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Exploring the relationship between trunk muscles and lower limb injuries in Australian badminton players

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ABSTRACT

Due to its dynamic nature, lower limb injuries are common in badminton. Overuse injuries of the knee, including tendon related conditions, are the most common. During jumping and landing, force transference and dissipation through the trunk is required, with the trunk muscles playing a vital role. However, the relationship between knee pain and the ability to voluntarily contract the trunk muscles has not yet been explored in badminton players. A cross-sectional study of Australian badminton players was therefore conducted. Players performed a single leg decline squat to identify those with knee pain. Ultrasound imaging was used to image and measure the size of the multifidus and quadratus lumborum, and the ability to contract the abdominal and multifidus muscles. Voluntary contraction of the trunk muscles was conducted with the subjects lying down. Independent samples T-Tests were performed to test for between group differences. Badminton players with knee pain had larger quadratus lumborum muscles and demonstrated a greater change in muscle thickness from the rested to contracted state. While we cannot comment on causation or direction, over co-contraction of trunk muscles has been shown in other studies to be associated with increased ground reaction forces on landing. Motor control training has been successfully used in other conditions to modify trunk muscle recruitment patterns and may therefore potentially represent a useful approach for badminton players.

1. Introduction

Badminton is recognized as the second most popular participation sport. More than 200 million participants play badminton in recreational and elite levels worldwide (Phomsoupha and Laffaye, 2015). Badminton injuries represent 1–5 % of all sport injuries (Phomsoupha and Laffaye, 2020). The sport is ranked 6th highest overall in terms of injury incidence, being only slighter lower than soccer, basketball and volleyball (Phomsoupha and Laffaye, 2020). The risk of injury in badminton is 1.6 to 2.9 injuries per 1000 h of play (Shariff et al, 2009), with the majority classified as chronic overuse injuries (Fahlström and Söderman, 2007). Fifty-eight to 76 % of injuries involve the lower limbs, 19–32 % involve the upper limbs and 11–16 % are back related (Phomsoupha and Laffaye, 2020). Overuse injuries of the lower leg are the most common problem with the most severe injuries being tendon related, affecting predominantly the Achilles and patella tendons (Boesen et al., 2011).

Badminton is the fastest racquet sport in the world, with shuttlecocks reaching speeds in excess of 300 km/h. A high level of technical skills, tactics and physical capacities are required during training and competition (Faude et al., 2008). Players need to maintain a high level of dynamic core stability to accommodate the rapid changes of body positions and centre of mass to allow the upper limbs to be in the best position to hit the shuttle (Lam et al., 2020). Many activities integral to badminton, such as jumping and rapid direction changes, require precise neuromuscular control of the lumbo-pelvic region (Loram & Lakie, 2002). During power shots, large forces generated from the upper limb need to be safely transferred through the trunk to the legs, and during jumping, large forces need to be distributed from the ground (ground reaction force), through the legs to the trunk, and finally to the upper limb. The trunk is the vital link between upper and lower limb function, with the trunk muscles playing a key role in spinal control and force dissipation.

There is currently a gap in the literature regarding the relationship between trunk muscle function and lower leg injuries in badminton players. While all trunk muscles can contribute to movement and protection of the spine, some key trunk muscles such as the multifidus, transversus abdominis and quadratus lumborum have been shown to play important roles (Macintosh et al., 1986, Richardson et al., 2002,

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McGill et al., 1999). The multifidus muscle controls segmental spinal motion (Macintosh et al., 1986). The muscle has a unique innervation with each vertebral level innervated by the medial branch of the dorsal rami, meaning that the muscle can control movement of individual segments and control the lumbar lordosis (Macintosh et al., 1986). Control of and optimal positioning of the lumbar lordosis is integral to optimal load transfer (Kiefer et al., 1997), especially in a dynamic sport like badminton. Of the abdominal muscles, the transversus abdominis muscle has been shown to play an important role in stabilising the lumbar spine and pelvis (Richardson et al, 2002). This muscle can be contracted independently of the other abdominal muscles (Hodges and Richardson, 1997). With respect to the quadratus lumborum muscle, there is debate and inconsistency in clinical, anatomical, and neurophysiological investigations regarding its contribution to protection of the spine (Phillips et al., 2008). While bioengineers have previously proposed that the quadratus lumborum (QL) muscle plays an important role in stabilization of the lumbar spine (McGill et al., 1999), an anatomical and biomechanical study proposed that the effects of the QL muscle on the lumbar spine were modest at best (Phillips et al., 2008).

The independent control of the trunk muscles primarily involved in spinal control and force dissipation can be assessed using clinical muscle tests. These tests involve measurement of muscle size (for the multifidus and quadratus lumborum muscles) and assessment of voluntary contraction (of the anterolateral abdominal muscles and the lumbar multifidus muscles). The clinical muscle tests have been shown to have acceptable clinimetric properties (Stokes et al., 2007, Teyhen et al., 2007), and show correlation with measures obtained by fine-wire electromyography (EMG) for isometric contractions at low levels of maximal voluntary contraction (Hodges et al., 2003; Kiesel et al., 2007). To date, these measures have been conducted in several athletic populations, including cricketers (Hides et al., 2010), Australian Football League players (Hides et al., 2020), weightlifters (Sitilertpisan et al., 2012), ballet dancers (Gildea et al., 2013), volleyball athletes (Hides et al., 2022) and rugby league and union players (Low et al., 2023; Hides et al., 2024). Previous prospective studies have demonstrated relationships between size (Hides et al., 2011, 2014; 2020) and contraction (Hides et al., 2024; Hides et al., 2017a) of trunk muscles and lower limb injuries in sports players. Smaller cross-sectional areas (CSAs) of the multifidus muscles (at rest) have been shown to be associated with lower limb injuries in Australian Football players (Hides et al., 2011, 2014; 2020). Varied results have been reported regarding the relationship between the CSA of the quadratus lumborum muscle (at rest) and injuries, with most prospective studies finding that increased size of the quadratus lumborum was related to lower limb injuries (Hides et al., 2020; Hajek et al., 2022). In contact/collision sports, increased contraction of the trunk muscles has been observed in players who went on to suffer injuries (Hides et al., 2024; Hides et al., 2017b).

As control of the trunk is integral to all athletic performance, and previous studies have demonstrated relationships between key trunk muscles and lower limb injuries, the aim of this exploratory study was to compare the size and motor control (ability to voluntarily contract the trunk muscles) in two groups of Australian badminton players. The groups consisted of players with and without knee pain elicited by a single leg decline squat (SLDS), which is a task that is commonly provocative of pain in athletes from sports with similar dynamics, such as volleyball (Coombes et al., 2020; Hannington et al., 2020). We hypothesized that badminton players who reported pain on a SLDS may have altered size and control of their trunk muscles.

2. Materials and methods

Participants included male and female athletes aged 18 years and over, who represented Australia in badminton at an international level. A convenience sample of athletes was recruited and tested during a routine training session at Melbourne Sports and Aquatic Centre (MSAC, Melbourne, Australia) over a two-day period in April 2023. All procedures were performed in compliance with relevant laws and institutional guidelines. Ethical approval was received from Griffith University (2017/896) and approval for testing was received from Badminton Australia. Participants were provided with information about the study prior to the training session and athletes provided written, signed consent on the day of testing.

2.1. Experimental procedure

All testing was completed courtside within the players' usual 3-hour morning training session. Participants first completed questionnaires to ascertain demographics, training levels, current symptoms (including the presence of low back pain) and history of symptoms over the last 12 months. History of current or previous low back pain was captured as this is known to impact the size and activation of trunk muscles. Participants were also asked to rate the intensity of badminton training completed prior to experimental testing on the Borg CR-10 scale, with 0 representing rest and 10 representing maximal intensity. After this, participants performed a single leg decline squat (SLDS, described below) on their most symptomatic leg, or on a randomly allocated leg if legs were equally symptomatic. Participants were divided into two groups based on the presence or absence of knee pain during the SLDS test on the day of testing. Following this, an examiner blinded to group allocation performed ultrasound imaging of the trunk muscles.

2.2. Questionnaires

Participants rated their worst level of knee pain in the test leg in the past 7 days and their worst level of knee pain today on a 11-point numerical rating scale (NRS), with endpoints of no pain and worst imaginable pain. The Oslo Sports Trauma Research Centre Overuse Injury Questionnaire (OSTRC-O2) was also used to record the severity of knee problems (in either leg) in the last 7 days (Clarsen et al., 2020). Responses were summed according to previously published methods to provide a total score ranging from 0 (full participation without knee pain) and 100 (unable to participate with severe knee pain) (Clarsen et al., 2013; Clarsen et al., 2020).

2.3. Single leg decline squat (SLDS) test

The SLDS was performed using previously published methods (Coombes et al., 2020; Hannington et al., 2020). Participants were asked to stand on their test leg on a 20° decline board, place their hands on their hips and slowly squat to 60° of knee flexion, visualised using a cardboard template with a 60° angle, then return to upright, keeping their trunk upright and heel in contact with the board. After returning to upright, participants rated the intensity of any knee pain during the SLDS on a 11-point NRS and listed the location(s) of any knee pain experienced using a pre-established list of regions (Coombes et al., 2020). This test was repeated twice with a 30 s rest interval.

2.4. Ultrasound imaging of the trunk muscles

2D-Ultrasound imaging was conducted using LOGIQ e apparatus with a 5-MHz curvilinear transducer (GE Healthcare, Wuxi, China), by an examiner with over 25 years of experience and established measurement reliability. Clinical measurements of trunk muscles were performed bilaterally as described in full previously (Hides et al., 2004), with the participant positioned in prone lying (for imaging of the multifidus and quadratus lumborum, Fig. 1) and in supine lying with the knees flexed and resting on a pillow, to relax the abdominal wall (for imaging of the transversus abdominis and internal oblique muscles, Fig. 2). Quadratus lumborum was measured at rest only, while the multifidus, transversus abdominis and internal oblique muscles were imaged both at rest and on voluntary contraction. All images were captured, annotated and stored for later measurement.

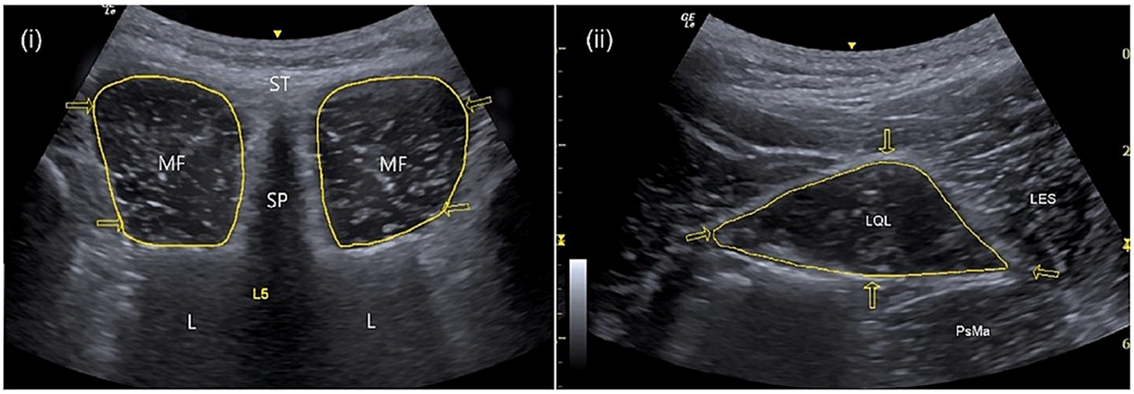

Fig. 1. Transverse ultrasound images of the (i) multifidus and (ii) quadratus lumborum muscle with borders outlined to demonstrate segmentation for measurement of muscle CSA.
Abbreviations: ST: subcutaneous tissue, SP: acoustic shadow of spinous process, MF: multifidus muscle, L5: vertebral level, L: acoustic shadow of the lamina, LQL: left quadratus lumborum, LES: lumbar erector spinae, PsMa: Psoas Major.

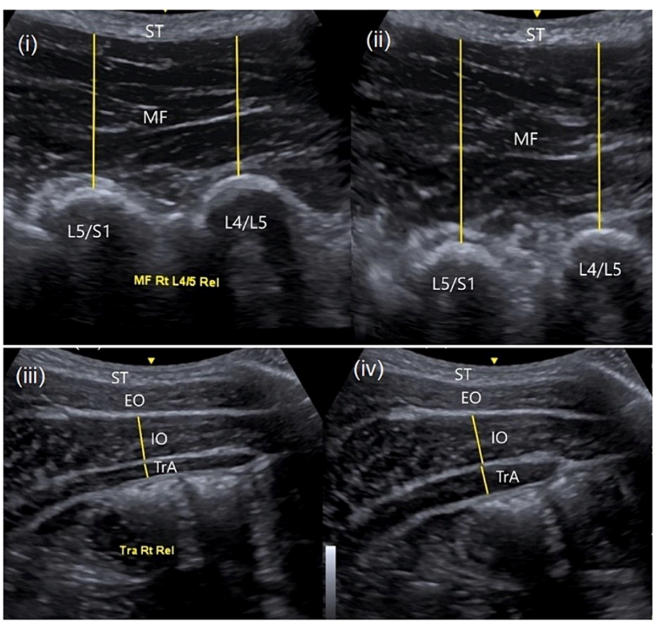

Fig. 2. Parasagittal ultrasound image of the multifidus muscle thickness measured in relaxed (i) and contracted (ii) conditions. Transverse ultrasound image of the internal oblique and transversus abdominis muscle thickness measured in relaxed (iii) and contracted (iv) conditions.
Abbreviations: ST: subcutaneous tissue, MF: multifidus muscle, L: vertebral level, EO: external oblique muscle, IO: internal oblique muscle, TrA: internal oblique muscle.

For measurement of muscle CSAs, transverse sections of the multifidus were imaged from L2 to L5 vertebral levels or at the L3–4 vertebral interspace for quadratus lumborum (Fig. 1) (Hides and Stanton., 2017).

To assess the thickness of the multifidus muscle when relaxed and contracted, imaging was performed in parasagittal section, allowing visualisation of the L2/3, L3/4, L4/5 and L5/S1 zygapophyseal joints, muscle bulk and thoracolumbar fascia (Fig. 2i-ii). Participants were instructed how to perform a voluntary isometric contraction and were given one practice contraction. The player was instructed to "relax the trunk muscles, then take a relaxed breath in, and out, hold the breath out and then to try to contract or swell the multifidus muscle into the examiner's fingers without moving the spine." The presence of the examiner's fingers on the multifidus muscle is facilitatory and helps guide the participant regarding location and amount of contraction required for the test. Participants were guided to contract multifidus without inducing spinal movement.

To assess the thickness of the anterolateral abdominal muscles when relaxed and contracted, images were collected in a transverse section midway between the inferior angle of the rib cage and the iliac crest (Hides et al., 2007) (Fig. 2i-iv). Participants were asked to "slowly and gently draw in the lower abdomen without moving the spine" (Hides et al., 2007). Participants were given a practice contraction to ensure that they understood the description of the low-level isometric contraction. If participants posteriorly tilted their pelvis, they were instructed to contract the muscles more gently, short of inducing spinal movement.

Ultrasound images were stored and measured offline using OsiriX medical imaging software (Geneva, Switzerland). Figs. 1 and 2 show segmentation of the multifidus and quadratus lumborum and linear measurements of the multifidus and abdominal muscles at rest and on contraction. An experienced researcher with demonstrated intra-rater reliability conducted the measurements of the quadratus lumborum (intra-class correlation co-efficient, ICC=0.99) (Hides and Stanton., 2017) and multifidus muscle CSA (ICC mean for L2–L5 = 0.94) (Hides et al., 1995), multifidus muscle thickness (ICC=0.88–0.95, relaxed and contracted) (Wallwork et al., 2007), and abdominal muscle thickness (transversus abdominis ICC=0.62–0.98; internal oblique ICC=0.69–0.99, relaxed and contracted) (Hides et al, 2007). To determine the percentage muscle contraction, the change in muscle thickness between the contracted and relaxed measures was calculated (contracted minus relaxed value). This was also expressed as a percentage of the resting value (percentage change in thickness). This calculation allowed for normalisation of contraction sizes across differently sized participants.

2.5. Statistical analysis

SPSS version 28.0 (IBM) was used for analyses. Means and standard deviations (SD) for demographic factors (age, height and weight) were calculated. Data were examined for outliers and normal distribution using summary statistics histograms, normality plots and the Kolmogorov-Smirnov test. As there were no between side differences, ultrasound measures were averaged across left and right sides. Differences in demographic data, measures of muscle size (CSA), resting muscle thickness and contraction (change in thickness) and percentage contraction (dependent variables) were compared between the two independent groups (players with and without knee pain on a SLDS) using independent samples T-tests with a Levene's test for the assumption of homogeneity of variance. For the multifidus muscles, analysis was performed for the measures taken at the levels of the L2/3, L3/4, L4/5 and

L5/S1 zygapophyseal joints separately. For measures of the internal oblique muscle thickness (which did not satisfy the assumption of normality), a Mann-Whitney *U* test compared differences between groups. Because this was an exploratory study aimed at identifying the priority for subsequent research, effect sizes (mean difference/pooled standard deviation) > 0.5 and liberal p values <0.1, were considered to help identify clinically meaningful effects (Bender and Lange, 2001). This approach has been previously adopted in exploratory studies with small sample sizes (e.g., Hides et al., 2017c), in order to avoid Type II errors in exploratory work.

3. Results

Fourteen participants (8 male, 6 female) participated in the study. Seven participants (50 %; five male, two female) reported pain during the SLDS and had a mean (SD) pain intensity of 3.9 (2.0). Symptoms were experienced over the patellar tendon (in four participants, 57 %) or patellofemoral joint (two participants, 29 %), with one participant (14 %) reporting lateral and posterior sites. There were no differences in demographic, sporting characteristics or training intensity prior to testing between the two groups (Table 1). All self-reported outcomes of knee symptoms (OSTRC-O2, pain in last seven days and pain today) were worse in participants who had knee pain during the SLDS.

Muscle size of the multifidus and quadratus lumborum muscles for the pain and no pain groups are shown in Table 2 and Fig. 3. CSA of the quadratus lumborum muscles ($p < 0.1$, ES=−0.8) and the multifidus muscles at the L2 vertebral level ($p < 0.05$, ES=−1.3) were greater in the group with pain.

Muscle thickness at rest and muscle contraction for the multifidus muscles and transversus abdominis are shown in Table 3 and Figs. 4 and 5 (represented as percentage increase in contraction). There were significant differences between groups for thickness of the multifidus muscles and transversus abdominis muscle at rest (for the multifidus muscles at L4/5, $p < 0.01$, ES=0.9; L3/4, L2/3 and the transversus abdominis (all $p < 0.05$, ES=1.1–2). There were significant differences between groups for change in thickness of the multifidus muscles L4/5 ($p < 0.05$, ES=1.1) and L3/4 ($p < 0.05$, ES=1.1) vertebral levels, with greater percentage contraction also observed in the group with pain (Fig. 4). For the abdominal muscles, there was a significant difference in change in thickness of the transversus abdominis muscle, ($p < 0.1$, ES=-0.8;), with greater contraction (change in thickness) observed in the group with pain. There was no differences between groups for thickness of the internal oblique muscle at rest (no pain on SLDS median = 0.97 cm, IQR=0.15 cm; pain on SLDS median = 1.19 cm, IQR=0.47 cm; U=36; p = 0.17) and no change in thickness (no pain on SLDS median = 0.06 cm, IQR=0.17 cm; pain on SLDS median = 0.2 cm, IQR=0.2 cm; U=33.5, p = 0.26, ES=-0.67).

4. Discussion

Results of this exploratory study showed that badminton players with knee pain on the SLDS had larger quadratus lumborum and multifidus muscles (at the L2 vertebral level) at rest. Badminton players with knee pain on the SLDS contracted their multifidus and transversus abdominis muscles more than those who did not report pain. These between group differences in muscle size and contraction exceeded the standard error or measurement (SEM) calculated values for these measures (Hides et al., 1995, Hides et al., 2007 Hides and Stanton, 2017., Wallwork et al., 2007).

Prospective studies of other sports have shown an association between increased size of the quadratus lumborum muscle and lower limb injury (Hajek et al., 2022; Hides et al., 2012; Hides and Stanton 2017). While it has been proposed that the role of the quadratus lumborum is to stiffen the spine, and control spinal buckling (McGill et al., 1996), the role of the quadratus lumborum muscle remains controversial (Phillips et al., 2008). While increased size and activation of the quadratus lumborum muscle may be advantageous in contact sports, it equally could be disadvantageous during activities such as running, where the

Table 1
Characteristics of all participants and those with and without knee pain on the single leg decline squat test (SLDS).

Demographic/sport	All participants	No knee pain on SLDS	Knee pain on SLDS	p-value
n	14	7	7	
Male n (%)	8 (57 %)	3 (43 %)	5 (71 %)	0.59
Female n (%)	6 (43 %)	4 (57 %)	2 (29 %)	
Age (years)	24.4 ± 5.5	24.6 ± 4.1	24.4 ± 7.0	0.89
Height (cm)	170.6 ± 6.9	171.7 ± 7.1	169.6 ± 7.1	0.58
Weight (kg)	66.7 ± 9.5	63.6 ± 8.6	69.9 ± 10.1	0.23
Low back injury in 2022	6 (43 %)	3 (43 %)	3 (43 %)	
Current LBP	1 (7 %)	1 (14 %)	0	
Sport experience (years)	13.8 ± 5.9	14.3 ± 5.1	13.3 ± 6.9	0.76
Sport (hours/week)	10.3 ± 5.0	9.9 ± 5.6	10.7 ± 4.8	0.78
Training intensity prior to testing	3.8 ± 1.3	3.3 ± 0.8	4.4 ± 1.5	0.17
Test leg	11 (78.6 %)	5 (71.1 %)	6 (85.7 %)	
Knee symptoms				
Knee pain last 7 days (NRS)	2.4 ± 2.1	0.4 ± 0.8	4.4 ± 3.3	0.009*
Knee pain today (NRS)	1.4 ± 2.2	0 ± 0	2.7 ± 2.4	0.01*
OSTRC-O2 (0–100)	12.4 ± 19.2	0 ± 0	24.7 ± 21.1	0.009*

NRS=numerical rating scale. OSTRC-O2 = Oslo Sports Trauma Research Centre Overuse Injury Questionnaire.

Table 2
Cross-sectional area (CSA) of multifidus (MF) and quadratus lumborum (QL) muscles for badminton players with and without knee pain on the single leg decline squat (SLDS) test.

Muscle CSA (cm^2)	Mean (SD)		Mean difference (95 % CI)	Effect size (Cohen's d)	Significance (p value)
	No pain on SLDS	Pain on SLDS			
QL	6.92 (1.57)	8.17 (1.65)	−1.26 (−3.14, 0.62)	**−0.8**	**0.085**
MF L5	7.45 (0.96)	7.51 (0.98)	−0.07 (−1.2, 1.06)	−0.1	0.449
MF L4	5.51 (1.04)	5.49 (1.06)	0.02 (−1.2, 1.25)	0.0	0.485
MF L3	2.69 (0.46)	2.83 (0.58)	−0.13 (−0.59, −0.04)	−0.3	0.319
MF L2	1.75 (0.16)	2.07 (0.3)	−0.32 (−0.59, −0.04)	**−1.3**	**0.014**

Differences between groups are reported as mean differences and effect sizes. cm^2 = centimetres squared; SD = standard deviation.

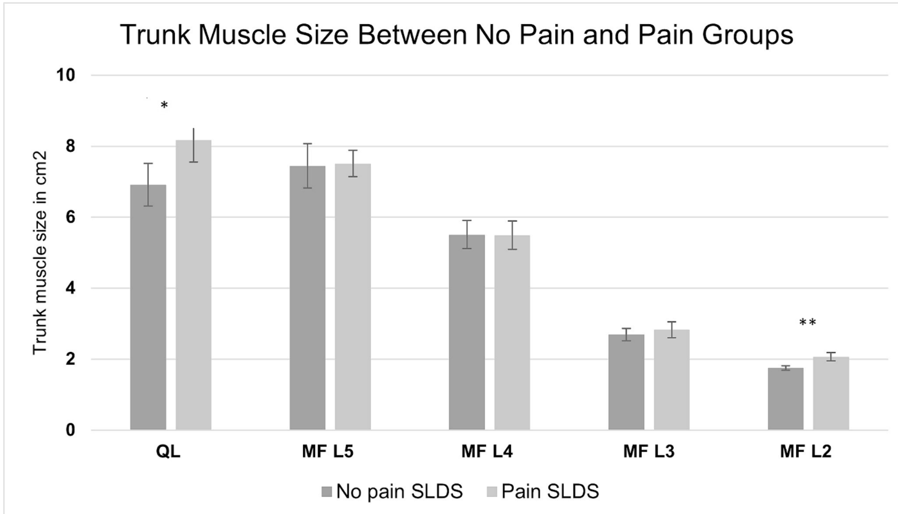

Fig. 3. Trunk muscle size of the quadratus lumborum and multifidus muscles (L2-L5 vertebral levels) averaged across sides for badminton players with and without knee pain on a single leg decline squat test.
Error bars represent standard error, *p = <0.1; **p = < 0.05. cm^2 = centimeters squared; SLDS = single leg decline squat.

Table 3
Muscle thickness at rest and change in thickness during contraction (contracted – relaxed state) of the multifidus (MF) (L2/3 to L5/S1) and transversus abdominis (TrA) muscles for badminton players with and without knee pain on a single leg decline squat (SLDS).

Muscle thickness (cm)	Relaxed value Mean (SD)		Mean difference (95 % CI)	Effect size (Cohen's d)	Significance (p value)	Contracted minus relaxed value Mean (SD)		Mean difference (95 % CI)	Effect size (Cohen's d)	Significance (p value)
	No pain on SLDS	Pain on SLDS				No pain on SLDS	Pain on SLDS			
MF L5/S1	2.88 (0.33)	2.98 (0.19)	0.1 (−0.21,0.41)	0.4	0.25	0.21 (0.17)	0.27 (0.18)	0.06 (−0.14,0.27)	0.4	0.252
MF L4/L5	2.71 (0.25)	2.95 (0.3)	0.24 (−0.07,0.56)	**0.9**	**0.060**	0.25 (0.15)	0.42 (0.17)	0.17 (−0.2,0.35)	**1.1**	**0.037**
MF L3/L4	2.16 (0.24)	2.44 (0.24)	0.28 (−0.001–0.55)	**1.2**	**0.025**	0.08 (0.06)	0.2 (0.15)	0.12 (−0.01, 0.25)	**1.1**	**0.037**
MF L2/L3	1.82 (0.08)	2.16 (0.23)	0.33 (0.22,0.55)	**2**	**0.003**	0.19 (0.08)	0.2 (0.15)	0.01 (−0.13, 0.15)	0.1	0.438
TrA	0.36 (0.9)	0.45 (0.09)	0.09 (−0.09,0.2)	**1.1**	**0.035**	0.12 (0.05)	0.2 (0.13)	−0.8 (−0.2,0.03)	**−0.8**	**0.074**

Note, results for the IO muscle (median and IQR) are presented in text. Differences between groups are represented by mean differences and effect sizes. cm = centimeters.

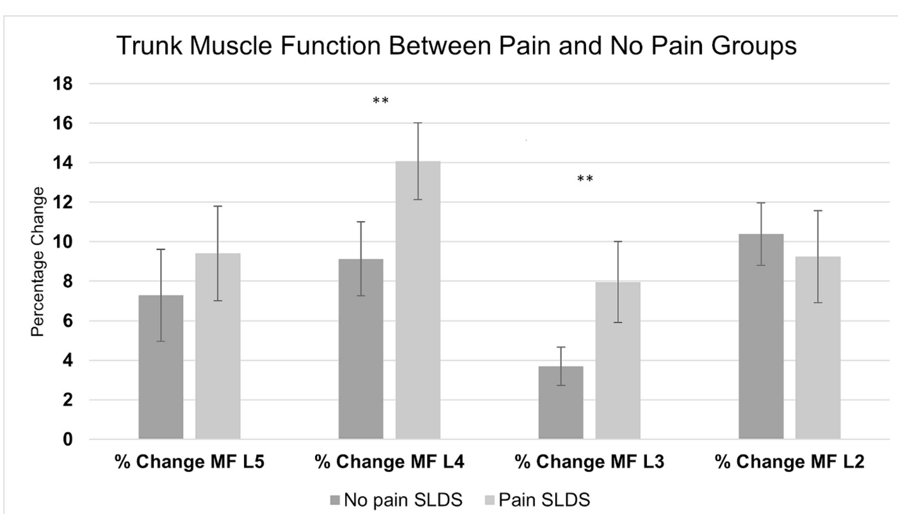

Fig. 4. Percentage change in muscle thickness (contracted value – relaxed value/ relaxed value x 100) for the multifidus muscle (MF) at the levels of the L5/S1 to L2/3 zygapophyseal joints, averaged across sides for badminton players with and without knee pain on a single leg decline squat test (SLDS).

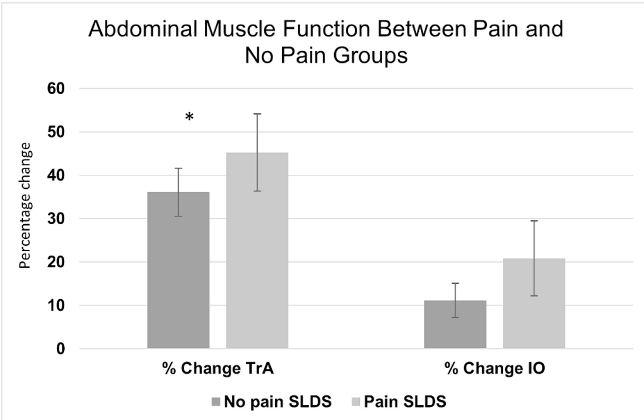

Fig. 5. Percentage change in thickness (contracted value – relaxed value/ relaxed value x 100) for the transversus abdominis (TrA) and internal oblique (IO) muscles, averaged across sides for badminton players with and without knee pain on a single leg decline squat test (SLDS).

spine needs to laterally flex. Bilateral over-recruitment could result in decreased lateral flexion of the lumbar spine, rigidity and an inability to absorb shock and distribute loads effectively, as has been previously proposed (Hides and Stanton, 2017). Furthermore, a review paper proposed that when back muscle fatigue occurs, muscles such as quadratus lumborum increase activity to compensate, resulting in a cascade of events potentially resulting in lower limb injuries (Colston, 2012).

In the current sample, one in two badminton players reported pain during the SLDS test, with the majority (57 %) reporting localised pain over the patellar tendon. While this test was originally described as a provocation test to discriminate people with patellar tendinopathy (Purdam et al., 2003), it is known to load multiple structures in the knee (Zwerver et al., 2007). Furthermore, heterogeneity in pain location during the SLDS has been found in athletes with patellar tendinopathy confirmed via ultrasound (Hannington et al., 2020). For this reason, we chose to dichotomise based on presence or absence of pain during the SLDS rather than based on location of pain. As similar rates of pain on the SLDS are reported in elite basketball players (Hannington et al., 2020), further research is needed to explore whether volleyball players also show greater trunk muscle size and contraction. Using inverse dynamics to compare different landing strategies, volleyball players with a history of patellar tendinopathy displayed strong tendencies of higher loading rate of vertical ground reaction force and higher knee extensor moment loading rate compared with asymptomatic players (Bisseling et al., 2007). While we are unable to comment on causation from the results of this cross-sectional study, possible explanations are that the over recruitment of the trunk muscles produces increased lower limb stiffness during landing or that the presence of knee pain playing badminton led to altered recruitment of the trunk muscles, as a strategy to stiffen the spine. While increased recruitment of trunk muscles has previously been observed in athletes with low back pain (Hides et al., 2016, Hyde et al., 2012), the increased contraction was unlikely to be related to the presence of low back pain in the current investigation, as only one player (from the no knee pain group on SLDS) reported current low back pain. The number of players with a history of low back pain in the last 12 months was also equally distributed across the two groups.

The method of assessment of the abdominal and back muscles was based on established clinical muscle testing procedures (assessment of muscle size and ability to voluntarily contract target muscles on demand) (Hides et al., 2004). This method was selected to allow testing of the individual muscles, as they perform specific roles with respect to control and protection of the spine. This type of testing is not possible during function (where several muscles are recruited simultaneously) so extrapolation of the results of muscle testing to dynamic situations must be interpreted with caution. It is possible that there is a 'sweet spot' or 'Goldilocks zone' of optimal trunk muscle contraction for jumping and landing sports. A negative consequence of overrecruiting (or over co-contracting) these muscles may be that the muscle system is no longer able to effectively dampen loading forces. It is possible that this could increase the risk of overuse injuries to the lower limb due to the combination of increased ground reaction forces and reduced flexion of the lower limbs on landing (Campbell et al., 2016).

5. Limitations and future directions

This study included a small sample size of convenience with multiple comparisons of interest. While liberal p values ($p < 0.1$) were specified for this exploratory investigation, results for the multifidus muscle size and contraction were less than $p < 0.05$, with large effect sizes (1.0–1.1). While the results for the CSA of QL ($p = 0.085$) and the TrA muscle (0.07) were less than $p < 0.1$, they had large effect sizes (0.8 for each). For this reason, the results were considered in this manuscript, to avoid the possibility of Type II errors (incorrectly accepting the null hypothesis of no difference when a clinically important between group difference may exist). Furthermore, as the current investigation was a cross-sectional study, we cannot speculate on cause and effect. We also did not measure joint kinematics or assess dynamic sports play, so the explanation that increased trunk muscle contraction may have affected lower limb kinematics in the badminton players tested would require verification. Despite the preliminary nature of these findings, the results of the current investigation suggest that clinical tests of voluntary contraction of the trunk muscles in prone and supine lying, may provide information about trunk muscle function in athletes involved in dynamic sports such as badminton. Future research using electromyography could be used to verify activation of trunk muscles during activities such as the SLDS and during landing in badminton.

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CRediT authorship contribution statement

Julie A. Hides: Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **M. Dilani Mendis:** Writing – review & editing, Funding acquisition, Data curation, Conceptualization. **Felix Leung:** Writing – review & editing, Funding acquisition, Conceptualization. **Brittany Grantham:** Writing – review & editing, Resources, Project administration, Data curation. **Brooke Coombes:** Writing – original draft, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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