slight problems completing my usual activities

○ I have moderate problems completing my usual activities

○ I have severe problems completing my usual activities

○ Iam unable to complete my usual activities

11

Thinking about your pain/discomfort levels, please select the option which best describes your health **today** *

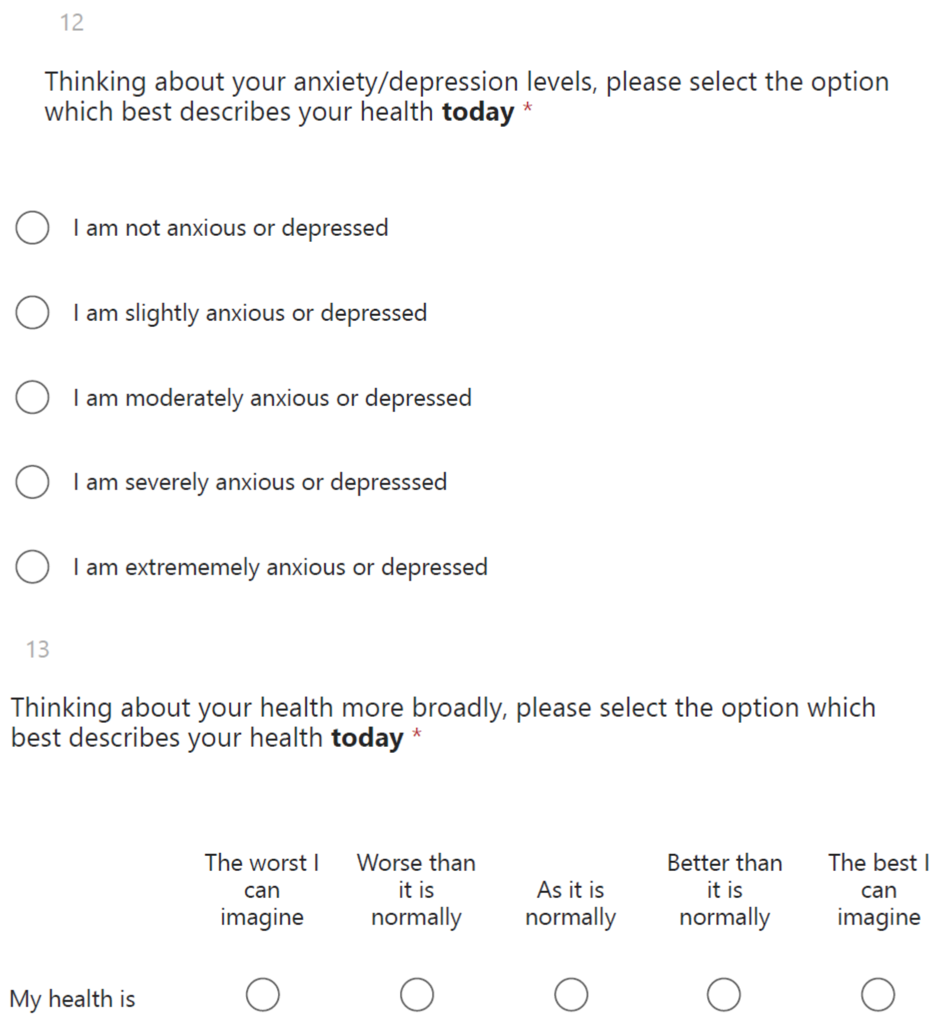
○ I have no pain or discomfort

○ I have slight pain or discomfort

○ I have moderate pain or discomfort

○ I have severe pain or discomfort

○ I have extreme pain or discomfort



12

Thinking about your anxiety/depression levels, please select the option which best describes your health **today** *

○ I am not anxious or depressed

○ I am slightly anxious or depressed

○ I am moderately anxious or depressed

○ I am severely anxious or depresssed

○ I am extrememely anxious or depressed

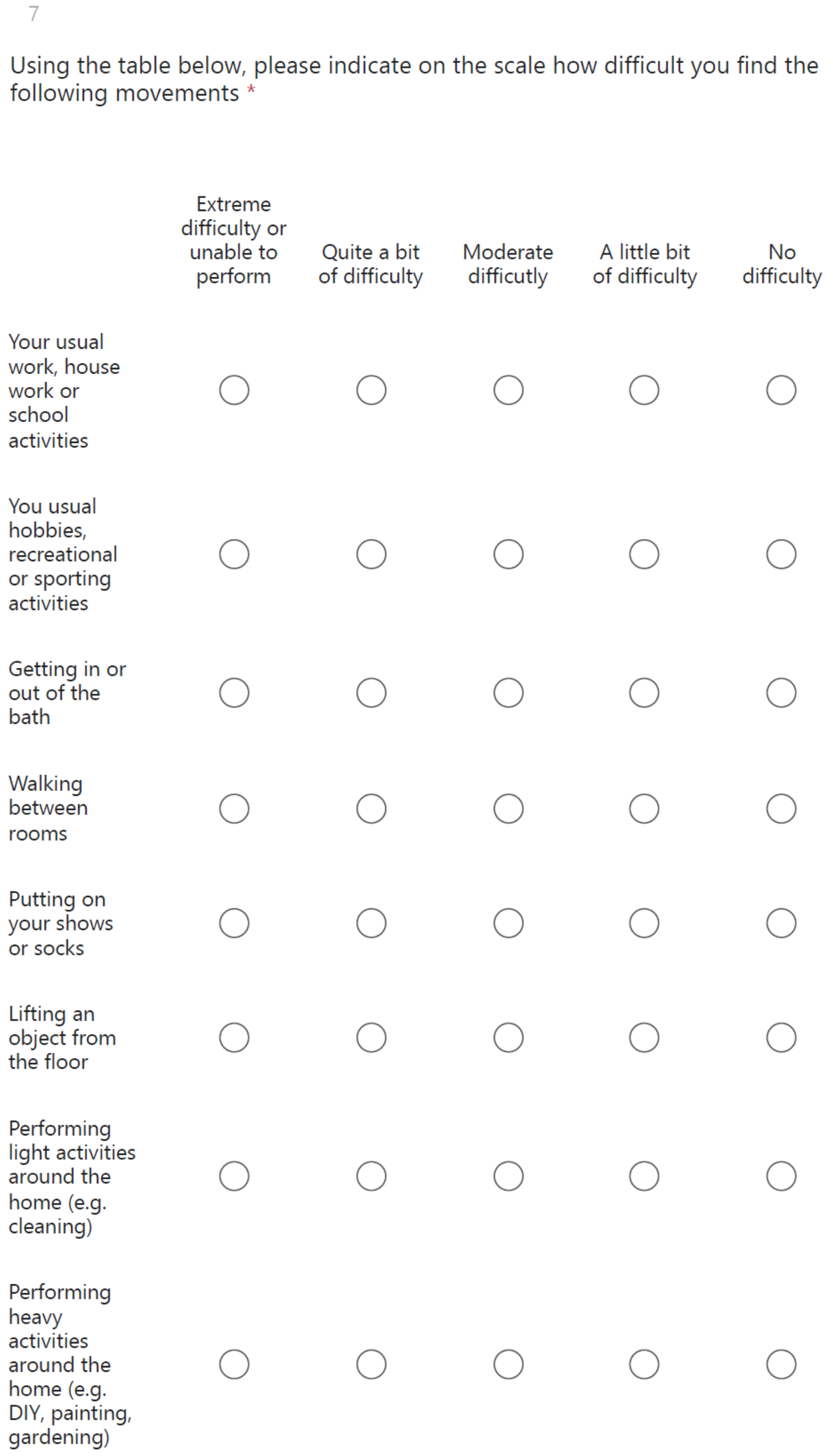
13

Thinking about your health more broadly, please select the option which best describes your health **today** *

	The worst I can imagine	Worse than it is normally	As it is normally	Better than it is normally	The best I can imagine
My health is	○	○	○	○	○

Appendix 1.4 Disability questionnaires

Patient Specific Functional scale



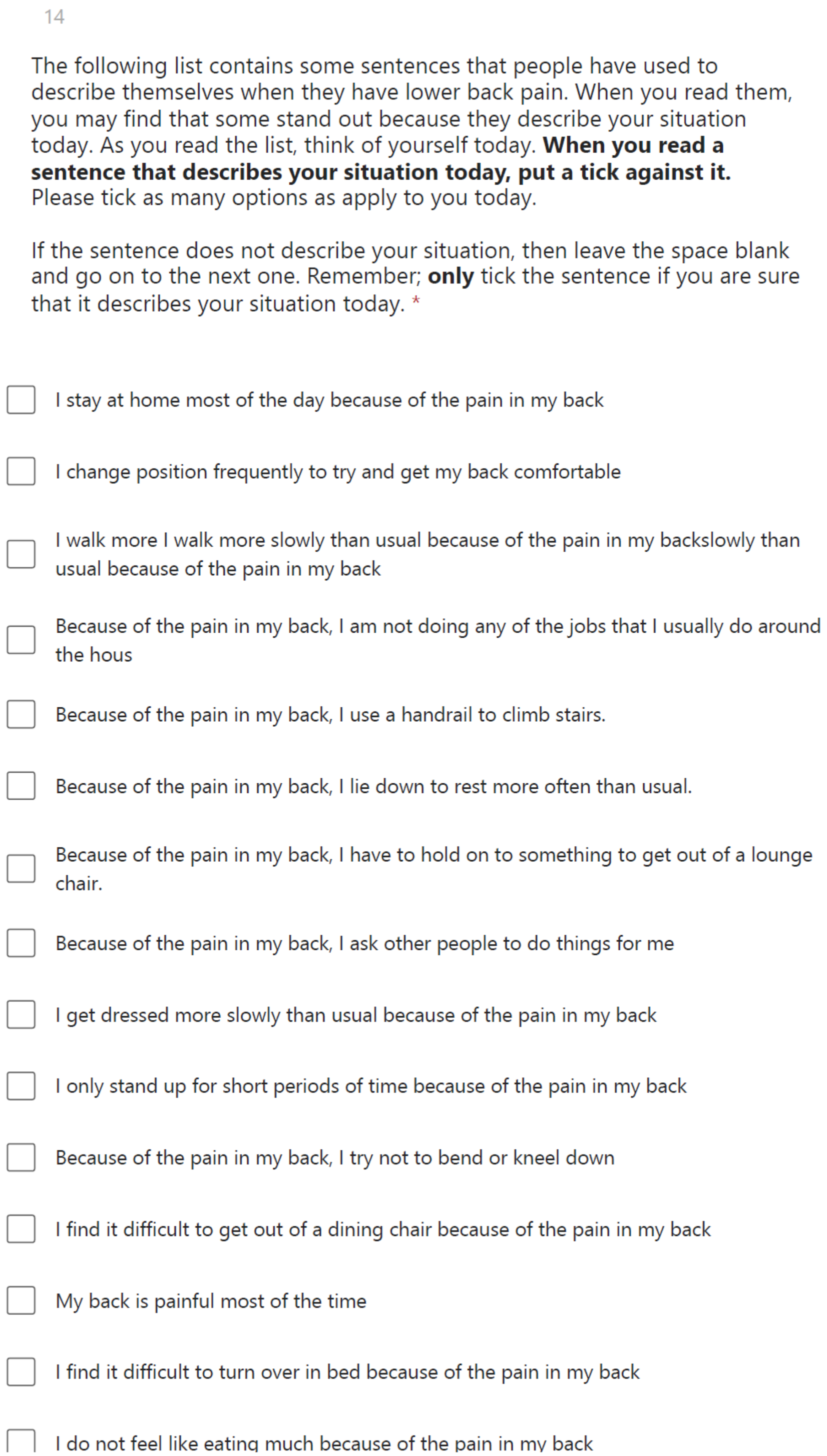
7

Using the table below, please indicate on the scale how difficult you find the following movements *

	Extreme difficulty or unable to perform	Quite a bit of difficulty	Moderate difficutly	A little bit of difficulty	No difficulty
Your usual work, house work or school activities	○	○	○	○	○
You usual hobbies, recreational or sporting activities	○	○	○	○	○
Getting in or out of the bath	○	○	○	○	○
Walking between rooms	○	○	○	○	○
Putting on your shows or socks	○	○	○	○	○
Lifting an object from the floor	○	○	○	○	○
Performing light activities around the home (e.g. cleaning)	○	○	○	○	○
Performing heavy activities around the home (e.g. DIY, painting, gardening)	○	○	○	○	○

and out of a car	○	○	○	○	○
Walking 2 blocks	○	○	○	○	○
Walking 1 mile	○	○	○	○	○
Going up or down 10 stairs (about 1 flight of stairs)	○	○	○	○	○
Standing for less than 1 hour	○	○	○	○	○
Standing for more than hour	○	○	○	○	○
Sitting for less than 1 hour	○	○	○	○	○
Sitting for more than 1 hour	○	○	○	○	○
Running on even ground	○	○	○	○	○
Running on uneven ground	○	○	○	○	○
Taking part in aerobics	○	○	○	○	○
Taking part in core strengthening exercises (e.g. pilates, yoga)	○	○	○	○	○

Roland-Moris Disability questionnaire



14

The following list contains some sentences that people have used to describe themselves when they have lower back pain. When you read them, you may find that some stand out because they describe your situation today. As you read the list, think of yourself today. **When you read a sentence that describes your situation today, put a tick against it.** Please tick as many options as apply to you today.

If the sentence does not describe your situation, then leave the space blank and go on to the next one. Remember; **only** tick the sentence if you are sure that it describes your situation today. *

☐ I stay at home most of the day because of the pain in my back

☐ I change position frequently to try and get my back comfortable

☐ I walk more I walk more slowly than usual because of the pain in my backslowly than usual because of the pain in my back

☐ Because of the pain in my back, I am not doing any of the jobs that I usually do around the hous

☐ Because of the pain in my back, I use a handrail to climb stairs.

☐ Because of the pain in my back, I lie down to rest more often than usual.

☐ Because of the pain in my back, I have to hold on to something to get out of a lounge chair.

☐ Because of the pain in my back, I ask other people to do things for me

☐ I get dressed more slowly than usual because of the pain in my back

☐ I only stand up for short periods of time because of the pain in my back

☐ Because of the pain in my back, I try not to bend or kneel down

☐ I find it difficult to get out of a dining chair because of the pain in my back

☐ My back is painful most of the time

☐ I find it difficult to turn over in bed because of the pain in my back

☐ I do not feel like eating much because of the pain in my back

☐ I have trouble putting on my socks (or stockings) because of the pain in my back.

☐ I only walk short distances because of the pain in my back

☐ Because of the pain in my back, I get dressed with help from someone else

☐ I sleep less than usual because of the pain in my back

☐ I sit down for most of the day because of the pain in my back

☐ I avoid heavy jobs in the house because of the pain in my back

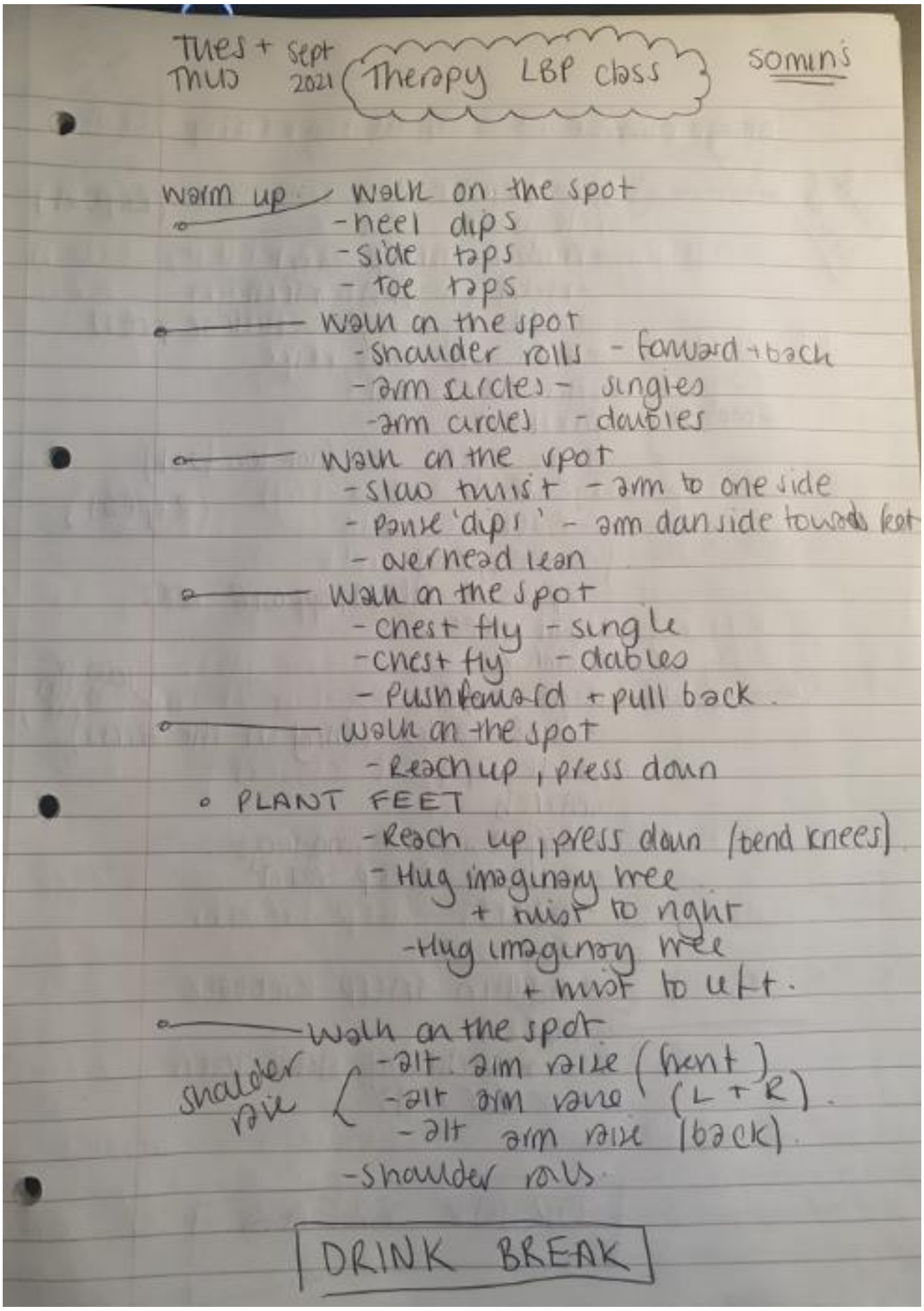
☐ Because of the pain in my back, I am more irritable and bad tempered with people than usual

☐ Because of the pain in my back, I climb stairs more slowly than usua

☐ I stay in bed most of the time because of the pain in my back

☐ None of the above

<u>Appendix 1.5 Example of lower back pain class</u>



Tues + Thur
Sept 2021
Therapy LBP class
Somin's

warm up
walk on the spot
- heel dips
- side taps
- toe taps

walk on the spot
- shoulder rolls - forward + back
- arm circles - singles
- arm circles - doubles

walk on the spot
- slow twist - arm to one side
- pause 'dips' - arm down side towards feet
- overhead lean

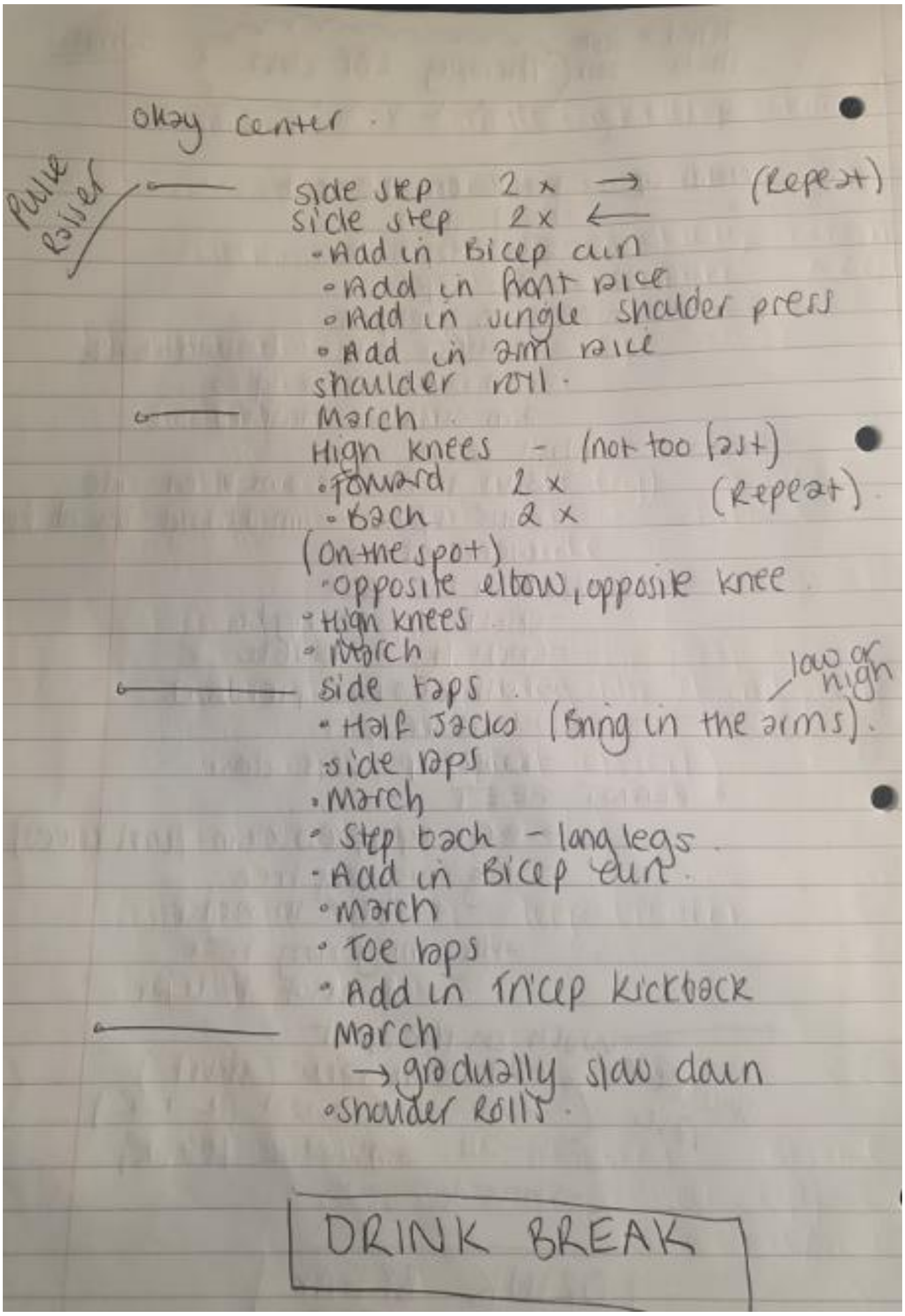
walk on the spot
- chest fly - single
- chest fly - doubles
- push forward + pull back.

walk on the spot
- Reach up, press down

- PLANT FEET
  - Reach up, press down (bend knees)
  - Hug imaginary tree + twist to right
  - Hug imaginary tree + twist to left.

walk on the spot
shoulder raise
- alt arm raise (bent)
- alt arm raise (L + R).
- alt arm raise (back).
- shoulder rolls.

DRINK BREAK



okay center.

Pulse Raiser

side step 2x → (Repeat)
side step 2x ←
- Add in Bicep curl
- Add in front raise
- Add in single shoulder press
- Add in arm raise

shoulder roll.

March
High knees - (not too fast)
- forward 2x (Repeat).
- back 2x

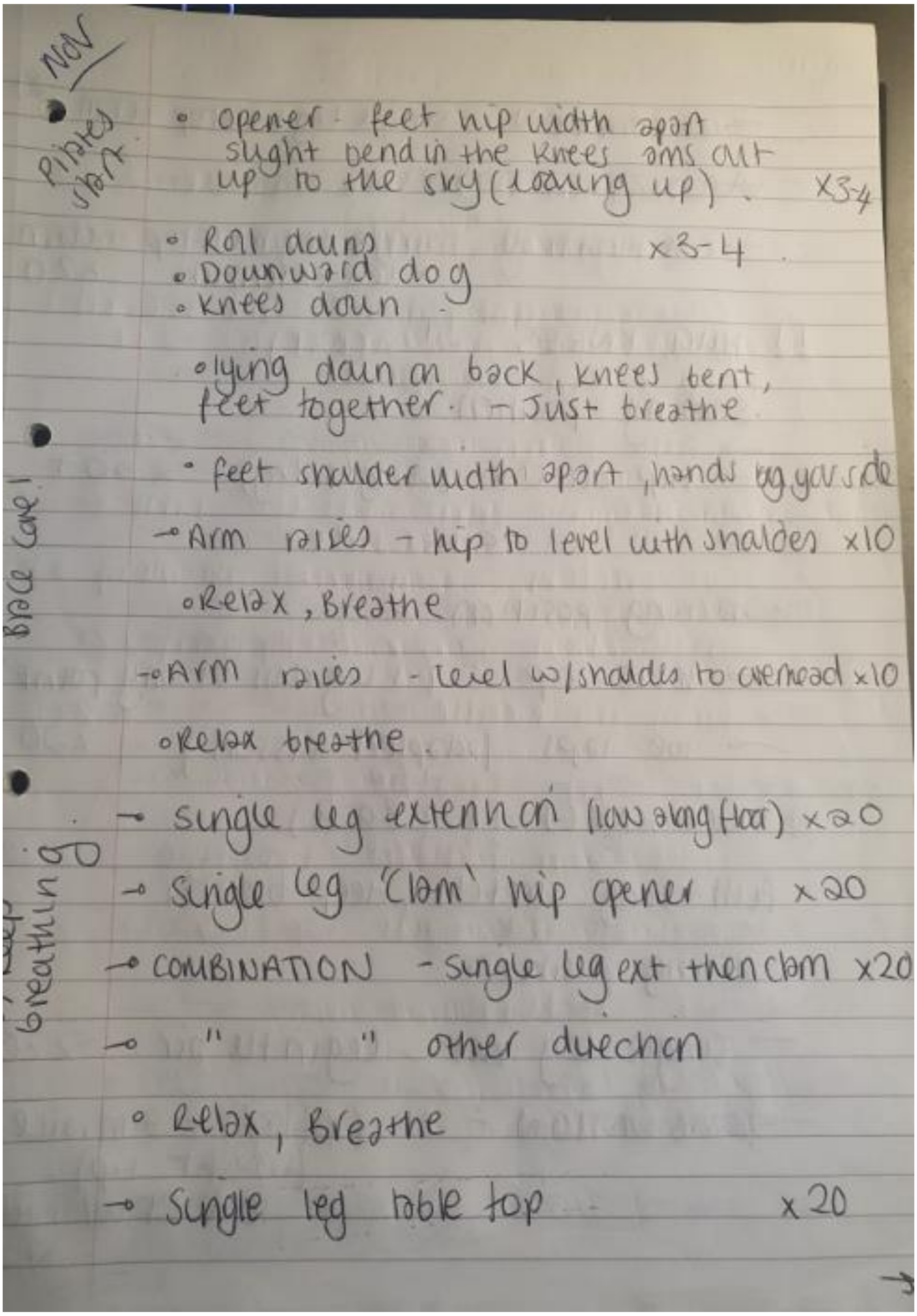
(on the spot)
- opposite elbow, opposite knee.
- High knees
- March

side taps. low or high
- Half Jacks (bring in the arms).

side taps
- March
- Step back - long legs.
- Add in Bicep curl.
- march
- Toe taps
- Add in Tricep kickback

March
→ gradually slow down
- shoulder Rolls.

DRINK BREAK



Nov

Pilates start

- opener - feet hip width apart slight bend in the knees arms out up to the sky (looking up) . x3-4
- Roll downs x3-4 .
- Downward dog
- knees down .

- lying down on back, knees bent, feet together. - Just breathe

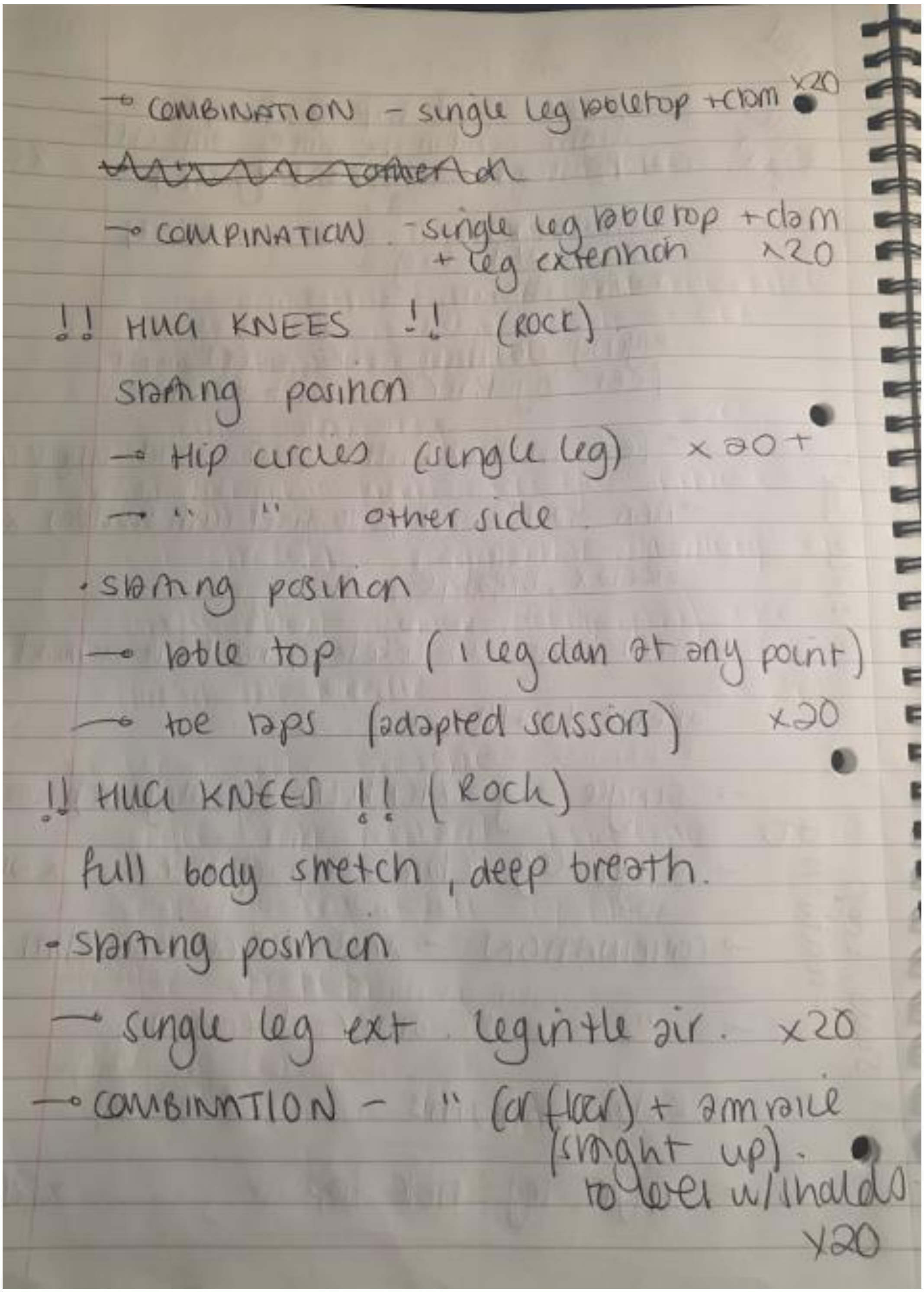
Brace Core!

- feet shoulder width apart, hands by your side
- → Arm raises - hip to level with shoulders x10
- Relax, Breathe
- → Arm raises - level w/shoulders to overhead x10
- Relax breathe .

breathing

- → single leg extension (low along floor) x20
- → Single leg 'Clam' hip opener x20
- → COMBINATION - single leg ext then clam x20
- → " " other direction
- Relax, Breathe
- → Single leg table top x20

→



→ COMBINATION - single leg tabletop + clam x20

[illegible]

→ COMBINATION - single leg tabletop + clam
+ leg extension x20

!! HUG KNEES !! (ROCK)

starting position

→ Hip circles (single leg) x20 +

→ " " other side.

• starting position

→ table top (1 leg down at any point)

→ toe taps (adapted scissors) x20

!! HUG KNEES !! (Rock)

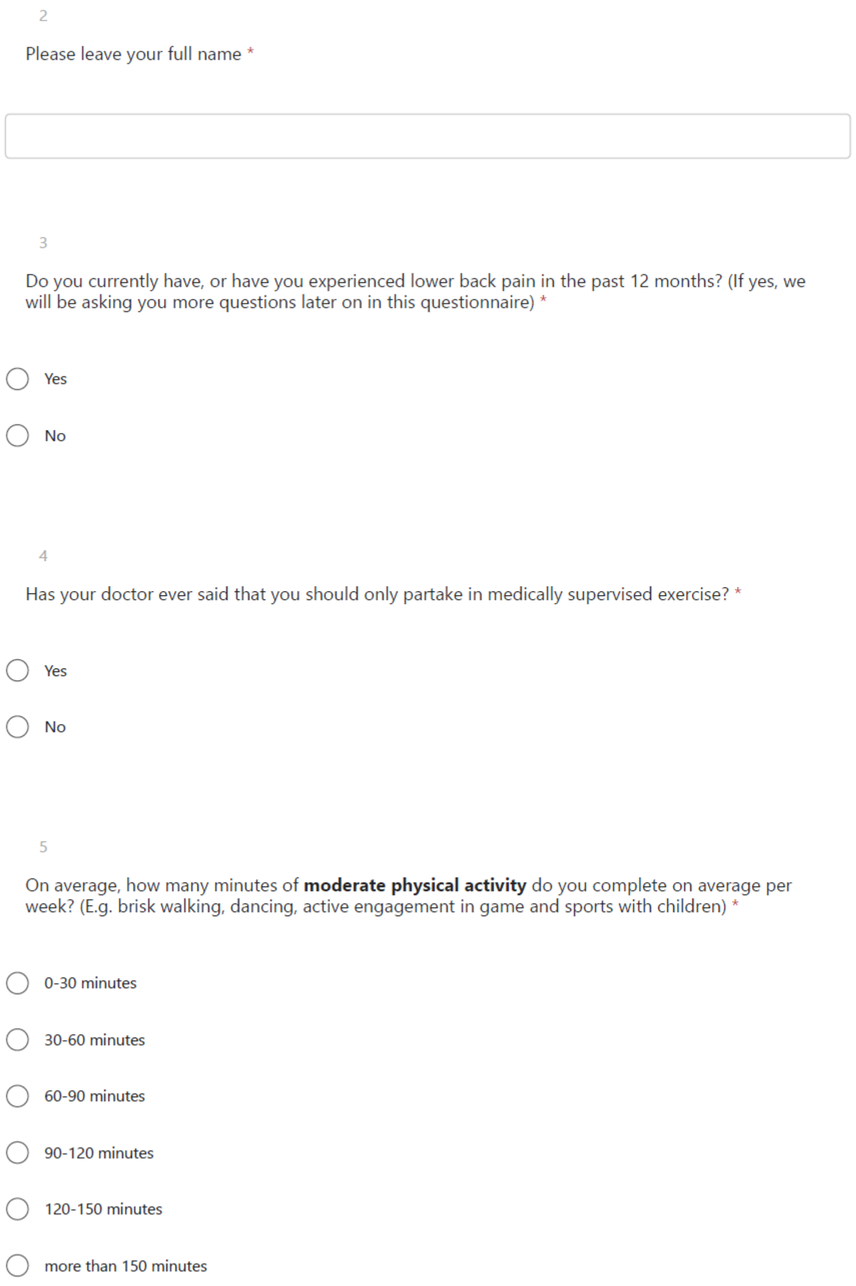
full body stretch, deep breath.

• starting position

→ single leg ext. leg in the air. x20

→ COMBINATION - " (on floor) + arm raise
(straight up).
to lower w/inhale
x20

Appendix 1.6 PAR-Q Form



2

Please leave your full name *

3

Do you currently have, or have you experienced lower back pain in the past 12 months? (If yes, we will be asking you more questions later on in this questionnaire) *

○ Yes

○ No

4

Has your doctor ever said that you should only partake in medically supervised exercise? *

○ Yes

○ No

5

On average, how many minutes of **moderate physical activity** do you complete on average per week? (E.g. brisk walking, dancing, active engagement in game and sports with children) *

○ 0-30 minutes

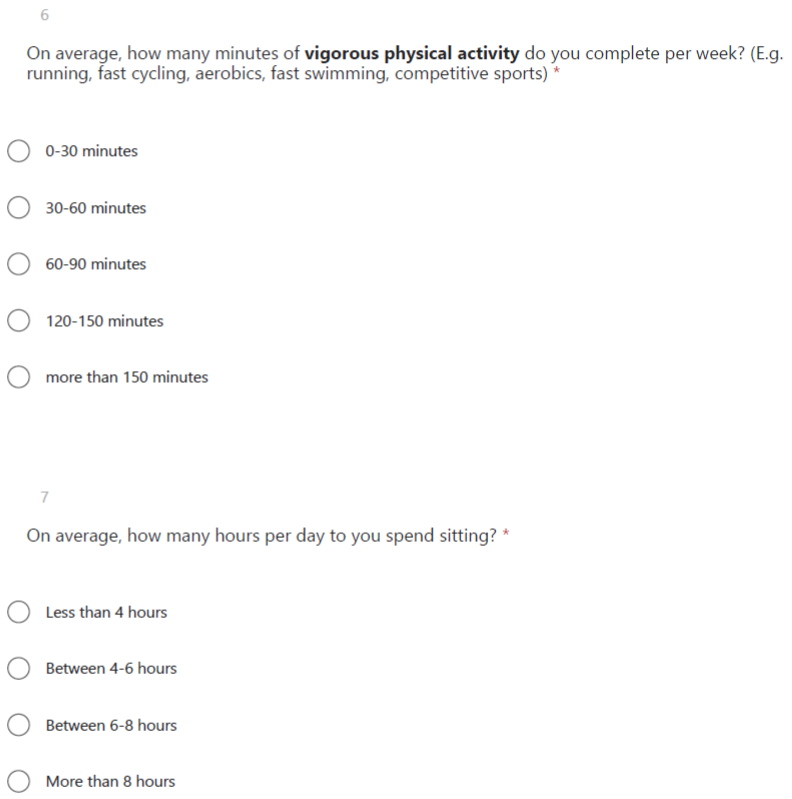
○ 30-60 minutes

○ 60-90 minutes

○ 90-120 minutes

○ 120-150 minutes

○ more than 150 minutes



6

On average, how many minutes of **vigorous physical activity** do you complete per week? (E.g. running, fast cycling, aerobics, fast swimming, competitive sports) *

○ 0-30 minutes

○ 30-60 minutes

○ 60-90 minutes

○ 120-150 minutes

○ more than 150 minutes

7

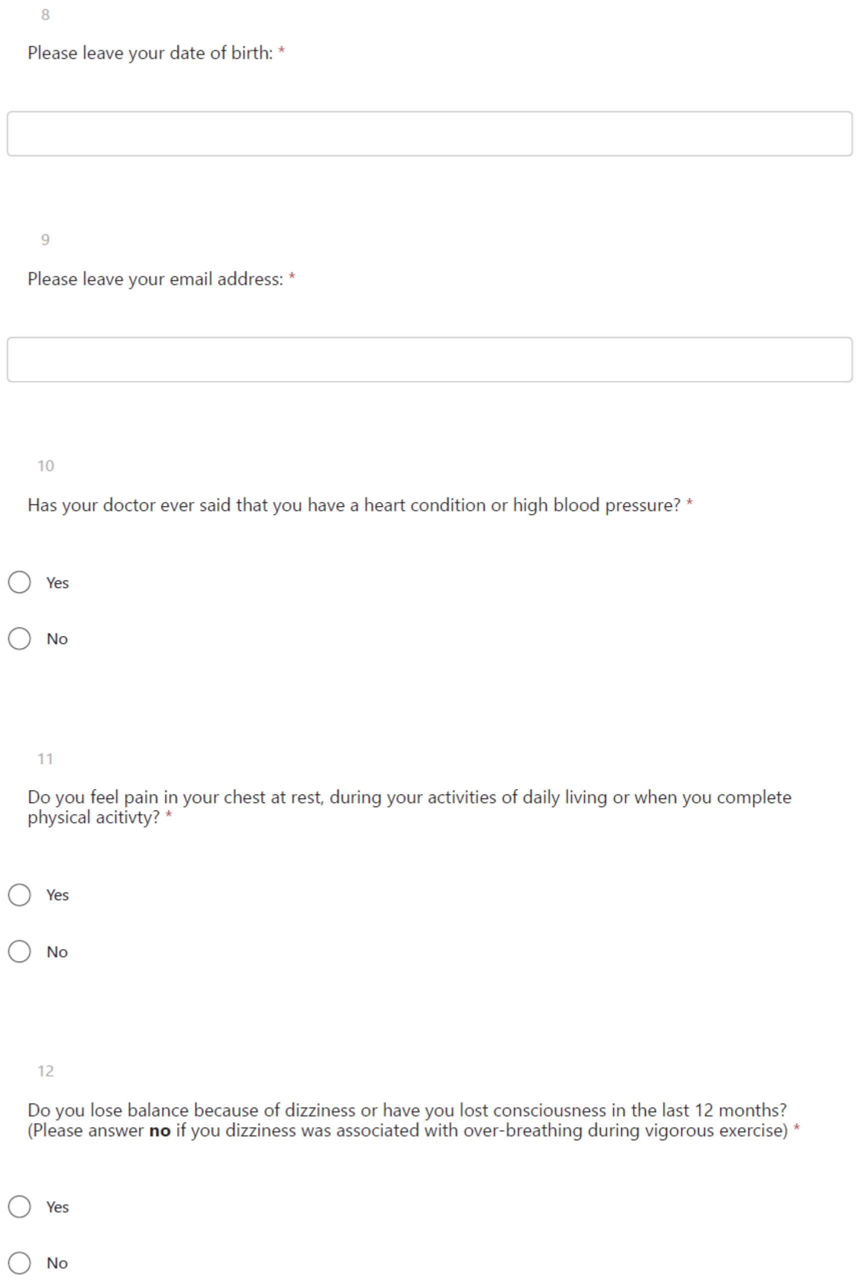
On average, how many hours per day to you spend sitting? *

○ Less than 4 hours

○ Between 4-6 hours

○ Between 6-8 hours

○ More than 8 hours



8

Please leave your date of birth: *

9

Please leave your email address: *

10

Has your doctor ever said that you have a heart condition or high blood pressure? *

○ Yes

○ No

11

Do you feel pain in your chest at rest, during your activities of daily living or when you complete physical acitivty? *

○ Yes

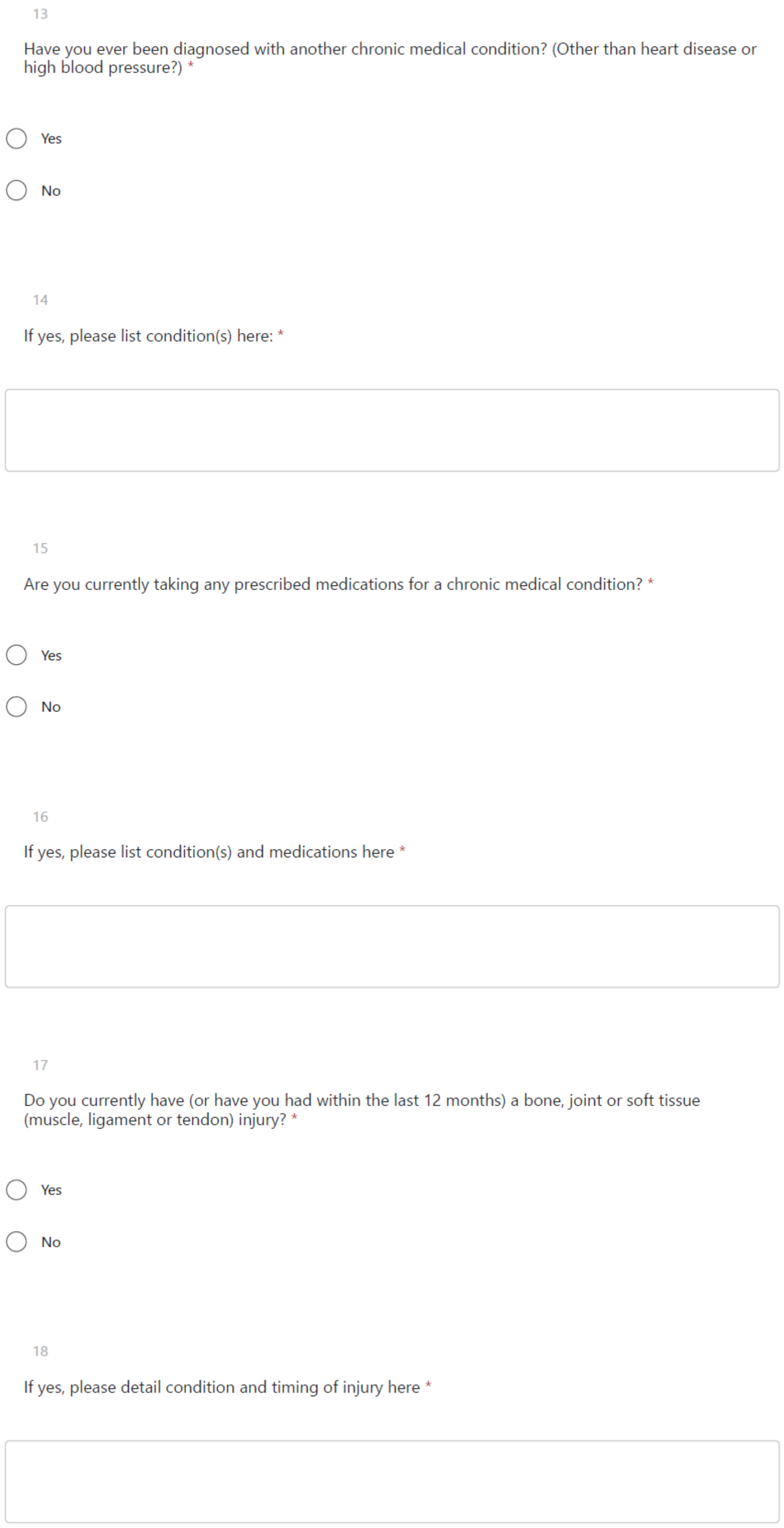
○ No

12

Do you lose balance because of dizziness or have you lost consciousness in the last 12 months? (Please answer **no** if you dizziness was associated with over-breathing during vigorous exercise) *

○ Yes

○ No



13

Have you ever been diagnosed with another chronic medical condition? (Other than heart disease or high blood pressure?) *

○ Yes

○ No

14

If yes, please list condition(s) here: *

15

Are you currently taking any prescribed medications for a chronic medical condition? *

○ Yes

○ No

16

If yes, please list condition(s) and medications here *

17

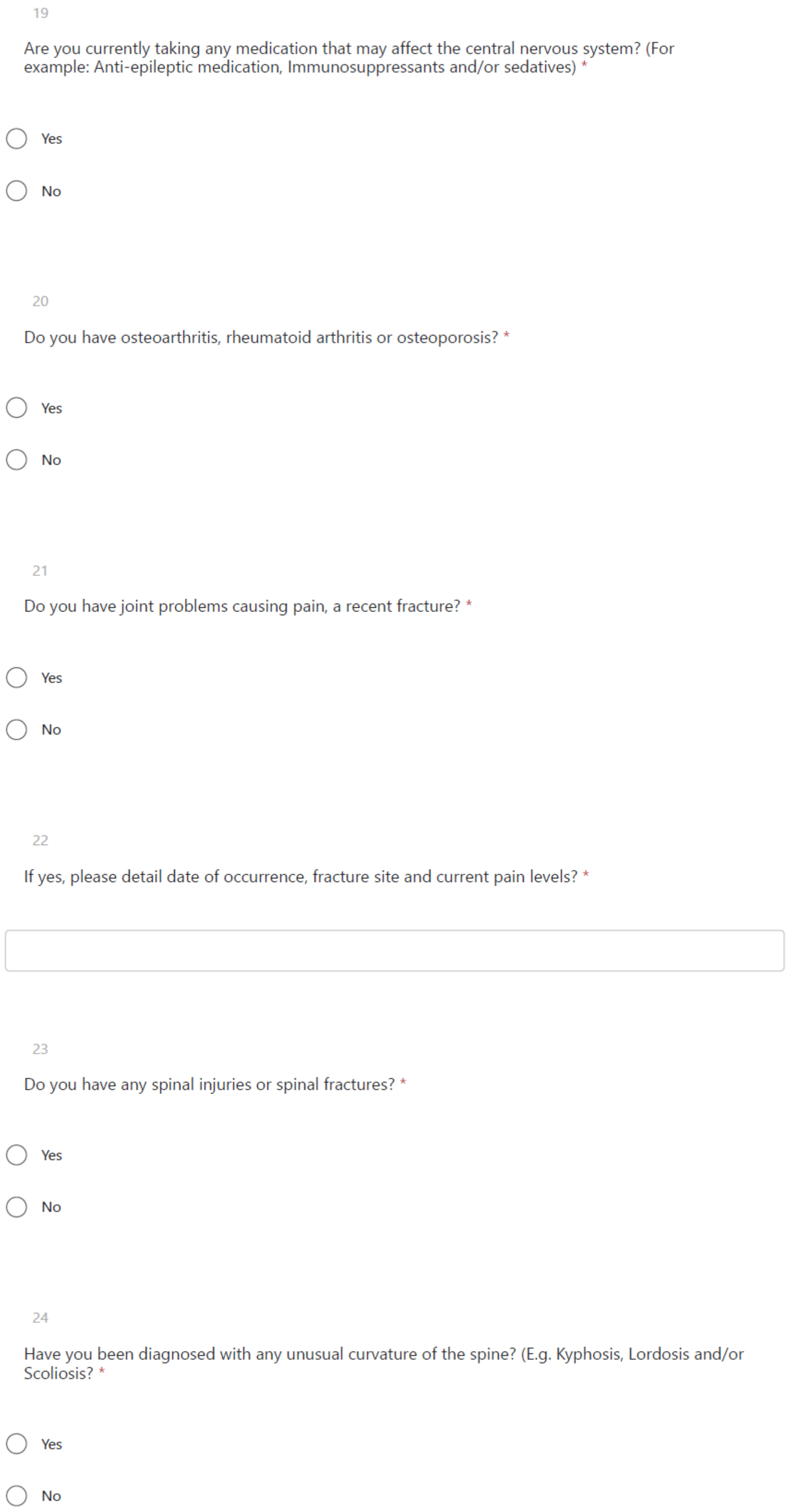
Do you currently have (or have you had within the last 12 months) a bone, joint or soft tissue (muscle, ligament or tendon) injury? *

○ Yes

○ No

18

If yes, please detail condition and timing of injury here *



19

Are you currently taking any medication that may affect the central nervous system? (For example: Anti-epileptic medication, Immunosuppressants and/or sedatives) *

○ Yes

○ No

20

Do you have osteoarthritis, rheumatoid arthritis or osteoporosis? *

○ Yes

○ No

21

Do you have joint problems causing pain, a recent fracture? *

○ Yes

○ No

22

If yes, please detail date of occurrence, fracture site and current pain levels? *

23

Do you have any spinal injuries or spinal fractures? *

○ Yes

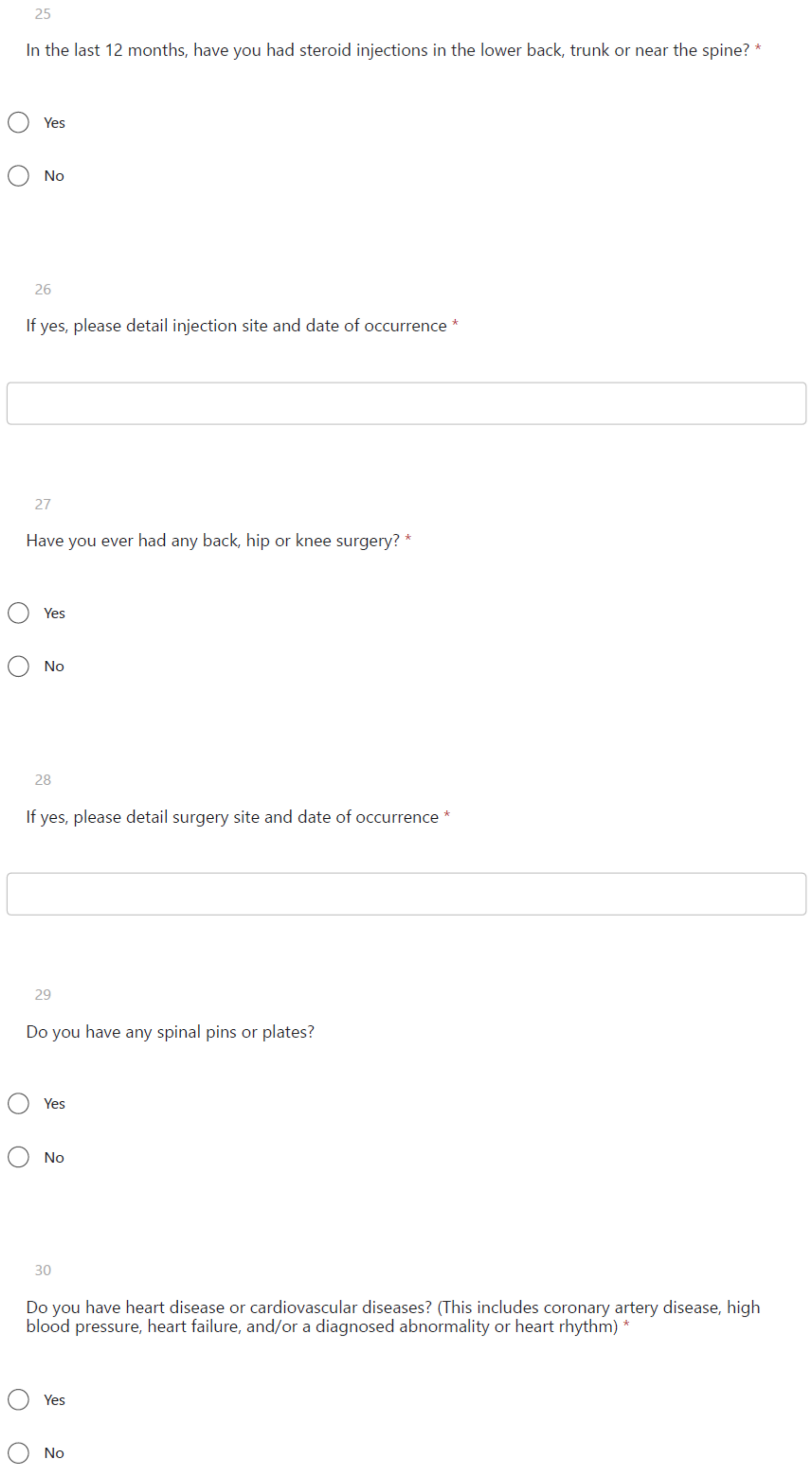
○ No

24

Have you been diagnosed with any unusual curvature of the spine? (E.g. Kyphosis, Lordosis and/or Scoliosis? *

○ Yes

○ No



25

In the last 12 months, have you had steroid injections in the lower back, trunk or near the spine? *

○ Yes

○ No

26

If yes, please detail injection site and date of occurrence *

27

Have you ever had any back, hip or knee surgery? *

○ Yes

○ No

28

If yes, please detail surgery site and date of occurrence *

29

Do you have any spinal pins or plates?

○ Yes

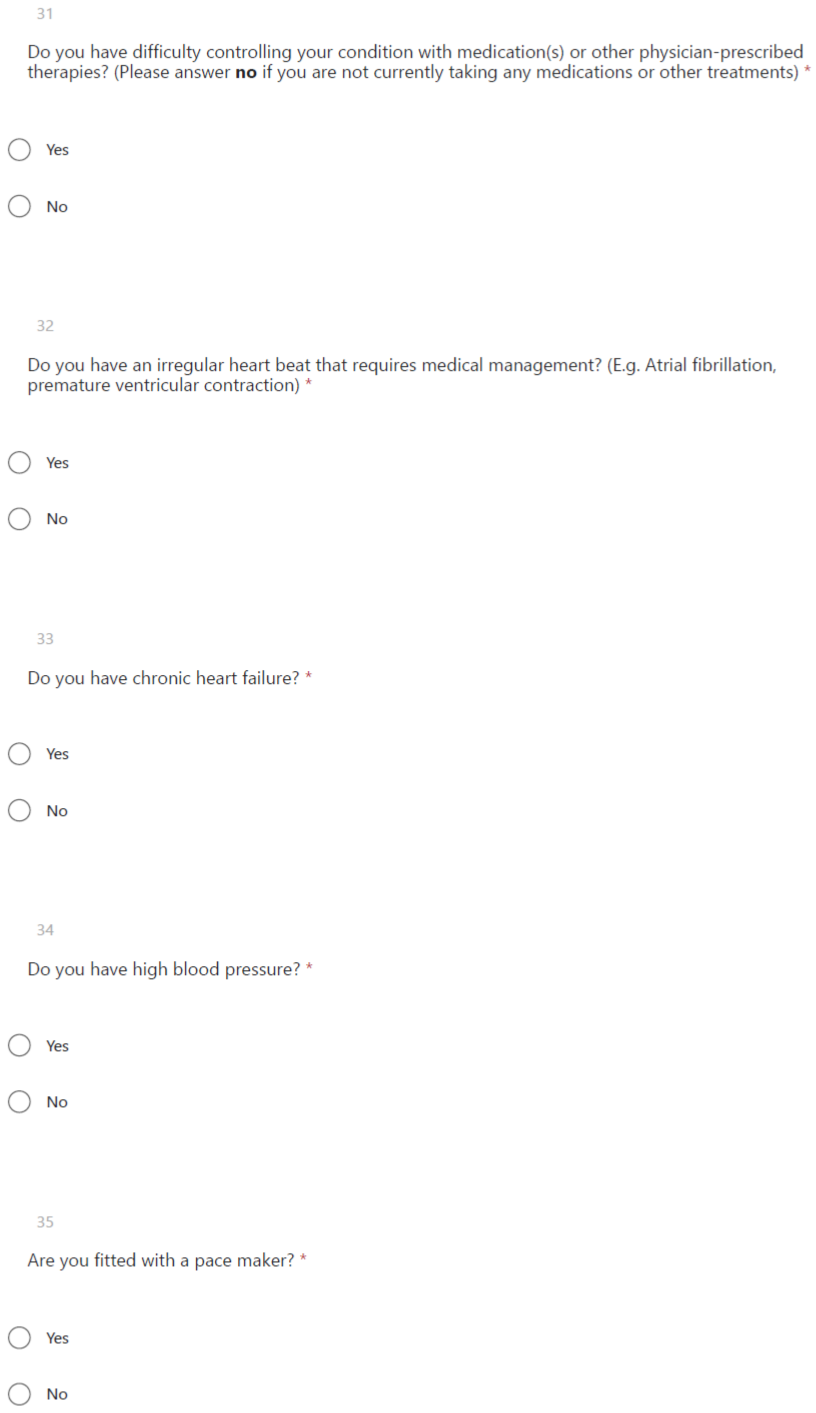
○ No

30

Do you have heart disease or cardiovascular diseases? (This includes coronary artery disease, high blood pressure, heart failure, and/or a diagnosed abnormality or heart rhythm) *

○ Yes

○ No



31

Do you have difficulty controlling your condition with medication(s) or other physician-prescribed therapies? (Please answer **no** if you are not currently taking any medications or other treatments) *

○ Yes

○ No

32

Do you have an irregular heart beat that requires medical management? (E.g. Atrial fibrillation, premature ventricular contraction) *

○ Yes

○ No

33

Do you have chronic heart failure? *

○ Yes

○ No

34

Do you have high blood pressure? *

○ Yes

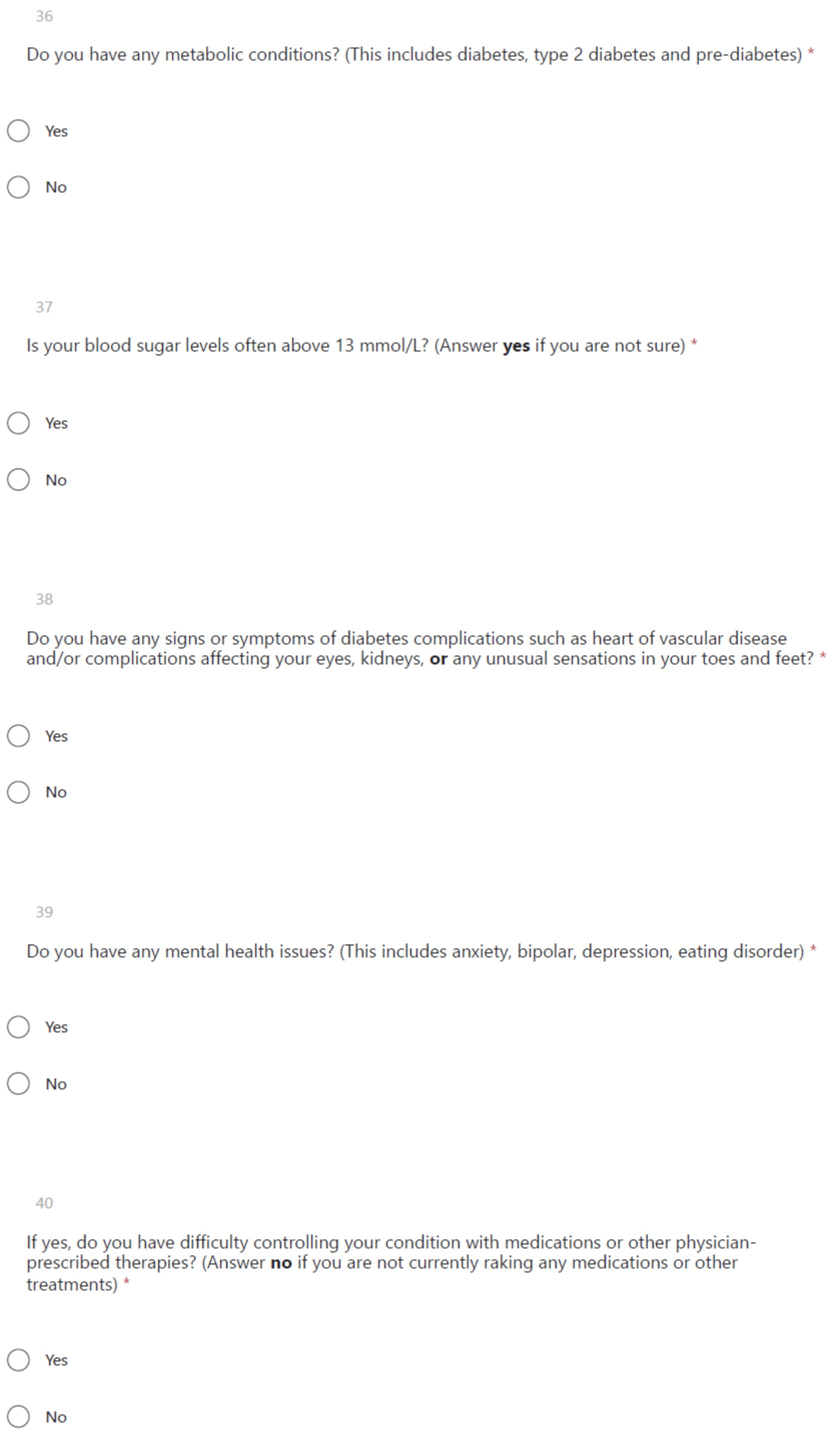
○ No

35

Are you fitted with a pace maker? *

○ Yes

○ No



36

Do you have any metabolic conditions? (This includes diabetes, type 2 diabetes and pre-diabetes) *

○ Yes

○ No

37

Is your blood sugar levels often above 13 mmol/L? (Answer **yes** if you are not sure) *

○ Yes

○ No

38

Do you have any signs or symptoms of diabetes complications such as heart of vascular disease and/or complications affecting your eyes, kidneys, **or** any unusual sensations in your toes and feet? *

○ Yes

○ No

39

Do you have any mental health issues? (This includes anxiety, bipolar, depression, eating disorder) *

○ Yes

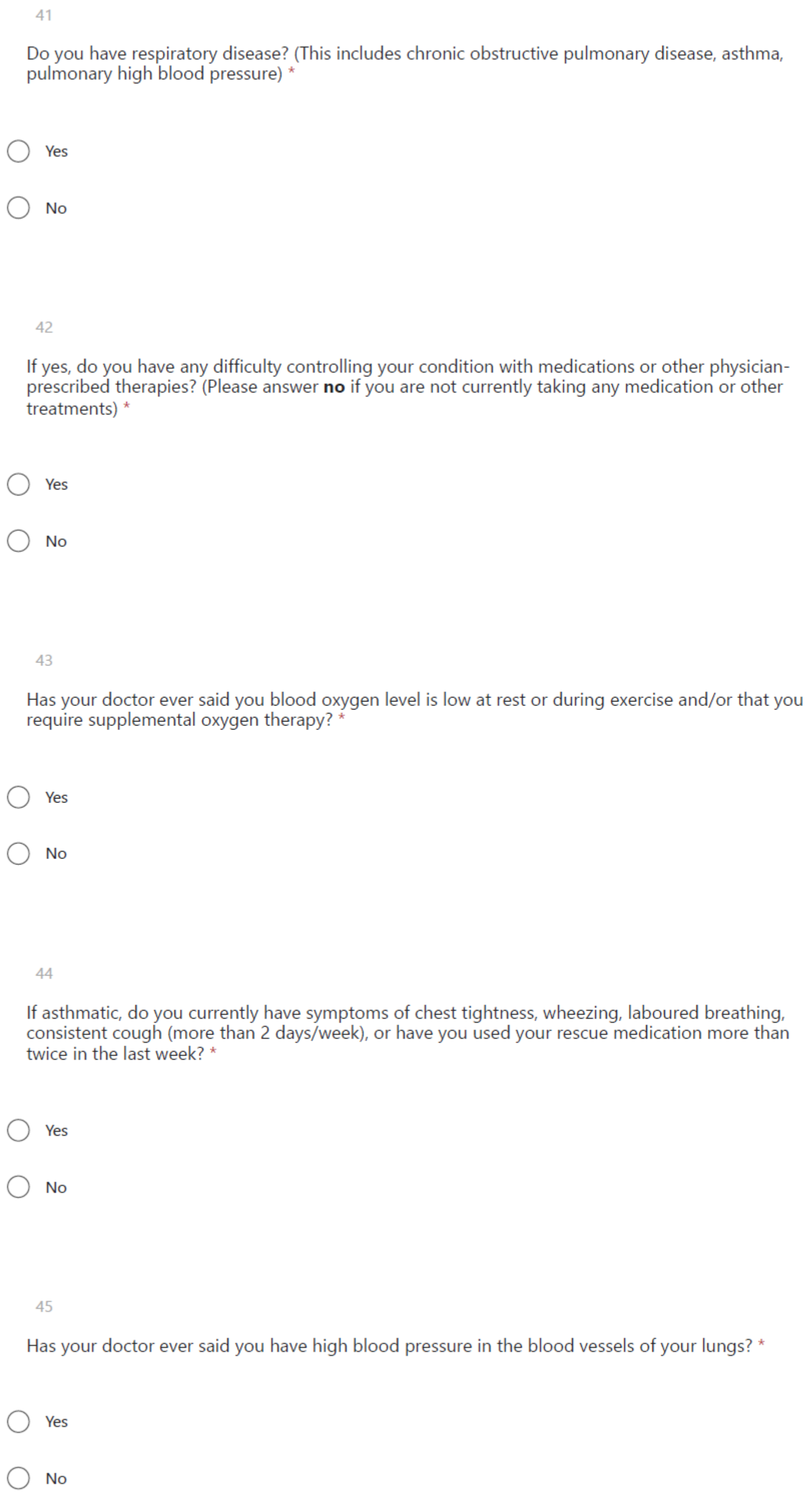
○ No

40

If yes, do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **no** if you are not currently raking any medications or other treatments) *

○ Yes

○ No



41

Do you have respiratory disease? (This includes chronic obstructive pulmonary disease, asthma, pulmonary high blood pressure) *

○ Yes

○ No

42

If yes, do you have any difficulty controlling your condition with medications or other physician-prescribed therapies? (Please answer **no** if you are not currently taking any medication or other treatments) *

○ Yes

○ No

43

Has your doctor ever said you blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy? *

○ Yes

○ No

44

If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week? *

○ Yes

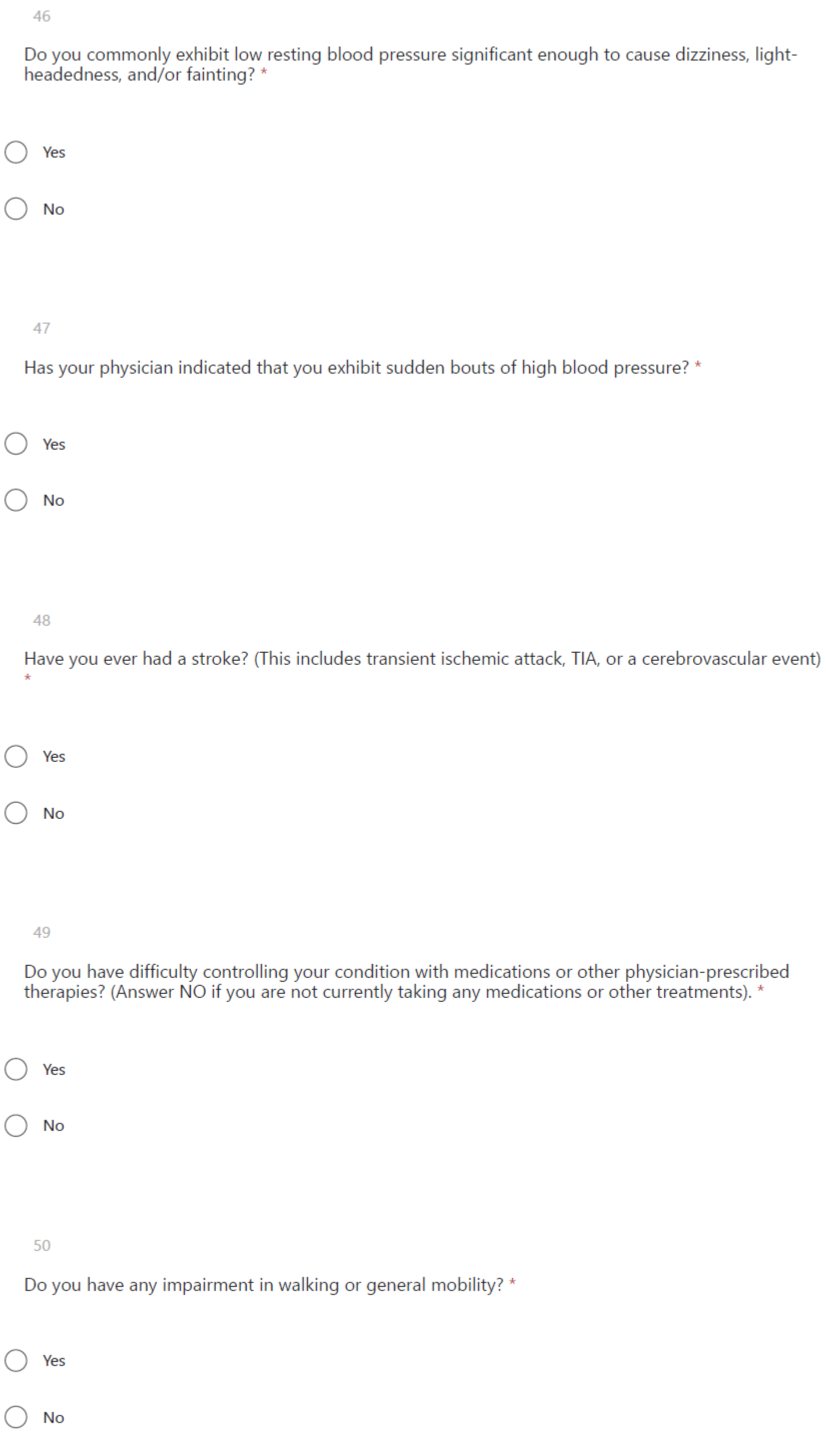
○ No

45

Has your doctor ever said you have high blood pressure in the blood vessels of your lungs? *

○ Yes

○ No



46

Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting? *

○ Yes

○ No

47

Has your physician indicated that you exhibit sudden bouts of high blood pressure? *

○ Yes

○ No

48

Have you ever had a stroke? (This includes transient ischemic attack, TIA, or a cerebrovascular event) *

○ Yes

○ No

49

Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments). *

○ Yes

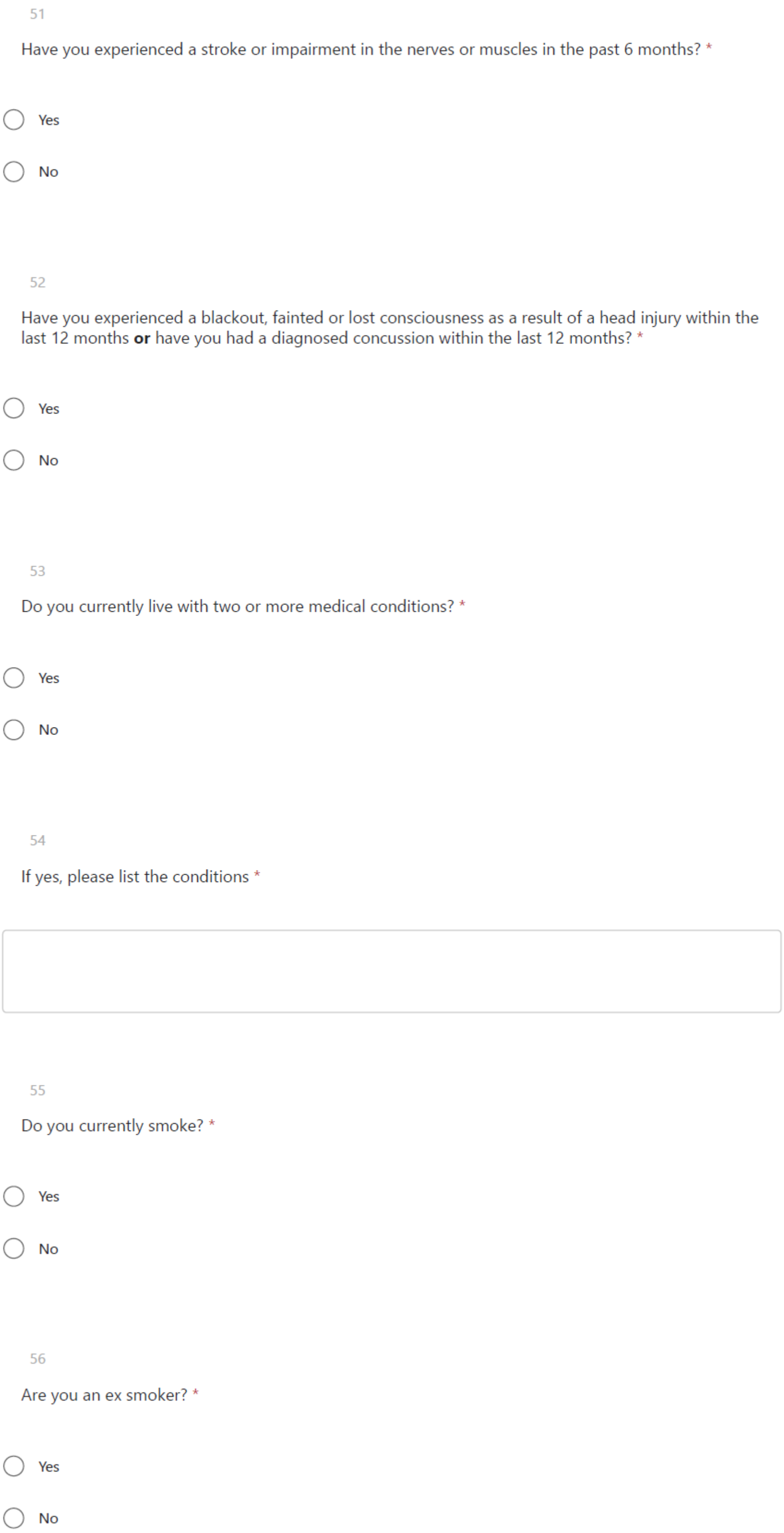
○ No

50

Do you have any impairment in walking or general mobility? *

○ Yes

○ No



51

Have you experienced a stroke or impairment in the nerves or muscles in the past 6 months? *

○ Yes

○ No

52

Have you experienced a blackout, fainted or lost consciousness as a result of a head injury within the last 12 months **or** have you had a diagnosed concussion within the last 12 months? *

○ Yes

○ No

53

Do you currently live with two or more medical conditions? *

○ Yes

○ No

54

If yes, please list the conditions *

55

Do you currently smoke? *

○ Yes

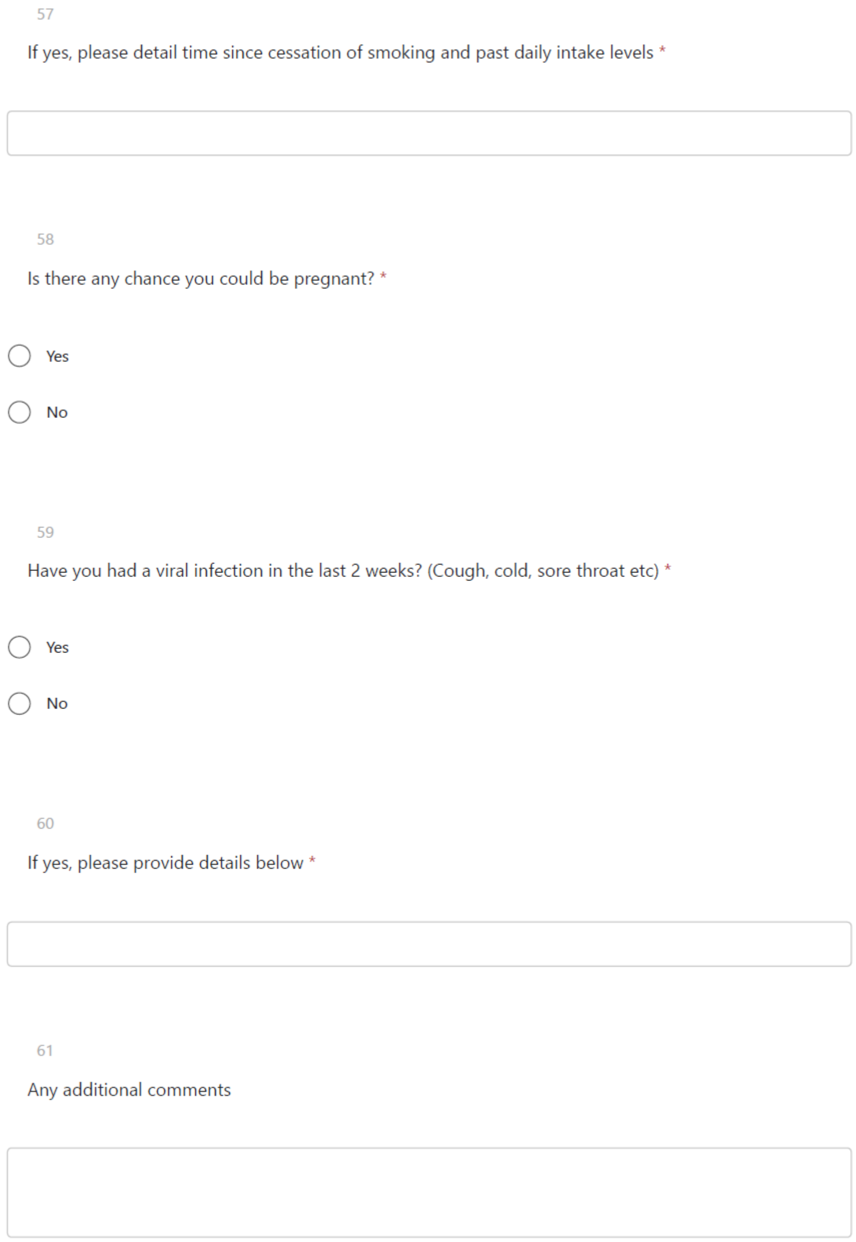
○ No

56

Are you an ex smoker? *

○ Yes

○ No



57

If yes, please detail time since cessation of smoking and past daily intake levels *

58

Is there any chance you could be pregnant? *

○ Yes

○ No

59

Have you had a viral infection in the last 2 weeks? (Cough, cold, sore throat etc) *

○ Yes

○ No

60

If yes, please provide details below *

61

Any additional comments