The Role of Latissimus Dorsi in Trunk Movement and Stability

by

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2025

A thesis submitted to fulfill the requirements of the degree of

Doctor of Philosophy

Authors Declaration

I certify that this thesis is entirely my own work, and to the best of my knowledge it contains no material previously published or written by another person, except where due reference is made. This thesis has not been submitted for any other degree or purpose.

Where the work is based on joint research, the relative contributions of the respective authors and collaborators have been acknowledged.

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Authorship Attribution Statement

This thesis contains material published in peer-reviewed journals. I am the primary author of these works, and all co-authors have approved their inclusion. Except where reference is made in the text of this thesis, this thesis contains no material published elsewhere.

Chapter 2 of this thesis has been published as *Price D, Ginn KA, Halaki M, Reed D. What is the contribution of latissimus dorsi to trunk movement and control? A systematic review and meta-analysis. Physical Therapy Reviews. 2024b:1-17.* I co-designed the study with Darren Reed, Karen Ginn and Mark Halaki, interpreted the analysis, and wrote the drafts of the manuscript.

Chapter 3 of this thesis has been published as *Price D, Ginn KA, Halaki M, Kwasi V, Reed D. Do maximal isometric trunk tasks produce maximum activity in latissimus dorsi? Journal of Electromyography and Kinesiology. 2024a;79*. I co-designed the study with Darren Reed, Karen Ginn, Mark Halaki, and Victor Kwasi, interpreted the analysis, and wrote the drafts of the manuscript.

Chapter 4 of this thesis has been published as *Price D, Ginn KA, Halaki M, Kwasi V, Reed D. The validity of surface electrodes to record latissimus dorsi activity during submaximal trunk movement and stability tasks. J Electromyogr Kinesiol. 2025;83:103013*. I co-designed the study with Darren Reed, Karen Ginn, Mark Halaki, and Victor Kwasi, interpreted the analysis, and wrote the drafts of the manuscript.

Chapter 5 of this thesis has been submitted to the Journal of Clinical Biomechanics as *Price D, Ginn KA, Halaki M, Kwasi V, Reed D. Revisiting the contribution of latissimus dorsi to trunk movement.* I co-designed the study with Darren Reed, Karen Ginn, Mark Halaki, and Victor Kwasi, interpreted the analysis, and wrote the drafts of the manuscript.

Chapter 6 of this thesis has been submitted to the Journal of Clinical Biomechanics as *Price D, Ginn KA, Halaki M, Kwasi V, Reed D. Latissimus dorsi's contribution to trunk stability in standing is minimal.* I co-designed the study with Darren Reed, Karen Ginn, Mark Halaki, and Victor Kwasi, interpreted the analysis, and wrote the drafts of the manuscript.

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Lead supervisor: Mark Halaki

Artificial Intelligence

During the preparation of this thesis, the author used ChatGPT to assist with language refinement, sentence structure and spelling. All generated text was reviewed and edited to ensure accuracy and originality.

Australian Government Support

This research was supported by an Australian Government Research Training Program (RTP) Scholarship.

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Acknowledgments

First and foremost, I would like to express my deepest gratitude to my wife, Catherine, for her unwavering love, patience, and support throughout this journey. Your encouragement during the challenging periods was invaluable, and your understanding, perseverance and countless sacrifices made it possible for me to see this work through to completion. Thank you for all you do for our three boys, Samuel, Oliver and Leo, and for keeping me grounded throughout this process.

I would like to sincerely thank all my supervisors for their invaluable guidance, expertise, and mentorship. Your insights and feedback have greatly shaped this research and my development as a researcher. To Dr Darren Reed, thank you for your patience and determination to see me through, always spurring me on. Thank you also for re-assuring my wife that there would be an end. To Victor Kwasi, thank you for your technical assistance during the experiments. To Professor Mark Halaki, thank you for your sharp analytical mind and attention to detail, which continued to challenge me. To Professor Karen Ginn, thank you for your willingness to see me through to the finish, and for your ability make the bigger picture clear – helping me not to lose the forest for the trees.

My heartfelt thanks go to all the participants who generously gave their time and effort to take part in this study. Without your contribution, this research would not have been possible.

Finally, I wish to acknowledge those who have offered support along the way, in particular the university's library staff and administrative teams, whose assistance has been greatly appreciated.

Summary

The latissimus dorsi is the largest and most expansive muscle in the human body. It has extensive attachments that extend from the iliac crest of the pelvis, the lumbar spine, lower ribs and inferior angle of the scapula and converge onto the floor of the intertubercular groove of the humerus. It is thought that latissimus dorsi can contribute to movement and stability at the trunk due to these broad attachment points and is often targeted in rehabilitation with the gluteus maximus due to the anatomical link through the thoracolumbar fascia. Electromyography (EMG) studies have shown latissimus dorsi to be strongly active during shoulder extension, adduction and internal rotation and these movements are commonly used to strengthen the latissimus dorsi. However, the EMG evidence during trunk tasks is less clear. There are inconsistencies within the EMG methodological process in previous studies, leading to potential misrepresentation of the muscle's involvement in trunk task. The studies in this thesis aim to address these methodological issues and subsequently improve the understanding of how latissimus dorsi is involved in trunk function.

This thesis is made up of 7 chapters, with chapters 2 to 6 being either published in peer reviewed journals or currently under review at time of submission. The flow of the thesis is as follows:

Chapter 1 introduces latissimus dorsi and relates its structural anatomy to how it may contribute to trunk function. In this chapter the limitations of previous EMG studies are discussed and how they may influence the current understanding of latissimus dorsi's involvement in trunk movement and stability.

Chapter 2 is a systematic review and meta-analysis that explores and synthesises the available literature investigating latissimus dorsi EMG data during trunk movement and stability tasks. This also involved examining the methodological processes used in the included studies. It provided weak evidence that latissimus dorsi is active at high levels during ipsilateral rotation and stronger evidence that it is active at low levels during contralateral rotation, extension and trunk stability tasks. The review also showed that surface electrodes are universally used in previous studies, and that trunk tasks were the most common task used to normalise the raw EMG data. This review has been published in the *Physical Therapy Reviews* Journal.

Chapter 3 and 4 are methodological studies that aimed to validate whether shoulder or trunk tasks produce maximal activity in latissimus dorsi for normalisation purposes and whether surface electrodes are valid when recording latissimus dorsi activity during trunk tasks. Chapter 3 showed that shoulder extension was superior to trunk tasks in eliciting a maximal contraction in latissimus dorsi and should be used as the normalisation task when investigating latissimus dorsi activity during trunk tasks. This study has been published in the *Journal of Electromyography and Kinesiology*. Chapter 4 showed that surface and indwelling electrodes recorded similar levels of activity during submaximal trunk tasks. However, different levels were recorded during maximal trunk tasks and trunk stability tasks. This led to the conclusion that surface electrodes are appropriate to use at submaximal trunk movement tasks, but indwelling electrodes should be used for maximal loads or during trunk stability tasks. This study has been published in the *Journal of Electromyography and Kinesiology.*

Chapter 5 and 6 are experimental studies utilising the validated methodology of the studies in chapters 3 and 4 to investigate the activity levels of latissimus dorsi during various trunk tasks. Chapter 5 explored latissimus dorsi activity during a combination of submaximal and maximal trunk extension, flexion, rotation and lateral in various positions. The results showed that latissimus dorsi activity was less than 20% MVC during all submaximal trunk tasks, and even during maximally resisted trunk tasks it only achieved between 31% and 43% MVC. This manuscript has been submitted to the *Journal of Clinical Biomechanics*. Chapter 6 assessed latissimus dorsi's contribution to trunk stability during isometric limb movements in standing and shows that latissimus dorsi is active at low levels during these trunk stability tasks, with no difference when supporting the contralateral arm on the pelvis. This manuscript has been submitted to the *Journal of Clinical Biomechanics.*

Chapter 7 is the concluding chapter and includes the summation of the main findings and contextualises it within the current understanding of latissimus dorsi function and discusses the implications for clinical practice.

The appendix contains the ethics approval, consent form and participant information sheet for the experiment.

Other presentations

World Congress of Physical Therapy 2025. Abstract accepted for poster presentation. Titled: Do maximal isometric trunk tasks produce maximum activation in latissimus dorsi?

Does latissimus dorsi contribute to trunk movement and stability? Australasian Society for Human Biology Conference 2022

Latissimus dorsi has limited contribution to trunk movement and stability: A systematic review and meta-analysis. Australian and New Zealand Association of Clinical Anatomists Conference 2022

Oral presentation to the research group at The University of Sydney 2021

The role of latissimus dorsi in trunk stability. Sydney Musculoskeletal Annual Scientific Meeting 2019.

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Chapter 1: Introduction and Literature Review

1.1 The latissimus dorsi

The latissimus dorsi is a broad, flat, triangular muscle that spans the trunk and upper limb, notable for its extensive attachments to the thoracic, lumbar and pelvic regions and its integration into the thoracolumbar fascia (TLF). Despite being the largest and most superficial muscle of the trunk, its functional role in trunk movement and stability remains poorly understood, making it an important but understudied target for research.

It originates from the trunk and inserts onto the floor of the intertubercular groove of the humerus via a wide, thin tendon (Fig. 1) (Palastanga and Soames, 2018, Siu et al., 2016). It is the largest and most superficial muscle of the trunk, with extensive attachments that include the lower six thoracic vertebrae, ribs nine to twelve, all lumbar and sacral vertebrae and the iliac crest of the pelvis (Fig. 2). A significant proportion of its muscle fibres are in the thoracic region, while in the lumbar region its fibres are primarily aponeurotic, forming the superficial layer of the TLF (De Ridder et al., 2013, Palastanga and Soames, 2018). The superior fibres are oriented more horizontally, while the inferior fibres run more vertically as described by Willard et al., (2012).

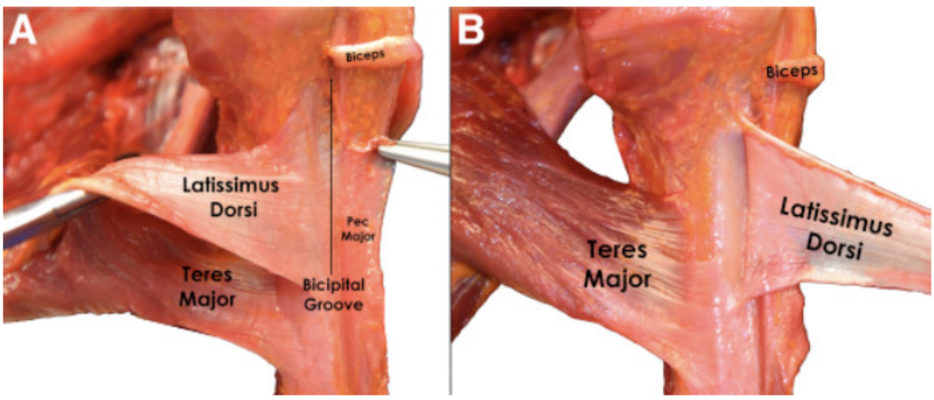


Figure 1.Wide, thin tendon of latissimus dorsi inserting onto the floor of the intertubercular groove. a) anterior view of tendon with pectoralis major removed, b) tendon pulled laterally. Source: Moatshe et al., 2018

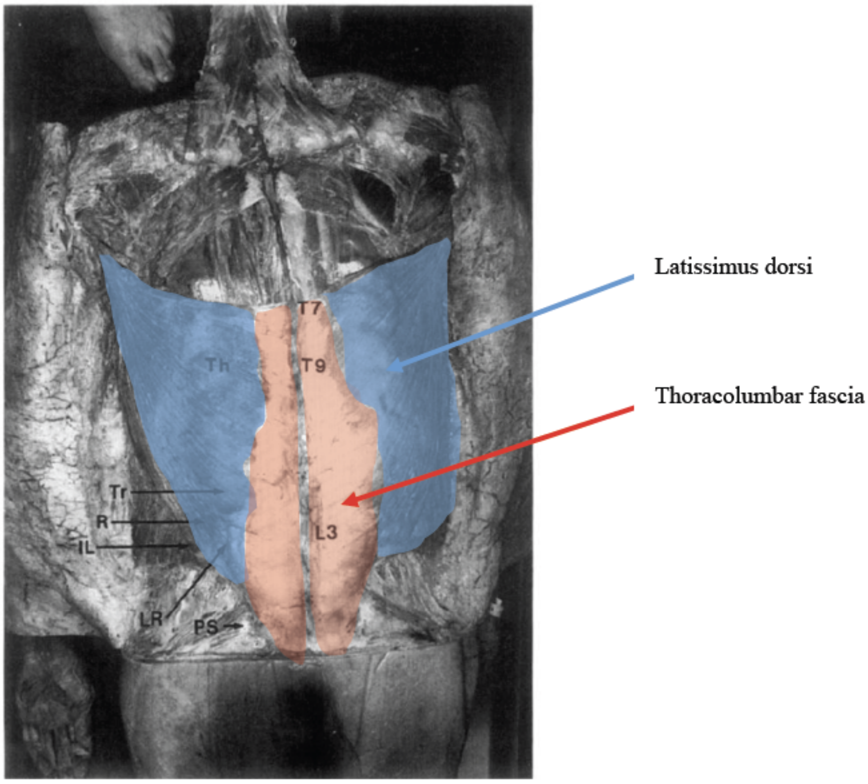


Figure 2. Posterior view of the trunk with latissimus dorsi dissection. LR: lateral raphe, Th: thoracic fibres, Tr: transitional fibres, R: raphe fibres, IL: iliac fibres, PS: posterior superior iliac spine. Adapted from Bogduk et al., 1998

Functionally, the latissimus dorsi is typically considered to be a shoulder muscle with its principal actions to extend, adduct and internally rotate the humerus when the proximal attachments are stabilised (Dark et al., 2007, Drake et al., 2006, Palastanga and Soames, 2018, Reed et al., 2010, Wattanaprakornkul et al., 2011). However, its broad trunk attachments and fascial connections suggest biomechanical plausibility for contributing to trunk movement and stability, particularly via force transfer through the TLF. When the origin and insertion are reversed, such in weight-bearing through the upper limb or hanging from a bar, it helps to elevate the trunk and depress the shoulder girdle (Veeger and van der Helm, 2007). These structural and functional features position the latissimus dorsi as a potential link between upper and lower body mechanics.

1.2 Rationale for research

Low back pain (LBP) is one of the most common and costly musculoskeletal conditions worldwide, affecting up to 84% of the population over a lifetime (Balague et al., 2012, Hayden et al., 2005). LBP imposes a substantial economic and social burden, accounting for 38.5% of musculoskeletal disorders resulting in work absence in 2016 (Balague et al., 2012, Hayden et al., 2005, Statistics, 2016). Around 10-50% of acute cases develop chronic symptoms (Balague et al., 2012, Costa et al., 2012, Itz et al., 2013, Pengel et al., 2003, Tsang et al., 2021), and 60-80% recur within a year (Airaksinen et al., 2006). Factors often associated with chronicity include psychosocial and lifestyle factors, occupational demands, and a prior history of LBP (Balague et al., 2012, da Silva et al., 2017, Tsang et al., 2021).

Many anatomical structures within the trunk can contribute to LBP, including joints, intervertebral discs, ligaments, muscles, organs, and nerves (Adams and Roughley, 2006, Balague et al., 2012, Bogduk et al., 2013). Among these, the intervertebral discs and muscles are commonly implicated. Intervertebral discs function as fibrous joints, allowing motion while supporting the spine, and are a well-recognised source of pain due to clearly defined injury mechanisms and symptom patterns. The sacroiliac joint (SIJ) facilitates force transfer from the lower limbs through the pelvis to the trunk, with stability maintained through form closure (joint shape and passive structures) and force closure (muscular compression across the joint) (Willard et al., 2012). Both spinal and pelvic structures are vulnerable to injury from high traumatic loads or repetitive shear forces.

While multiple anatomical structures can be involved, impaired trunk muscle coordination is increasingly recognised as a key factor in symptom persistence and recurrence (Tsang et al., 2021). Muscles with broad trunk attachments and connections to the TLF, such as the latissimus dorsi, are well placed to influence both spinal movement and load transfer, yet their contributions remain under-investigated. There is growing evidence suggesting that individualised strengthening exercise programs can be helpful in treating chronic LBP by targeting trunk muscles that control spinal segmental movement, such as the latissimus dorsi, multifidus, and transverse abdominis (Balague et al., 2012, Hayden et al., 2005, Tsang et al., 2021). Current rehabilitation approaches, such as the Keele STarT Back model, recommend stratified care, ranging from general exercise for low-risk patients to specific trunk muscle retraining for higher-risk groups in combination with psychological approaches (Hay et al., 2008, Hill et al., 2011). However, without a clear understanding of whether the latissimus dorsi meaningfully contributes to trunk function, its inclusion in such targeted programmes is based more on anatomical assumption rather than evidence.

Understanding the functional contribution of latissimus dorsi to trunk movement and stability in the asymptomatic population may help guide targeted rehabilitation strategies for individuals with low back pain, where impaired trunk muscle coordination is often observed. Given the high prevalence of LBP, the potential but unproven role of latissimus dorsi in trunk movement and stability, and the lack of methodological clarity in EMG studies, there is a clear need for research that directly investigates its functional contribution to trunk movement and stability.

1.3 Trunk Movement

The trunk comprises the spine, pelvis, and ribcage along with the muscles and soft tissues attaching to these structures. As described in Panjabi's model, trunk movement is achieved through the coordination of three interdependent subsystems: passive, active and neural (Panjabi, 1992a).

The *passive subsystem* consists of all the non-contractile structures in the trunk, such as the vertebrae, intervertebral discs, facet joints, ligaments and joint capsules. The summation of the shape and size of the joints in the trunk determine the direction and amount of movement available. In the thoracic spine, the articular facets are vertically aligned, with the superior facets facing posteriorly and the inferior facets anteriorly. This facilitates axial rotation while limiting flexion and extension and the presence of the rib cage limits the amount of lateral flexion available in the trunk. In contrast, the lumbar spine has obliquely oriented, J-shaped facet joints that facilitate flexion and extension while limiting rotational movement. The spinal ligaments are also important passive structures which provide increasing levels of resistance at end ranges to limit excessive joint motion (Panjabi, 1992b).

The *active subsystem* consists of the muscles and their tendinous attachments, which generate movement by applying tension to the skeletal structures. Depending on their anatomical positioning and orientation, muscles may either function to generate movement at a segment or limit movement and create stability.

As described above, latissimus dorsi has the potential to contribute to trunk movement due to its extensive attachments. Electromyography (EMG) is the most effective method for assessing muscle activation during motor tasks and is, therefore, a valuable resource in studying muscle function. EMG studies have demonstrated that the latissimus dorsi contributes significantly to trunk movements with high levels of latissimus dorsi activation during trunk rotation, extension and lateral flexion (Palastanga and Soames, 2018, Stevens et al., 2007a, Vera-Garcia et al., 2010). However, reported activity levels vary widely between studies when compared at the same load, particularly during maximum efforts. For example, latissimus dorsi activity at maximum load ranged from 26% to 82% maximum voluntary contraction (%MVC) during ipsilateral trunk rotation (O'Brien and Potvin, 1997, Stevens et al., 2007a), 15% to 85% MVC during ipsilateral trunk lateral flexion (Perez and Nussbaum, 2002, Vera-Garcia et al., 2010) and 10% to 78% MVC during trunk extension (Perez and Nussbaum, 2002, Vera-Garcia et al., 2010). However, the extent to which latissimus dorsi can contribute to trunk movement has been questioned by some authors. They argue that it primarily functions as an upper limb muscle due to the fibre directions only allowing the muscle to influence specific regions of the lumbar spine and only allows low levels of force generation (Bogduk et al., 1998).

1.4 Trunk Stability

The *neural subsystem*, consisting of nerves and receptors embedded within muscles, tendons, and ligaments, plays a critical role in determining muscle recruitment patterns, timing, and activation intensity through proprioceptive feedback. This coordinated interaction between neural and muscular elements not only produces movement but is also fundamental in maintaining stability. Trunk stability, or trunk control, refers to the ability to control the position and motion of the trunk and pelvis in a desired trajectory while facilitating the optimal production and transfer of force to and from the limbs (Cholewicki and VanVliet, 2002, Kibler et al., 2006, Stevens et al., 2007b). To achieve both trunk movement and protection of neurovascular structures, efficient muscle recruitment is essential to control and limit motion at the vertebral and sacroiliac joints (Cholewicki and VanVliet, 2002, Lee et al., 2009, McGill et al., 2003, Panjabi, 1992a). Muscles have an important role in providing stability to these joints through their compressive forces, particularly in the neutral zone where the ligaments are lax and contribute minimally to mechanical stability (Panjabi, 1992b). While ligaments contribute minimal mechanical stability in the neutral zone, they are thought to have an important proprioceptive role. Feedback from ligament and tendon receptors aids coordination of the balanced activation of the deep and superficial trunk muscles in response to changes in posture and movement, and thus creating controlled motion and dynamic trunk stability (Hodges et al., 1999, Lee et al., 2009, 2011, McGill et al., 2003).

Optimal muscle recruitment is task specific and dependent on many factors such as load, speed and direction of movement (Hodges et al., 1999, Lee et al., 2009, 2011, McGill et al., 2003). In individuals with dysfunctional movement patterns, such as movements seen in people with LBP, rehabilitation is often targeted at improving the motor control and strength of trunk muscles to restore the balance of forces across the vertebrae. Delayed or altered muscle recruitment has been consistently observed in this population and this is a common focus of intervention (Brandl et al., 2022, Panjabi, 1992a, Pool-Goudzwaard, 1998, Suehiro et al., 2025). As previously mentioned in section 1.2, current rehabilitation recommendations suggest a stratified approach, with individuals at higher risk of developing chronic pain may benefit from more targeted interventions, whereas those at lower risk may respond well to general exercise programs (Hay et al., 2008, Hill et al., 2011).

Multiple muscle recruitment strategies have been observed which are thought to contribute to trunk stability, depending on the demands of a task at a particular point in time (Kavcic et al., 2004). These strategies include:

- Activation of the diaphragm and muscles of the anterior abdominal wall muscles, which increases intra-abdominal pressure to stiffen the spine (Bojairami and Driscoll, 2022, Hodges et al., 1999, Kennedy, 1965)
- The recruitment of segmentally attached muscles, such as the psoas major and quadratus lumborum, directly compress the vertebra, thereby 'pre-tensioning' the intervertebral discs and enhancing spinal stiffness (Cholewicki and McGill, 1996, McGill, 1991).

- Activation of intersegmental muscles, such as the multifidi and the rotatores, which help limit intervertebral shear forces and may also provide proprioceptive feedback as a protective mechanism (Cholewicki et al., 1997, Kavcic et al., 2004a).
- Coordinated contraction of muscles attaching to the TLF, including the latissimus dorsi, gluteus maximus, internal oblique and transverse abdominis. These muscles tension the TLF facilitating load transfer from the pelvis to the lumbar spine, thereby enhancing spinal stiffness and reducing shear forces (Barker and Briggs, 1999, Bojairami and Driscoll, 2022, Carvalhais et al., 2013, Marpalli et al., 2022, Pool-Goudzwaard, 1998). The latissimus dorsi is thought to contribute to trunk stability through its extensive attachment to the TLF.

The TLF is a large, diamond-shaped structure composed of aponeurotic and fascial layers that attach along the spinous and transverse processes of the vertebra from the sacrum to the thoracic spine (Fig. 3) (Vleeming et al., 1995). It is commonly described as comprising of three layers (Fig. 4): the superficial (posterior) layer, which blends the latissimus dorsi, gluteus maximus, trapezius and serratus posterior inferior and encloses the erector spinae (Marpalli et al., 2022); the middle layer, which passes between the paraspinals and the quadratus lumborum and connects with the internal oblique and transverse abdominis; and the deep (anterior) layer which lies anterior to the quadratus lumborum and also links the transverse abdominis and internal oblique along with the biceps femoris via the sacrotuberous ligament (Palastanga and Soames, 2018, Pool-Goudzwaard, 1998, Willard et al., 2012). Collectively, these muscles modulate the stiffness of the TLF to balance force transmission across the lumbar spine and SIJ (Carvalhais et al., 2013, Willard et al., 2012). The overlapping cross-pattern fibres of the TLF over the SIJ are thought to contribute to the force closure by facilitating the coordinated contraction of the contralateral gluteus maximus and latissimus dorsi (Pool-Goudzwaard, 1998). This anatomical configuration, termed the posterior oblique sling (Fig. 5), functionally couples the lumbosacral region with both upper and lower limbs, integrating the trunk into the kinetic chain and enhancing central stability during distal movements (De Ridder et al., 2013, Kibler et al., 2006, Marpalli et al., 2022, Ng et al., 2001, Stevens et al., 2007b).

Figure 3. Posterior view of the superficial layer of the thoracolumbar fascia with fascial lines. Adapted from Willard et al., 2012

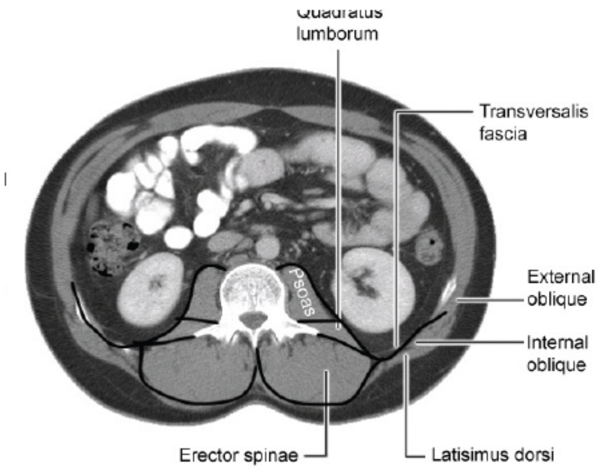


Figure 4. Transverse view of the thoracolumbar fascia (black line). Adapted from LumbarTriangle.jpg (Zyryab, 2007, Wikimedia Commons, CC BY-SA 3.0).

Figure 5. The posterior oblique sling. Adapted from Willard et al., 2012

The posterior oblique sling is thought to play a critical role in trunk and pelvic stability, particularly through its influence on the lumbar spine and SIJ. For example, during gait there is a reciprocal pattern of activity where during right trunk rotation, the right latissimus dorsi and left gluteus maximus demonstrate increased activity (Willard et al., 2012). Cadaveric and imaging studies have demonstrated that contraction of muscles inserting into the TLF can tension the fascia, increasing stiffness and enhancing spinal stability (Barker and Briggs, 1999, Vleeming et al., 1995). This mechanism has been proposed as a target in rehabilitation for LBP, with studies reporting reduced myofascial force transmission in individuals with chronic LBP (Procopio et al., 2025). Accordingly, exercises aimed at enhancing coordination between the latissimus dorsi and gluteus maximus have formed part of rehabilitation strategies (Barker and Briggs, 1999, Willard et al., 2012). However, the significance of latissimus dorsi contributing to SIJ and lumbar spine stability remains unclear, with some evidence suggesting the role may be minimal (Bogduk et al., 1998). Additionally, the TLF may also contribute to proprioception through mechanoreceptors within the fascial tissue and connections with spinal ligaments (Willard et al., 2012).

It has been observed that in individuals with chronic LBP there is an alteration in the connective tissue of the lumbar spine compared to those without LBP, with ultrasound imaging showing increased thickness and echogenicity of the peri-muscular connective tissue, and reduced elasticity of the TLF (Langevin et al., 2009). Additionally, in individuals with LBP, the stiffness of the TLF has also been shown to be reduced (Langevin et al., 2011, Procopio et al., 2025, Vatovec and Voglar, 2024). At this stage it is unknown as to whether this is a cause of LBP or a result of LBP.

EMG studies investigating trunk stability tasks have shown that some muscles work in a direction specific pattern, while others, such as the multifidus and erector spinae muscles, work independent of movement direction (Hodges et al., 1999, Lee et al., 2011). The coordinated timing of muscle activation is also crucial for trunk stability as stabilising muscles, such as the transverse abdominis, activate prior to the torque generating muscles, serving as anticipatory postural adjustments (Hodges et al., 1999; Marras & Granata, 1995; Willard et al., 2012).

A limited number of EMG studies have investigated the role of latissimus dorsi in trunk stability. During low-load frequently used trunk stability tasks in the four-point kneeling position latissimus dorsi was shown to be activated at low levels (≤13% MVC) (Stevens et al., 2007b). As the load increases (e.g. from lifting one to two limbs) its activity also increased systematically (Callaghan et al., 1998a, Drake et al., 2006, Stevens et al., 2007b). A pattern was observed in some studies during leg extension where the contralateral latissimus dorsi exhibited higher activity levels compared to the moving side (Drake et al., 2006, Kavcic et al., 2004b). This contrasted with other studies reporting no side-specific differences (Callaghan et al., 1998a, Stevens et al., 2007b). This increase in activity may reflect a stabilising rather than mobilising function of the latissimus dorsi. One study investigating the timing of latissimus dorsi activation during arm flexion in standing, found that during right shoulder flexion the contralateral latissimus dorsi activity increased at the time of movement onset, indicating an anticipatory postural adjustment to stabilise the trunk by anchoring the shoulder girdle (Esposti and Baldissera, 2013).

1.5 Electromyography methodological considerations

1.5.1 Normalisation processes

In EMG research, the normalisation process is a critical methodological factor in the analysis and interpretation of EMG data. Normalisation refers to the process where the EMG signals recorded during a task are expressed relative to a standard reference value. Ideally, this task is repeatable, such as a percentage of maximal voluntary contraction (%MVC) (Besomi et al., 2020). This reference value is typically produced from a maximal effort task that is assumed to activate the muscle to its full capacity. This process is crucial as it allows comparisons across individuals, tasks and studies, thereby enhancing the validity and reproducibility of findings (Besomi et al., 2020). Differences in normalisation methods, such as using MVCs from either trunk or upper limbs, can substantially influence reported activity levels and complicate comparisons within and between studies and may obscure the true role of the muscle.

In studies investigating trunk movements, maximally resisted trunk tasks have commonly been used to normalise latissimus dorsi activity (Lavender et al., 1992, McGill et al., 2003, Ng et al., 2002, Perez and Nussbaum, 2002, Talebian et al., 2010). However, these maximal trunk tasks have not been rigorously compared to determine if they produce true maximal latissimus dorsi activation. Two isometric shoulder tasks, maximally resisted shoulder extension with internal rotation and shoulder internal rotation in 90° abduction (Boettcher et al., 2008, Ginn et al., 2011) have been shown to elicit maximum activity from latissimus dorsi during shoulder movements and are commonly used for normalisation purposes when recording latissimus dorsi activity during shoulder movements. If unvalidated trunk movements, which produce submaximal latissimus dorsi activation levels, are used as a reference point, it may lead to inaccurate or inconsistent %MVC values within a study and between studies. This could result in considerable variability in EMG data across previous studies and misrepresentation of the muscle's actual contribution during trunk tasks. More specifically, using submaximal normalisation tasks may overestimate the role of latissimus dorsi in trunk function, leading to incorrect assumptions regarding its involvement in normal function and in back pain. Validation of the commonly used trunk tasks, rotation, lateral flexion and extension, by comparing them to validated maximum eliciting tasks, is needed to confirm whether these tasks are appropriate to use for normalising latissimus dorsi activity.

1.5.2 Electrode choice

Surface EMG is a widely used method for studying muscle activation patterns and is universally used to record latissimus dorsi activity due to the muscle's large, broad, and superficial anatomical features. However, recording from latissimus dorsi presents specific challenges as it is relatively thin, which increases the risk of crosstalk from nearby muscles (Ginn and Halaki, 2015). This is a potential limitation when using surface electrodes to study latissimus dorsi function. A study by Ginn and Halaki (2015) directly compared surface and indwelling electrode recordings by inserting an indwelling electrode into the latissimus dorsi at a commonly used insertion site, 4 cm below the inferior angle of the scapula, and placing two bipolar surface electrodes directly over the same region. Muscle activity was then recorded during shoulder movements expected to elicit high latissimus dorsi activation levels (shoulder extension and adduction), as well as movements expected to produce low activation levels (shoulder flexion and abduction). The results showed no difference between electrode types during movements that strongly engaged latissimus dorsi. However, during movements of the shoulder that involved minimal latissimus dorsi activation, the surface electrodes recorded higher activity levels compared to the indwelling electrodes. Further investigation confirmed that this was due to crosstalk from the underlying erector spinae, which was active in these tasks to stabilise the spine. The authors therefore concluded that surface electrodes are not valid for recording latissimus dorsi activity during shoulder movements where the latissimus dorsi was expected to be inactive or low activation. It remains unclear whether similar misrepresentation occurs when surface electrodes are used to record latissimus dorsi activity during trunk tasks. If so, previous studies using surface electrodes to investigate latissimus dorsi activity during trunk movements and stability tasks may have overestimated the muscle's involvement.

These methodological considerations are not trivial; if activation is overestimated due to suboptimal normalisation or electrode use, conclusions about latissimus dorsi's contribution to trunk stability may be misleading.

1.6 Aim of thesis

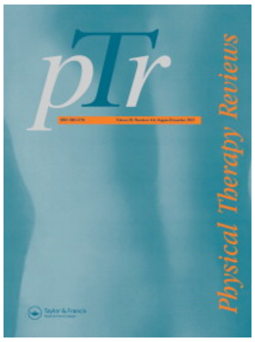
Despite a general belief that latissimus dorsi contributes to both trunk movement and stability and is commonly targeted alongside gluteus maximus in trunk rehabilitation programs, there is limited robust evidence to support this role. The existing literature is confounded by methodological limitations, particularly the widespread use of surface electrodes and non-validated EMG normalisation techniques, which may compromise data accuracy and interpretation. It remains unclear whether surface EMG is appropriate for this muscle, or whether trunk tasks are suitable for EMG normalisation. These choices can significantly affect how latissimus dorsi function is represented, leading to uncertainty around its role in trunk control and partly explain the conflicting findings regarding latissimus dorsi's involvement in trunk function. Therefore, there is a need to adopt validated, consistent EMG methodologies to ensure a more accurate understanding of latissimus dorsi's contribution to both research and clinical practice.

Therefore, the overall aim of this thesis was to comprehensively investigate the role of latissimus dorsi during trunk movement and stability tasks, using methodologically sound EMG approaches. This thesis seeks to clarify whether latissimus dorsi meaningfully contributes to trunk function and provide practical recommendations for future research and rehabilitation. The following questions, and their hypotheses, helped to guide the research for this thesis and formed the focus for each chapter:

1. What is the current understanding of latissimus dorsi's contribution of trunk movement and stability?
2. Do maximal isometric trunk tasks produce maximum activity in latissimus dorsi?
    - It is hypothesised that maximal trunk tasks do not produce maximal activity in latissimus dorsi. It is hypothesised that shoulder MVCs produce higher activity levels than trunk MVCs.
3. Are surface electrodes valid in measuring activity levels from latissimus dorsi?
    - It is hypothesised that surface electrodes are not valid for measuring latissimus dorsi activity levels and will record higher levels of latissimus dorsi activity compared to indwelling electrodes due to activity from the underlying erector spinae.
4. How active is latissimus dorsi during trunk movements (using validated methodology)?
    - It is hypothesised that latissimus dorsi will be active at high levels during resisted ipsilateral rotation, lateral flexion, and extension.
5. Does latissimus dorsi contribute to trunk stability?
    - It is hypothesised that latissimus dorsi contributes to trunk stability, particularly the contralateral latissimus dorsi during shoulder flexion. Additionally, it is hypothesised that fixing the contralateral upper limb to the pelvis would result in increased latissimus dorsi activity as it can exert more force onto the trunk.

Taken together, the anatomical plausibility, biomechanical models and inconsistent EMG evidence point to a clear gap in understanding the functional role of latissimus dorsi in trunk movement and stability. This thesis addresses that gap by systematically examining its activation across a range of trunk tasks, considering both methodological influences and clinical implications for rehabilitation.

Chapter 2: What is the contribution of latissimus dorsi to trunk movement and control? A Systematic Review and Meta-Analysis.



Physical Therapy Reviews

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/yptr20

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To cite this article: Declan Price, Karen A. Ginn, Mark Halaki & Darren Reed (05 Jun 2024): What is the contribution of latissimus dorsi to trunk movement and control? A systematic review and meta-analysis, Physical Therapy Reviews, DOI: 10.1080/10833196.2024.2359815

To link to this article: https://doi.org/10.1080/10833196.2024.2359815

Published online: 05 Jun 2024.

PHYSICAL THERAPY REVIEWS
https://doi.org/10.1080/10833196.2024.2359815

What is the contribution of latissimus dorsi to trunk movement and control? A systematic review and meta-analysis

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ABSTRACT

Background: Latissimus dorsi may contribute to trunk movement and control because of its extensive attachments to the trunk. However, electromyography studies have shown highly variable activity levels during trunk tasks.
Objective: To critically evaluate whether latissimus dorsi has a role in trunk movement and/or control.
Methods: Studies assessing the activation of latissimus dorsi using electromyography during trunk movements and/or trunk stability tasks were sourced (May 2022). Risk of biases and quality of evidence was assessed. Activation levels were pooled and meta-analysed where possible.
Results: Thirty nine of 6125 studies identified in the search met the inclusion criteria. The meta-analyses showed high latissimus dorsi activity levels (60% maximal voluntary contraction [MVC]) during ipsilateral trunk rotation and low levels (<20% MVC) during contralateral trunk rotation, extension and stability tasks. Considerable variability of activity levels existed between studies when using high loads. Quality of evidence was very low to moderate.
Conclusion: Although high activity levels were found during ipsilateral trunk rotation, there is very low confidence that these activity levels reflect the true levels. There is moderate confidence latissimus dorsi has a limited contribution to trunk control. The use of surface electrodes and non-validated normalisation processes were critical methodological issues that contributed to lower quality of evidence.

ARTICLE HISTORY
Received 7 February 2023
Accepted 19 May 2024

KEYWORDS
Electromyography; latissimus dorsi; trunk; control; movement

Introduction

Latissimus dorsi is a broad, flat, triangular muscle with extensive attachments arising from the spine, ribs and pelvis that converge onto the intertubercular groove of the humerus [1]. Because of these expansive attachments to the axial skeleton, latissimus dorsi has the potential to play a significant role in trunk movement and/or control. As a result, treatment aimed at improving latissimus dorsi function has been incorporated into rehabilitation programs for people with back pain [2].

Efficient trunk control and movement are required to successfully interact with our environment by allowing optimal production and transfer of force to the lower limbs for locomotion and to the upper limbs for manipulation [3]. This is achieved by the muscular system working in a coordinated manner to create a stable yet adaptable platform from which the limbs can work, with many muscles contributing to this system depending on the requirements of the task [4–8]. Trunk control will be compromised if there is a non-optimal recruitment pattern of the trunk muscles, which will consequently impact task performance and can lead to increased abnormal loads on spinal structures potentially resulting in pain [9,10].

It is believed that latissimus dorsi contributes to trunk control *via* its attachment through the thoracolumbar fascia (TLF) to the transverse and spinous processes of the spine [11,12]. In conjunction with other muscles that attach to the TLF (gluteus maximus, internal oblique, transverse abdominus) latissimus dorsi can tension the TLF to stiffen the spine and allow forces to be transmitted between the upper and lower limbs [11–14]. Exercises targeting this group of muscles that tension the TLF are often incorporated into rehabilitation programs aimed at improving trunk control in people with low back pain [2,15].

The contribution of latissimus dorsi to trunk movement and control has been investigated by measuring the activity levels of latissimus dorsi as a percentage of maximal voluntary contraction (%

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MVC) during various trunk tasks. However, electromyographic (EMG) studies have shown wide variations in latissimus dorsi activity levels when investigating similar trunk tasks at similar loads. For example, levels range from 26% to 116% MVC [16,17] during ipsilateral trunk rotation with high resistance, and from 15% to 85% MVC [18,19] during ipsilateral trunk lateral flexion with high resistance. With such wide variations in activity levels, it is difficult to draw conclusions in regards to the contribution of this important muscle to trunk movement and control. Therefore, the aim of this systematic review was to synthesise and critically evaluate all EMG evidence investigating latissimus dorsi activity levels during trunk tasks to determine its contribution to trunk movement and control.

Methods

Protocol

This systematic review was conducted and reported according to the PRISMA statement [20]. The protocol was registered on the international prospective register of systematic reviews (PROSPERO), ID number: CRD42018089210 (February, 2018).

Eligibility criteria

All studies assessing the activation of latissimus dorsi using EMG during trunk movements and/or lower limb movements were included in this systematic review. All study designs were included if they reported on adults over 18 years of age with no current shoulder or back pain, were published in English and reported a muscle activation level as % MVC during cardinal plane trunk movements and exercises traditionally used for trunk control. Studies were excluded if they were conference abstracts, used unstable surfaces or investigated latissimus dorsi activity involving upper limb movements as it would be difficult to differentiate between the latissimus dorsi effect on the shoulder or trunk.

Search strategy

A search of all relevant literature prior to May 2022 was completed using the following databases: Medline, EMBASE, PubMed, CINAHL, SCOPUS and SPORTDiscus. In consultation with a librarian, the following search strategy was developed: *(EMG OR electromyography) AND ('latissimus dorsi' OR 'superficial back muscles' OR trunk OR torso OR back OR pelvis OR thorax) AND (stability OR movement)*. Screening of the reference lists was also undertaken on all relevant articles.

Study selection

The studies were retrieved from the databases, collated in Endnote software (EndNote X9) and duplicates removed. Two authors (DP and DR) independently reviewed the titles and abstracts of all sourced articles. Relevant studies identified from this process were saved for further review of the full text. Full texts were sourced and independently reviewed by pairs of authors. Disagreements were discussed within the pairs and if an agreement could not be reached a third author was consulted until a consensus was formed. A list of relevant articles was finalised for data extraction.

Data extraction and synthesis

Descriptive data from relevant studies were extracted by DP and independently checked by DR with any discrepancies discussed by all authors. Data included mean age, sex, electrode type, electrode location, normalisation process and tasks.

The primary outcome measure of this study was the activation level of latissimus dorsi expressed as % MVC. The activation levels were extracted by DP, independently checked by DR and grouped based on the tasks performed and load employed. Load was divided into seven categories based on either the percentage of maximum voluntary exertion (MVE) (minimal = 0–9% MVE, low = 10–29% MVE, moderate = 30–59% MVE, high = 60–89% MVE and maximum = 90–100% MVE), use of body weight (unresisted) or other load (speed, N.m, kg). Where activation levels were presented in graphs a customised script in Matlab (R2019, the Mathworks, Inc., Natick, MA) was used to estimate the values.

Methodological quality assessment

Methodological quality of the studies was assessed using 11 items from the Downs and Black quality assessment tool [21]. The items retained from this tool were considered relevant for laboratory EMG studies and gave a total score out of 11. These included: clear hypothesis (Item 1), outcome measures clearly described (Item 2), participant characteristics clearly described (Item 3), experimental conditions clearly described (Item 4), main findings clearly described (Item 6), estimates of random variability provided (Item 7), lost data reported (Item 9), actual p values reported (Item 10), participants represent entire population (Item 12), appropriate statistical tests used (Item 18) and valid and reliable outcome measures used (Item 20). The descriptive explanation for item 9 was defined as the reporting of lost data from an EMG channel during the experiment, item 12 was defined as asymptomatic subjects but not elite or trained individuals and for item 20 the use of surface electrodes to record latissimus dorsi activity was considered invalid due to potential cross-talk from adjacent muscles [22]. The description of all other items was as per the original form. To standardise the methodological quality extraction process and clarify the meaning and interpretation of critical appraisal items, data were extracted from two studies independently by all authors and discussed. Two authors (DP and DR) then independently extracted data from the remaining studies and any discrepancies were resolved with a third author.

Overall quality of the evidence used in each individual meta-analysis was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) rating approach. Quality was downgraded for the following reasons [23,24]:

- High risk of bias: >60% of studies scoring <9/11 on the modified Downs and Black or the use of surface electrodes to record latissimus dorsi activity, which was considered to be a crucial limitation sufficient to lower confidence in the outcome [25].
- High publication bias: Visual inspection of funnel plot showing asymmetrical spread.
- Imprecision: Large 95% confidence intervals.
- Inconsistency: Heterogeneity between studies was large ($I^2 > 50\%$).
- Indirectness was not considered as only studies with similar target populations, methodological conditions and outcome measures were included.

Statistical analysis

Separate meta-analyses to pool the means and standard deviations (SDs) across studies were performed using the Comprehensive Meta-Analysis software (CMA version 3, Biostat, Englewood, NJ) for each task where there were three or more homogenous studies reporting % MVC values for latissimus dorsi with a SD. A random effects model was used when heterogeneity among studies was significant as indicated by a significant Q-value. The results indicate that all Q values were significant; therefore, a random effects model was used for all meta-analyses. Studies were grouped together if they used the same load, same electrode type, similar normalisation processes and if they provided a measure of variability (standard error or SD). Studies that reported more than one outcome value for latissimus dorsi activation levels during each task had their values pooled together using the meta-analysis software to give one value per study per load range. If the values within the same study were unable to be pooled (no variability measure) then the values were averaged but not included in the meta-analyses.

Results

The results of the literature search are presented in Figure 1. The combined searches yielded a total of 6125 studies following the removal of duplicates. After reviewing the titles and abstracts and manually scanning the reference lists, 79 studies were selected for full text review. Thirty-nine studies met the criteria for inclusion in this systematic review.

Study characteristics

Characteristics of the included studies are summarised in Table 1. The overall age of the combined cohort was young (<30 years old) and mostly male (66%). The tasks and the number of studies investigating each task (note that some studies reported on multiple tasks) were as follows: ipsilateral trunk rotation (16 studies), contralateral trunk rotation (13 studies), trunk extension (18 studies), trunk flexion (14 studies), ipsilateral trunk lateral flexion (11 studies), contralateral trunk lateral flexion (8 studies), combined trunk movements (2 studies) and limb movements in four-point kneeling (4 studies).

Surface electrodes were used in all but one included study. The placement of electrodes varied slightly with 21 studies (54%) placing the electrodes lateral to T9, about 4 cm below inferior angle of the scapula, five studies (13%) placing them lateral to T12, four studies (10%) placing them lateral to T7, one study (3%) placing them 15 cm lateral to T9 and eight studies (21%) not mentioning a specific location.

Out of the 39 studies, 38 (97%) used a MVC to normalise the EMG data. Twelve studies (31%) used shoulder movements (extension and/or lateral pull down) and 21 studies (54%) used a combination of trunk movements (flexion, extension, lateral flexion and/or rotation) as the MVC task. It was unclear in five studies (13%) how normalisation was completed. Direct comparison could only be made between latissimus dorsi activity normalised to a trunk or a shoulder task during trunk extension and ipsilateral trunk lateral flexion [18,19,22]. Large variations in latissimus dorsi activity were reported, ranging from 10% to 79% MVC during trunk extension and 15–85% MVC during ipsilateral trunk lateral flexion, dependant on the chosen normalisation task (Figure 2).

Methodological quality

Most studies ($n = 33$, 85%) included in this review scored highly (≥8/11) using the modified Downs and Black checklist (Appendix 1). All studies scored well with the description of their hypothesis (Item

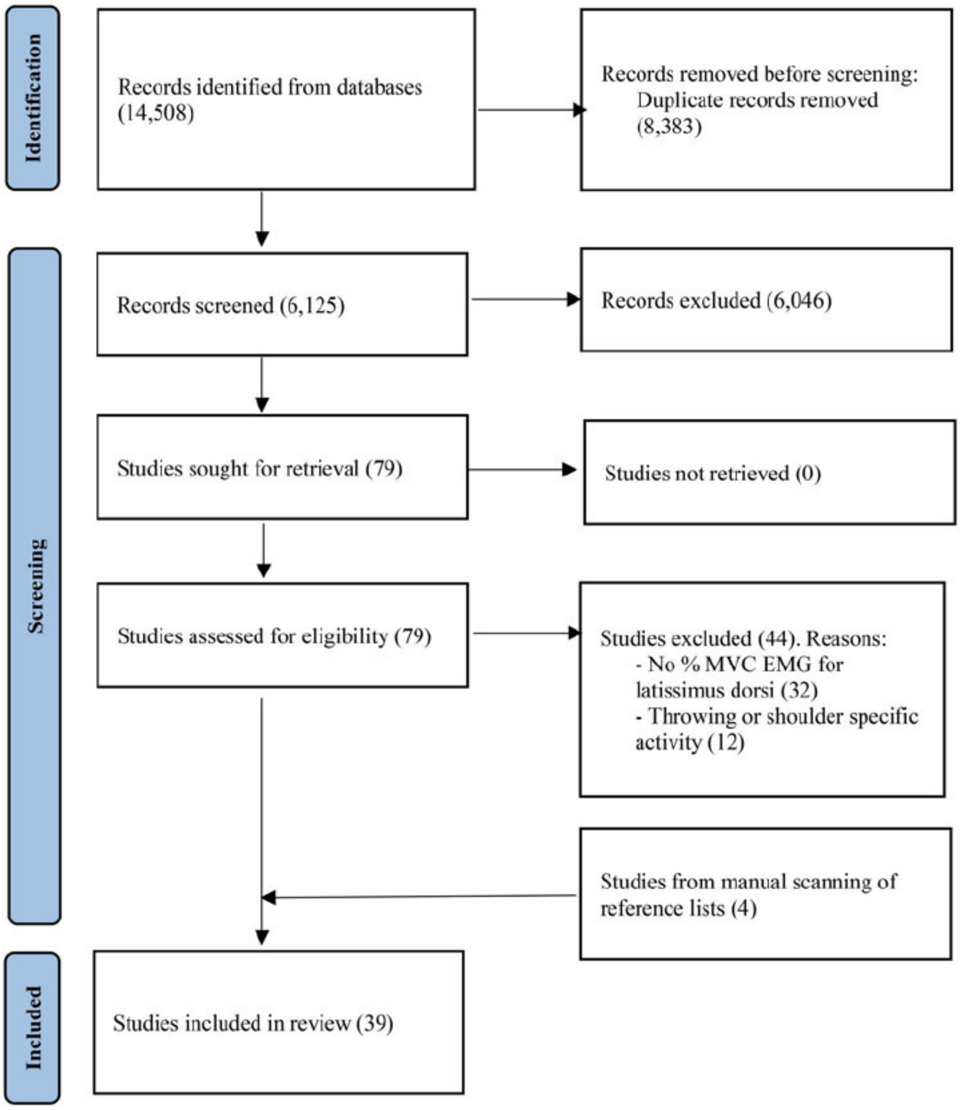

Figure 1. PRISMA flowchart literature search.

1) and outcome measures (Item 2), whereas all studies failed to report any lost data or that there was no lost data (Item 9). All but one study scored poorly for the use of valid outcome measures (Item 20) based on the use of surface electrodes.

Meta-analyses

Fourteen of the thirty nine studies (36%) were included in the meta-analyses representing seven trunk tasks (Figure 3) with only three of the meta-analyses including more than three studies. The results of the meta-analyses showed high latissimus dorsi activation levels during ipsilateral trunk rotation and low levels during contralateral trunk rotation, prone trunk extension and the trunk control tasks performed in four-point kneeling.

GRADE

Overall quality of evidence for ipsilateral rotation was 'very low' due to the use of surface electrodes, high risk of publication bias, imprecision due to large confidence intervals and inconsistency ($I^2 > 50\%$) (Table 2). Consequently, there is limited confidence in the latissimus dorsi activation estimate during ipsilateral trunk rotation as the true activation level may be substantially different. Overall quality of evidence for contralateral trunk rotation, prone trunk extension and each control (four-point kneeling) task was downgraded to 'moderate' due to high risk of methodological bias due to the use of surface electrodes and inconsistency ($I^2 > 50\%$). There is moderate confidence that the true level of latissimus dorsi activation could be close to or substantially different to this estimate.

Activation levels

Latissimus dorsi activation levels stratified under task and load, and summarised as a pooled range of % MVC are shown in Appendices 2 and 3 with levels at maximum load during all trunk movements also illustrated in Figure 4. Single studies not included in the meta-analyses but investigating

Table 1. Study characteristics.

Author	Cohort size and gender	Mean age or range in years (±SD)	Electrode type	Electrode placement	EMG normalisation - MVC - Test position	Trunk task (position)	Movement type	Load/speed	Downs and Black Methodological quality (/11)
[26]	9 M	23.9 (2.8)	Surface	Muscle belly	MVC Trunk flexion, lateral flexion and rotation in modified sit-up position; reverse curl-up in supine	1- Flexion (side-lying) 2- Extension (side-lying) 3- Lateral flexion (supine)	Dynamic	Minimal	9
[27]	13 M	21.0 (1.0)	Surface	Lateral to T9	MVC Lateral pull-down	Four point kneel: 1- Ipsilateral leg extension 2- Contralateral leg extension 3- Ipsilateral leg extension with contralateral arm flexion 4- Contralateral leg extension with ipsilateral arm flexion	Dynamic	Body weight	9
[14]	14 (8 M, 6 F)	24.7 (3.2)	Surface	3 cm lateral and inferior to inferior angle of scapula	MVC Shoulder extension	Extension (prone)	Isometric and dynamic	Body weight	9
[15]	8 M	23.4 (1.8)	Surface	Lateral to T9	MVC Lateral pull down	1- Extension (prone) Four point kneel: 2- Ipsilateral leg extension 3- Contralateral leg extension 4 - Contralateral leg extension with ipsilateral arm flexion	Dynamic	Body weight	9
[28]	18 (9 M, 9 F)	27.7 (7.7)	Surface	4 cm below inferior angle of scapula and midway between the spine and lateral edge of the torso.	MVC Shoulder extension	Flexion (supine)	Dynamic	Body weight	8
[29]	11 M	28.2 (4.4)	Surface	Lateral to T9	MVC Trunk flexion, extension, lateral flexion and rotation	1- Extension (standing) 2- Flexion (standing)	Dynamic	22 N, 67 N, 156 N @ 2s, 1.5s, 1s	8
[30]	21 M	35.9 (6.6)	Surface	Not reported	MVC Trunk extension	Extension (kneeling and standing)	Isometric and dynamic	Maximal @ 30°/s, 60°/s, 90°/s	9
[22]	8 (5 M, 3 F)	19–49	Surface and indwelling	4 cm below inferior angle of scapula	MVC Shoulder internal rotation at 90° abduction, shoulder extension at 30° abduction	Extension (Prone)	Isometric	Maximal	10

(continued)

Table 1. Continued.

Author	Cohort size and gender	Mean age or range in years (±SD)	Electrode type	Electrode placement	EMG normalisation - MVC - Test position	Trunk task (position)	Movement type	Load/speed	Downs and Black Methodological quality (/11)
[31]	12 M	26.1	Surface	Not reported	MVC Trunk flexion, extension, lateral flexion and rotation	Extension (standing)	Dynamic	13.6 kg, 27.3 kg @ preferred speed and faster	8
[32]	10 M	21 (3)	Surface	Not reported	MVC Trunk extension	Four-point kneeling: 1- Contralateral arm flexion and ipsilateral leg extension 2- Ipsilateral leg extension 3- Contralateral leg extension	Dynamic	Body weight	8
[33]	50 (27 M, 23 F)	$M = 22.1$ (3.8), $F = 22.1$ (4.3)	Surface	Superior lateral aspect where the muscle bands together	MVC Trunk rotation	Rotation (sitting)	Isometric Peak	Low, moderate, high, maximal	8
[34]	19 (7 M, 12 F)	$M = 23$ (4), $F = 21$ (3)	Surface	15 cm lateral to T9	MVC Trunk extension and rotation in flexed position	Combined rotation and extension (standing in flexed and rotated position)	Isometric Peak	Maximal	9
[35]	19 (7 M, 12 F)	$M = 23$ (4), $F = 21$ (3)	Surface	Not reported	MVC Trunk flexion from flexed and rotated trunk (task)	Combined rotation and flexion (standing in flexed and rotated position)	Isometric	Maximal	8
[36]	10 M	20–36	Surface	Muscle belly at T7, 13–15 cm lateral from midline	MVC Trunk flexion, extension and rotation	Flexion, extension and lateral flexion.	Isometric	10, 20, 30, 40 and 50 Nm	8
[37]	10 M	24–36	Surface	T7 over muscle belly	MVC Trunk flexion, extension and rotation in rotated position	Flexion, extension, lateral flexion (standing in rotated position)	Isometric	20 Nm, 40 Nm	5
[38]	19 M	19–41	Surface	T7 over muscle belly	MVC Normalised to moment direction and magnitude. Trunk flexion, extension and rotation in flexed position	Flexion, extension, lateral flexion (standing in flexed position)	Isometric	20 Nm, 40 Nm	5
[39]	15 (13 M, 2 F)	20–38	Surface	T7 over muscle belly	MVC Trunk flexion, extension, rotation while in laterally flexed position	Flexion, extension, lateral flexion (standing in laterally flexed position)	Isometric	20 Nm, 40 Nm	6
[40]	12 M	24–33	Surface	Not reported	MVC Movement not specified	Lateral flexion (standing)	Isometric and dynamic	13.6 kg, 27.3 kg @ 15, 30, 45°/s.	7

(continued)

Table 1. Continued.

Author	Cohort size and gender	Mean age or range in years (±SD)	Electrode type	Electrode placement	EMG normalisation - MVC - Test position	Trunk task (position)	Movement type	Load/speed	Downs and Black Methodological quality (/11)
[41]	12 M	21–31	Surface	Lateral to T9	MVC as a function of velocity and trunk posture. Trunk rotation	Rotation (standing)	Isometric	40Nm	9
[42]	15 (10 M, 5 F)	*M* = 21.2 (8.5), *F* = 24 (1.9)	Surface	Lateral to T9	MVC Bent knee sit up, trunk flexion, lateral flexion and rotation	Rotation (standing)	Isometric	Maximal	8
[43]	11 M	22 (3.2)	Surface	Lateral to T9	MVC Trunk flexion, extension, lateral flexion and rotation	Rotation (standing)	Isometric	Maximal	8
[44]	12 (5 M, 7 F)	*M* = 68.8 (5); *F* = 69 (3.5)	Surface	Lateral to T9	MVC Lateral pull down	1- Lateral flexion (standing) 2- Rotation (standing) 3- Flexion (standing)	Isometric	Body weight	9
[9]	23 M	30.2 (7.9)	Surface	T12 level along a line connecting superior point of the axillary fold and S2	MVC Trunk flexion, extension, lateral flexion and rotation	Rotation (standing)	Isometric	Moderate, high, maximal	8
[45]	24 M (controls only = 12)	30 (7.6)	Surface	T12 level along a line connecting superior point of the axillary fold and S2	MVC Trunk flexion, extension, lateral flexion and rotation	Rotation (standing)	Isometric	Moderate, high, maximal	9
[16]	23 M	30.2 (7.9)	Surface	T12 level along a line connecting superior point of the axillary fold and S2	MVC Trunk flexion, extension, lateral flexion and rotation	Rotation (standing)	Isometric	Maximal	8
[46]	22 (11 M, 11 F)	*F* = 23.3 (2.2) *M* = 24.3 (2.8)	Surface	Lateral to T9	MVC Trunk rotation	Rotation (standing)	Isometric	Maximal	8
[27]	16 M	21–24	Surface	4 cm below inferior tip of scapula and midway between the spine and lateral edge of the torso.	MVC Peak level of: extension in prone, caudal depression, body lift, right and left upper trunk lateral flexion, lateral pull down	Lateral flexion (side-lying)	Isometric	Maximal	8
[48]	18 M	21.94 (2.24)	Surface	Lateral to T9	MVC Shoulder extension	Extension (Roman chair)	Dynamic	Body weight	8
[49]	16 M	23 (1.92)	Surface	Medial LD: lateral to T9 over the muscle belly. Lateral LD: 4 cm below inferior angle of scapula.	MVC Peak of either shoulder extension with adduction in prone or isometric lateral pull down.	1- Extension (prone) 2- Lateral flexion (side-lying)	Isometric	Body weight	9

(*continued*)

Table 1. Continued.

Author	Cohort size and gender	Mean age or range in years (±SD)	Electrode type	Electrode placement	EMG normalisation - MVC - Test position	Trunk task (position)	Movement type	Load/speed	Downs and Black Methodological quality (/11)
[50]	24 (17 M, 7 F)	$M = 22$ (3.4), $F = 20.4$ (.5)	Surface	Lateral to T9	MVC Bent knee sit up, trunk extension, isometric exertions similar to body builder poses	1- Rotation (standing) 2- Extension (standing) 3- Flexion (standing) 4- Lateral flexion (standing)	Dynamic	Body weight	8
[19]	16 (8 M, 8 F)	$M = 27$ (6.93), $F = 25$ (2.51)	Surface	Lateral to T9	MVC Trunk extension, flexion, lateral flexion, rotation, and one armed brachiation	1- Rotation (standing) 2- Extension (standing) 3- Flexion (standing) 4- Lateral flexion (standing)	Isometric	Moderate	9
[51]	18 (13 M, 5 F)	$M = 29.8$ (4), $F = 27.2$ (8)	Surface	T12 -L1 level	MVC Trunk movement	1- Rotation (standing) 2- Extension (standing) 3- Flexion (standing)	Isometric	Moderate, high, maximal	8
[52]	30 (15 M, 15 F)	$M = 25.0$ (3.8), $F = 22.8$ (2.7)	Surface	Lateral to T9	MVC Isometric pull down with shoulder abducted to 90 degrees, with the arm externally rotated and the elbow flexed to 90 degrees	1- Rotation (standing) 2- Flexion (standing) 3- Lateral flexion (standing)	Dynamic	Body weight	8
[2]	30 (Gender not reported)	20.52 (1.74)	Surface	3 cm lateral and inferior to inferior angle of scapula	MVC Position not reported	Rotation (sitting)	Dynamic	Moderate, high	7
[17]	30 (15 M, 15 F)	19.6	Surface	3 cm lateral and inferior to inferior angle of scapula	MVC Shoulder extension	4 point kneel: 1- Ipsilateral leg extension 2- Contralateral leg extension 3- Ipsilateral leg extension with contralateral arm flexion 4- Contralateral leg extension with ipsilateral arm flexion	Dynamic	Body weight	9
[53]	12 M	25.9 (3.3)	Surface	T12 level along a line connecting the most superior point of the axillary fold and S2	MVC Trunk flexion, extension, lateral flexion, rotation and 4 biaxial exertions.	1- Extension (standing) 2- Flexion (standing)	Isometric Peak	Moderate, high, maximal	9
[54]	9 M	24 (3)	Surface	Not reported	Rectified and averaged	Extension (semi-seated position)	Isometric	Low, moderate	9

(continued)

Table 1. Continued.

Author	Cohort size and gender	Mean age or range in years (±SD)	Electrode type	Electrode placement	EMG normalisation - MVC - Test position	Trunk task (position)	Movement type	Load/speed	Downs and Black Methodological quality (/11)
[55]	13 (4M, 9F)	22.6 (2.1)	Surface	3 cm lateral and inferior to inferior angle of scapula	MVC Shoulder extension	Extension (prone)	Dynamic	Body weight	9
[18]	8 F	26.0 (5.8)	Surface	Lateral to T9	MVC Upper and lower trunk flexion, extension and rotation; shoulder internal rotation and adduction; maximal effort abdominal hollowing and bracing. (Task)	1- Rotation (crook lying) 2- Extension (prone) 3- Flexion (crook lying) 4- Lateral flexion (side-lying)	Isometric	Maximal	7

F: female; LD: latissimus dorsi; M: male; MVC: maximal voluntary contraction; MVE: maximal voluntary exertion; SP: spinous process
Loads expressed as absolute loads or as a % of MVE: minimal = 0–9% MVE, low = 10–29% MVE, moderate = 30–59% MVE; high = 60–89% MVE; maximal = 90–100% MVE.

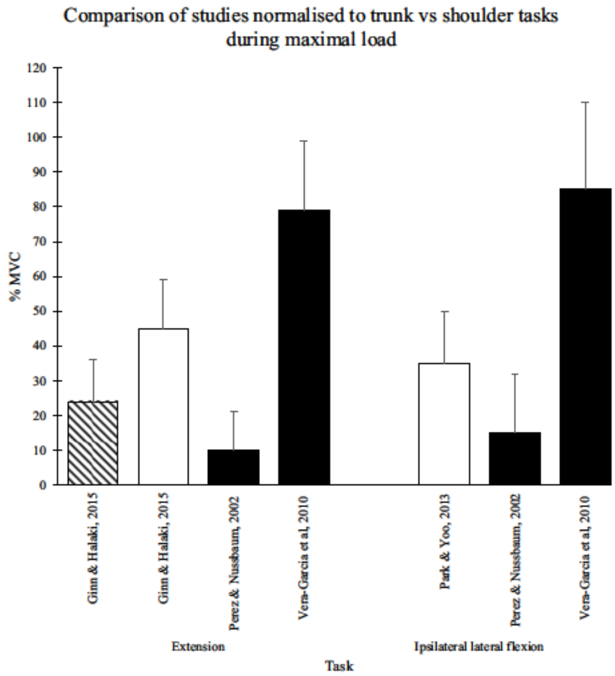

Figure 2. Comparison of studies normalised to trunk *vs.* shoulder tasks. Mean and (SD). Solid black columns = EMG data normalised to trunk movements, white columns = EMG data normalised to shoulder movements, diagonal pattern = normalised to shoulder movements and using indwelling electrodes. MVC = maximum voluntary contraction.

similar tasks, reported: very high levels of latissimus dorsi activity (73–116% MVC) during ipsilateral trunk rotation at high to maximal load [17,51], low activity (10% MVC) during contralateral trunk rotation at high to maximal load [51], and low activity (11–22% MVC) during limb movements in the four-point kneeling position [8]. For other trunk movements for which not enough studies were available to complete a meta-analysis, single studies investigating trunk movements at maximal load reported high to very high activation levels during ipsilateral lateral flexion (85 ± 25% MVC) [18], extension (79 ± 20% MVC) [18] and flexion (41 ± 14% MVC) (Figure 4) [18].

Discussion

There is considerable variability in the contribution of latissimus dorsi to trunk movements across previous EMG studies. Therefore, one of the aims of this study was to conduct a meta-analysis to synthesise the evidence in order to clarify the contribution of latissimus dorsi to trunk movement. Only three trunk movements (ipsilateral and contralateral rotation, and extension) could be included in the meta-analyses with ipsilateral rotation being the only movement where mean latissimus dorsi activity was moderate to high. Although this result was supported by two studies not able to be included in the meta-analysis [17,51], the overall quality of evidence,

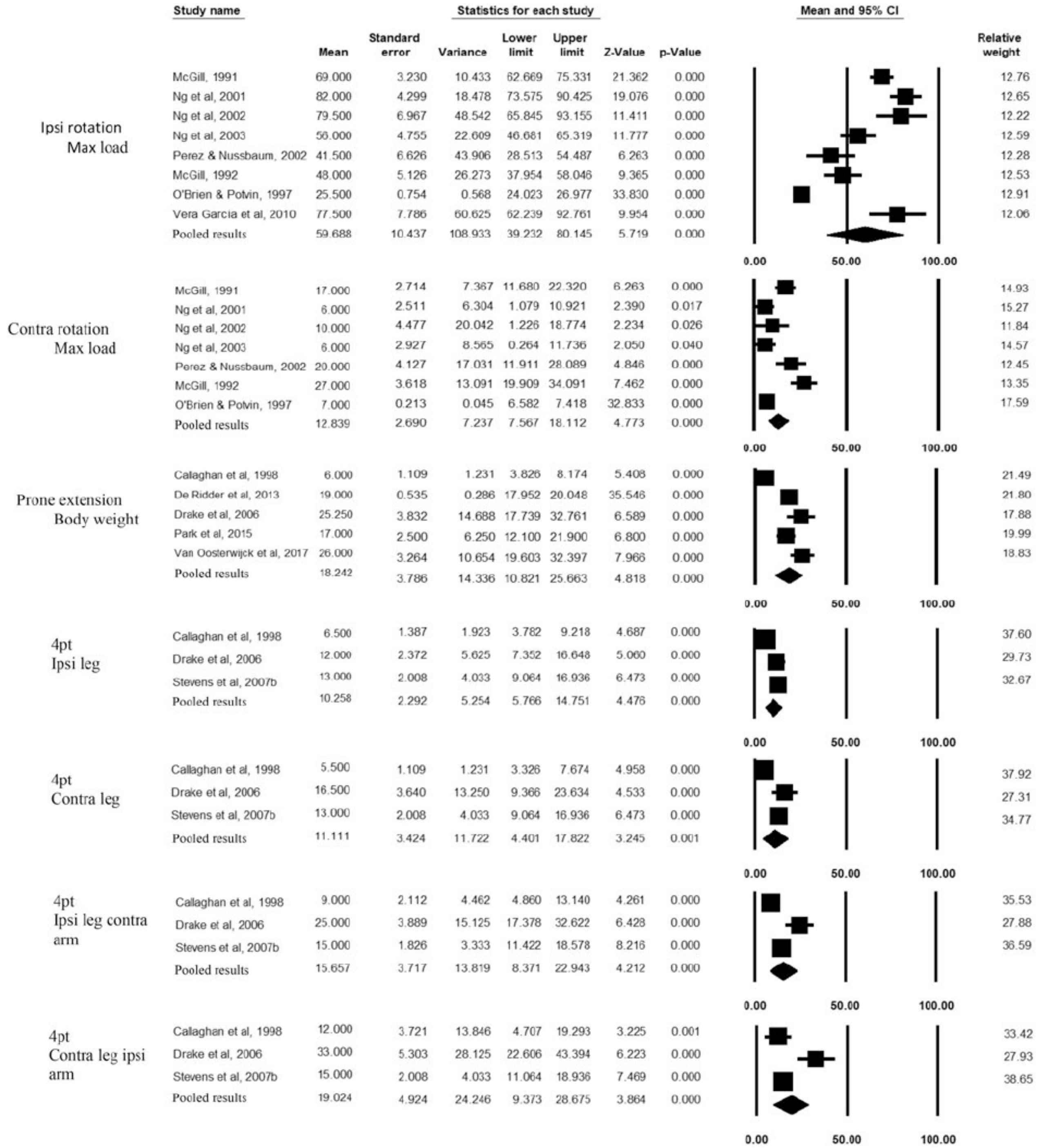

Figure 3. Forest plot of meta-analyses. 4 pt: Four-point kneeling; contra: contralateral; ipsi: ipsilateral.

Table 2. Heterogeneity and tau-squared data for meta-analyses.

	Heterogeneity				Tau-squared			
	Q-value	df (Q)	*p* Value	I-squared	Tau-squared	Standard error	Variance	Tau
Ipsilateral rotation	457.57	7	0	98.47	842.95	720.26	518776.55	29.03
Contralateral rotation	54.23	6	6.63E-10	88.94	41.1	38.26	1463.5	6.41
Prone extension	124.49	4	0	96.79	65.47	72.51	5257.42	8.09
4 pt kneeling – ipsi leg	8.76	2	0.01	77.18	12.05	15.97	254.89	3.47
4 pt kneeling – contra leg	16.71	2	2.35E-04	88.03	29.68	37.97	1441.61	5.45
4 pt kneeling – ipsi leg, contra arm	13.89	2	9.64E-04	85.6	34.65	43.65	1904.88	5.87
4 pt kneeling – contra leg, ipsi arm	11.67	2	2.93E-03	82.86	58.7	75.73	5735.19	7.66

4 pt: four-point kneeling; contra: contralateral; ipsi: ipsilateral

as assessed using the GRADE rating, was 'very low'. Therefore, the result of moderate to high latissimus dorsi activity during ipsilateral trunk rotation needs to be interpreted with caution as there is limited confidence that this activity is representative of its true levels.

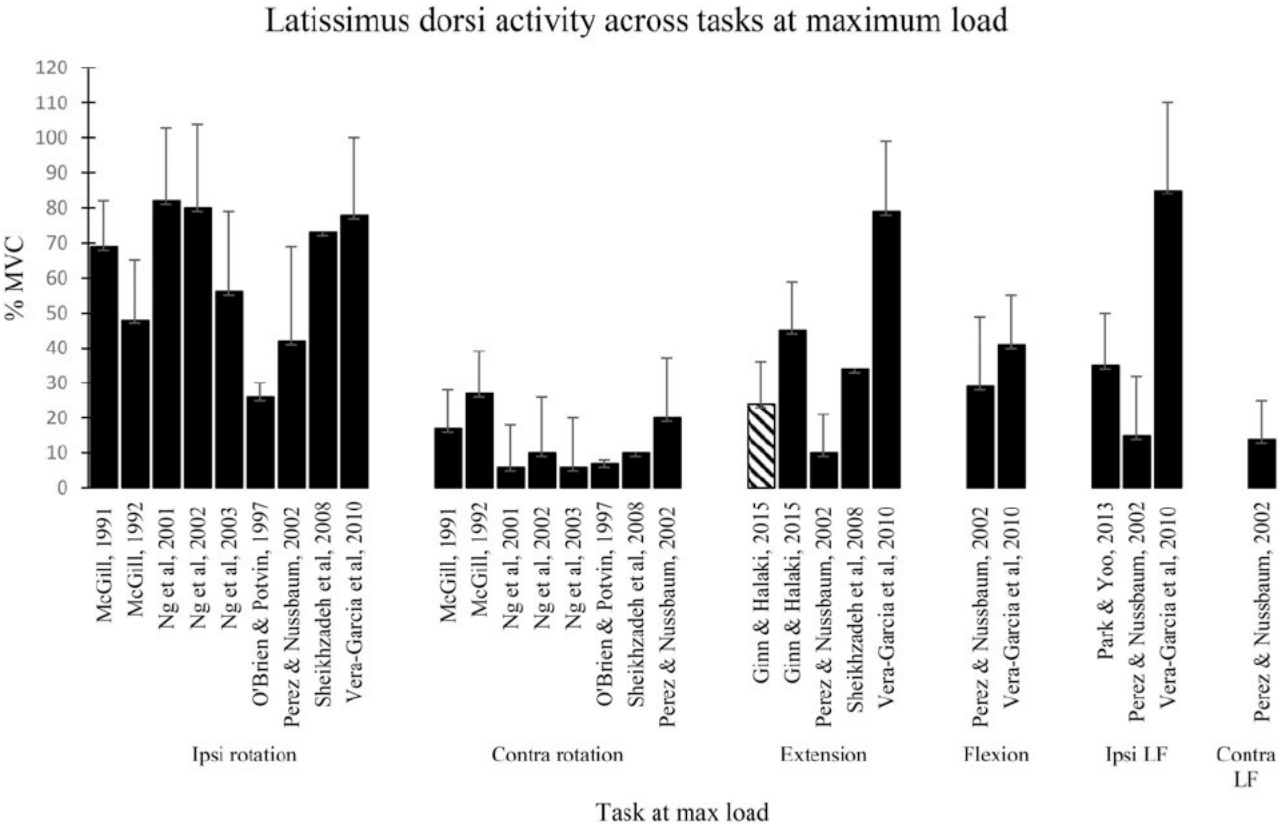

Figure 4. Latissimus dorsi activity across tasks at maximum load. Solid black bars represent surface electrodes being used to record latissimus dorsi activity and the diagonal pattern represents indwelling electrodes being used to record latissimus dorsi activity. Contra: contralateral; Ipsi: ipsilateral; LF: lateral flexion; MVC: maximal voluntary contraction.

The meta-analyses for contralateral trunk rotation and trunk extension resulted in low mean latissimus dorsi activity levels. A single study not able to be included in the meta-analysis showed similarly low levels during contralateral trunk rotation [51]. As the quality of studies assessing both these trunk movements obtained a ‘moderate’ GRADE rating, there is some confidence the reported latissimus dorsi activity levels are representative of their true value. These results indicate that the actions of latissimus dorsi are unlikely to include contralateral trunk rotation and trunk extension.

The findings from the meta-analyses of studies investigating the role of latissimus dorsi during trunk control tasks support previous understanding that it is active at low levels. With a ‘moderate’ GRADE rating there is some confidence the reported activity levels may be close to their true values. Although this low level of activity suggests latissimus dorsi has a limited contribution to trunk control, this still may be an important contribution as part of the normal trunk muscle recruitment required to achieve optimal trunk control.

This systematic review revealed considerable variability in latissimus dorsi activity between studies during trunk movements. This was most evident when latissimus dorsi was working at high to maximum loads (Figure 4). For example, mean latissimus dorsi activity levels during ipsilateral rotation ranged from 26% to 116% MVC, during extension from 10% to 79% MVC and during ipsilateral lateral flexion from 15% to 85% MVC. Although these individual studies were of similarly high methodological quality (≥7/11 on the modified Downs and Black quality assessment tool) they differed with respect to EMG methodology. These methodological differences could account for the large variability in latissimus dorsi activity in previous studies.

All but one of the included studies in this review recorded latissimus dorsi activity using surface electrodes. The only study that has directly compared latissimus dorsi activity during trunk movements, using surface and indwelling electrodes [22], concluded that surface electrode recording greatly overestimated latissimus dorsi activity due to crosstalk from the underlying erector spinae (Figures 2 and 4). As erector spinae is active during many trunk movements the vast majority of studies in this review using surface electrodes to record latissimus dorsi activity are likely to be overestimating its contribution to trunk movement.

The majority of studies in this review (54%) used maximally resisted trunk movements to obtain maximal latissimus dorsi activation for EMG normalisation. Two studies [18,47] using surface electrodes have compared latissimus dorsi activity levels during maximally resisted trunk tasks to maximally resisted shoulder tasks, which have been shown to generate high levels of activity in latissimus dorsi [56]. Similar high latissimus dorsi activity levels were reported during maximal trunk extension and rotation when compared to shoulder adduction [18]. However, for maximally resisted trunk lateral flexion, results are conflicting with one study reporting similarly high levels of latissimus dorsi activity when compared to shoulder adduction [18] and another study reporting statistically significantly lower levels [47]. The use of surface electrodes in these studies may have resulted in an overestimation of latissimus dorsi activity due to potential cross talk from adjacent muscles. Support for such overestimation can be found in the only study that has compared latissimus dorsi activity during a maximally resisted trunk task to a shoulder task using indwelling electrodes [22]. In this study, significantly lower activity was reported during trunk extension compared to shoulder extension. If trunk tasks used to normalise the EMG data do not result in maximal latissimus dorsi activity, the reported % MVC levels will be higher than true % MVC levels, leading to an overestimation of the potential contribution of latissimus dorsi to trunk movement and control.

Limitations

Literature searches were conducted in six major databases: Medline, EMBASE, PubMed, CINAHL, SCOPUS and SPORTDiscus; however, there is a possibility relevant studies in journals not indexed in these databases may have been missed. In addition, no grey literature was included and only studies published in English were included precluding any potential studies in different languages. Finally, the utilisation of meta regression models to explore between-study heterogeneity was not possible due to the small number of studies evaluating each task.

Conclusion

The results of this systematic review provide little evidence that trunk movements will result in significant strength increases in latissimus dorsi. Even though relatively high latissimus dorsi levels were found during ipsilateral trunk rotation there is very low confidence this represents the true estimate of its activity level. There is moderate confidence in the finding that latissimus dorsi is only activated at low levels during trunk extension and contralateral trunk rotation. The results also indicate, with moderate confidence, that latissimus dorsi has a limited contribution to trunk control. This suggests that any therapeutic benefit from trunk control exercises in the treatment of people with low back pain is potentially due to their impact on other trunk muscles.

However, the critical EMG methodological issues identified in this review, that is the use of surface electrodes and non-validated EMG normalisation processes, challenges the validity and reliability of the reported latissimus dorsi activity levels. Further research using indwelling electrodes and a validated EMG normalisation procedure is needed to confirm the contribution of latissimus dorsi to trunk movement and control.

Acknowledgements

Elaine Tam (librarian) for assistance with search strategy.

Disclosure statement

The authors declare that there is no conflict of interest.

Funding

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

PROSPERO registration number

CRD42018089210

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Appendix 1. Methodological quality of included studies. Criteria items are numbered based on items adapted from the Downs and Black checklist [21]

	1. Clear hypothesis	2. Outcome measures clearly described	3. Participant characteristics clearly described	4. Experimental conditions clearly described	6. Main findings clearly described	7. Estimates of random variability provided	9. Lost data reported	10. Actual p values reported	12. Participants represent entire population	18. Appropriate statistical tests used	20. Valid and reliable outcome measures	Score /11
[26]	1	1	1	1	1	1	0	1	1	1	0	9
[27]	1	1	1	1	1	1	0	1	1	1	0	9
[14]	1	1	1	1	1	1	0	1	1	1	0	9
[15]	1	1	1	1	1	1	0	1	1	1	0	9
[28]	1	1	1	1	1	1	0	0	1	1	0	8
[29]	1	1	1	1	1	1	0	0	1	1	0	8
[30]	1	1	1	1	1	1	0	1	1	1	0	9
[22]	1	1	1	1	1	1	0	1	1	1	1	10
[31]	1	1	1	1	1	1	0	0	1	1	0	8
[32]	1	1	1	1	1	1	0	0	1	1	0	8
[33]	1	1	1	1	1	0	0	1	1	1	0	8
[34]	1	1	1	1	1	1	0	1	1	1	0	9
[35]	1	1	1	1	1	1	0	1	1	0	0	8
[36]	1	1	1	1	1	0	0	1	1	1	0	8
[37]	1	1	0	1	1	0	0	0	0	1	0	5
[38]	1	1	0	1	1	0	0	0	0	1	0	5
[39]	1	1	0	1	1	0	0	1	0	1	0	6
[40]	1	1	0	1	1	1	0	0	1	1	0	7
[41]	1	1	1	1	1	1	0	1	1	1	0	9
[42]	1	1	1	1	1	1	0	1	1	0	0	8
[43]	1	1	1	1	1	1	0	0	1	1	0	8
[44]	1	1	1	1	1	1	0	1	1	1	0	9
[9]	1	1	1	1	1	1	0	0	1	1	0	8
[45]	1	1	1	1	1	1	0	1	1	1	0	9
[16]	1	1	1	1	1	1	0	0	1	1	0	8
[46]	1	1	1	1	1	1	0	0	1	1	0	8
[47]	1	1	1	1	1	1	0	0	1	1	0	8
[48]	1	1	1	1	1	1	0	0	1	1	0	8
[49]	1	1	1	1	1	1	0	1	1	1	0	9
[50]	1	1	1	1	1	1	0	0	1	1	0	8
[19]	1	1	1	1	1	1	0	1	1	1	0	9
[51]	1	1	1	1	1	0	0	1	1	1	0	8
[52]	1	1	1	1	1	1	0	0	1	1	0	8
[2]	1	1	1	1	1	0	0	0	1	1	0	7
[17]	1	1	1	1	1	1	0	1	1	1	0	9
[53]	1	1	1	1	1	0	0	1	1	1	0	8
[54]	1	1	1	1	1	1	0	1	1	1	0	9
[55]	1	1	1	1	1	1	0	1	1	1	0	9
[18]	1	1	1	1	1	1	0	0	0	1	0	7

Appendix 2. Mean latissimus dorsi activation % MVC (±SD) during cardinal plane trunk movements of individual studies and pooled results

Study	Body weight	Minimal load (0–9% MVE)	Low load (10–29% MVE)	Moderate load (30–59% MVE)	High load (60–89% MVE)	Maximal load (90–100% MVE)	Nm/kg (Load)	Speed
Ipsilateral trunk rotation (ipsilateral latissimus dorsi to movement direction)								
[33]			22 (peak)	42 (peak)	73 (peak)			
[41]							19 (34) (40 Nm)	
[42]						69 (13)		
[43]						48 (17)		
[44]		34 (7)						
[9]				21 (16)	51 (21)	82 (21)		
[45]				17 (14)	45 (19)	80 (24)		
[16]						56 (23)		
[46]						26 (4)		
[50]	22 (13)							
[19]				27 (19)		42 (27)		
[51]				10	30	73		
[52]	15 (10)							
[2]				88	116			
[53]				88 (peak)				
[18]						78 (22)		
Range	15–22	34	22	10–88	30–116	26–82	19	–
Contralateral trunk rotation (contralateral latissimus dorsi to movement direction)								
[33]			25 (peak)	46 (peak)	68 (peak)			
[42]						17 (11)		

(continued)

Continued.

Study	Body weight	Minimal load (0–9% MVE)	Low load (10–29% MVE)	Moderate load (30–59% MVE)	High load (60–89% MVE)	Maximal load (90–100% MVE)	Nm/kg (Load)	Speed
[43]						27 (12)		
[9]				1 (6)	4 (9)	6 (12)		
[45]				4 (8)	7 (12)	10 (16)		
[16]						6 (14)		
[46]						7 (1)		
[50]	5 (5)							
[19]				16 (15)		20 (17)		
[51]				2	6	10		
[52]	8 (3)							
[2]				22		27		
[53]				18 (peak)				
Range	5–8	–	25	1–46	4–68	6–27	–	–
Trunk extension (unilateral left or right latissimus dorsi)								
[26]		2 (3)	4(6)					
[27]	6 (4)							
[14]	19 (2)							
[15]	26 (11)							
[22]						24 (10), 45 (12)		
[31]							13 (17) (13.6 kg) 14 (19) (27.3 kg)	
[36]							1 (10 Nm) 1 (20 Nm) 1 (30 Nm) 4 (40 Nm) 5 (50 Nm)	
[37]							6,6 (20 Nm) 2,2 (40 Nm)	
[38]							6,5 (20 Nm0 2,2 (40 Nm)	
[39]							3,3,3 (40 Nm)	
[48]	18 (10)							
[49]	17 (10)							
[50]	5 (12)							
[19]				9 (13)		10 (11)		
[26]				7	17	34		
[54]			0 (1)					
[55]	26 (12)							
[18]						79(20)		
Range	5–26	2	0–4	7–9	17	10–79	2–18	–
Trunk flexion (unilateral left or right latissimus dorsi)								
[26]		3 (3)	5 (8)					
[28]	8 (3)							
[29]							5–20 (22–156 Nm)	
[36]							1 (10 Nm) 2 (20 Nm) 3 (30 Nm) 2 (40 Nm) 5 (50 Nm)	
[37]							2,2 (20 Nm) 6,5 (40 Nm)	
[38]							3 (20 Nm) 4 (40 Nm)	
[39]							3,3 (40 Nm)	
[44]	11 (6)							
[50]	5 (5)							
[19]				12 (16)		24 (20)		
[51]				4	6	25		
[53]						23 (peak)		
[52]	9 (5)							
[18]						41 (14)		
Range	5–11	3	5	4–12	6	23–41	2–20	–
Ipsilateral trunk lateral flexion (ipsilateral latissimus dorsi to movement direction)								
[36]							1 (10 Nm) 2 (20 Nm) 4 (30 Nm) 6 (40 Nm) 12 (50 Nm)	
[37]							9,9 (20 Nm) 2,3 (40 Nm)	
[38]							4 (20 Nm) 6 (40 Nm)	
[39]							3,4 (40 Nm)	
[40]								43,46 (0°/s) 70,74 (45°/s)
[47]						35 (15)		
[49]	40 (15)							
[50]	7 (3)							
[19]				10 (15)		15 (17)		
[52]	6 (3)							
[18]						85 (25)		
Range	6–40	–	–	10	–	15–85	1–12	43–74
Contralateral trunk lateral flexion (contralateral latissimus dorsi to movement direction)								
[37]							0,9 (20 Nm) 2,3 (40 Nm)	
[39]							6,7 (40 Nm)	

(*continued*)

Continued.

Study	Body weight	Minimal load (0–9% MVE)	Low load (10–29% MVE)	Moderate load (30–59% MVE)	High load (60–89% MVE)	Maximal load (90–100% MVE)	Nm/kg (Load)	Speed
[40]								3,4 (0°/s) 7,9 (45°/s)
[44]	12 (10)							
[50]	5 (2)							
[19]				10 (11)		14 (11)		
[52]	11 (7)							
Range	5–12	–	–	10	–	14	0–9	– 3–9

Appendix 3. Latissimus dorsi activation levels % MVC (SD) during combined trunk movements (peak) and trunk stability tasks (mean)

Study	Ipsilateral trunk rotation and flexion	Contralateral trunk rotation and flexion	Ipsilateral trunk rotation and extension	Contralateral trunk rotation and extension
Peak latissimus dorsi activation % MVC (±SD) during combined trunk movements (maximal load)				
[35]	44 (22)–238 (449)	61 (36)–171 (185)		
[34]			78 (41)–204 (198)	78 (37)–161 (112)
Mean latissimus dorsi activation %MVC (±SD) during trunk stability tasks (body weight)				
[27]	7 (5)	6 (4)	9 (8)	12 (13)
[15]	12 (7)	17 (10)	25 (11)	33 (15)
[32]	11 (7)	15 (5)	15 (13)	22 (16)
[17]	13 (11)	13 (11)	15 (10)	15 (11)
Range	7–13	6–17	9–25	12–33

Chapter 3: Do maximal isometric trunk tasks produce maximum activity in latissimus dorsi?

Journal of Electromyography and Kinesiology 79 (2024) 102933

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Do maximal isometric trunk tasks produce maximum activity in latissimus dorsi?

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ARTICLE INFO

Keywords:
Electromyography
Latissimus dorsi
Normalisation

ABSTRACT

Introduction: Electromyography (EMG) studies investigating latissimus dorsi activity during trunk tasks have reported high activation levels and described latissimus dorsi as an important contributor to trunk movement and stability. However, the normalisation of EMG data in these studies is inconsistent with some normalising to shoulder tasks and a majority normalising to trunk tasks. Therefore, this study aimed to compare commonly used shoulder and trunk normalisation tasks to determine if trunk tasks produce maximum activity in latissimus dorsi.
Methods: Ten asymptomatic participants completed maximal isometric trunk (extension, ipsilateral rotation and ipsilateral lateral flexion) and shoulder (extension and internal rotation) tasks while recording EMG signals from right latissimus dorsi using surface and indwelling electrodes. The signals were high-pass filtered, rectified then low-pass filtered to obtain an EMG linear envelope to represent muscle activity levels. The maximum activity levels across tasks were compared for each electrode type.
Results: Shoulder extension elicited significantly higher (>1.5 times) latissimus dorsi activity levels when recorded using both surface and indwelling electrodes compared to other shoulder and trunk tasks.
Conclusion: Maximal isometric trunk tasks do not produce maximal latissimus dorsi activity and therefore when used for normalisation purposes potentially overestimate the contribution of latissimus dorsi to trunk tasks.

1. Introduction

Latissimus dorsi is a broad, flat, triangular muscle with extensive attachments arising from the pelvis, ribs and vertebral column, which all converge onto the humerus (Palastanga and Soames, 2018). Due to these broad attachment points on the trunk, the latissimus dorsi is considered not only a prominent shoulder muscle but also an important contributor to trunk movement and stability (Ng et al., 2001, Perez and Nussbaum, 2002, Sheikhzadeh et al., 2008, Vera-Garcia et al., 2010, Park and Yoo, 2014, Park et al., 2015).

Normalisation is a critical methodological consideration in EMG studies investigating muscle activity (Halaki and Ginn, 2012, Besomi et al., 2020). To allow for comparison between muscles, tasks, individuals and studies the most common normalisation method is to compare activity in a given muscle to its maximum capacity. Measuring maximum muscle capacity is often determined by maximum voluntary isometric contractions (MVC). Identifying an appropriate MVC that validly produces maximum activity in a given muscle is crucial.

Previous EMG research using indwelling electrodes has indicated that maximum levels of latissimus dorsi can be obtained during maximal isometric shoulder extension and/or internal rotation (Boettcher et al., 2008, Ginn et al., 2011). However, when investigating latissimus dorsi activity during trunk tasks many studies have used maximal isometric trunk tasks to normalise latissimus dorsi activity, although it has not been established if these tasks are able to produce maximal activity in latissimus dorsi. Of the 39 EMG studies identified in a recent systematic review investigating latissimus dorsi activity during trunk tasks 54 % (21 studies) used a variety of maximal trunk tasks to normalise the data (Price et al., 2024).

Two previous studies have compared latissimus dorsi activity levels during trunk and shoulder normalisation tasks (Vera-Garcia et al., 2010, Park and Yoo, 2013). One study reported similar levels of latissimus dorsi activity when comparing trunk extension, rotation and lateral flexion to shoulder internal rotation and adduction (Vera-Garcia et al.,

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https://doi.org/10.1016/j.jelekin.2024.102933
Received 21 May 2024; Received in revised form 1 August 2024; Accepted 18 September 2024
Available online 24 September 2024

2010), which would imply that trunk tasks are acceptable for normalisation purposes. However, Vera-Garcia et al. (2010) did not compare data to shoulder extension which has been shown to elicit high levels of latissimus dorsi activity. The other study, which did include shoulder extension, reported higher activity levels during shoulder extension when compared to trunk lateral flexion (Park and Yoo, 2013). However, not all trunk activities that have been reported to produce high activity in latissimus dorsi were included in this study.

In order to gain an understanding of the contribution of latissimus dorsi activity to trunk movement and stability tasks a consistent and validated EMG normalisation process needs to be established. Therefore, the aim of this study was to compare shoulder extension and internal rotation with commonly used trunk tasks (ipsilateral rotation, ipsilateral lateral flexion and extension) used to normalise latissimus dorsi EMG data in previous studies to determine if trunk tasks produce maximal activity in latissimus dorsi and can, therefore, be used as valid normalisation tasks.

2. Method

2.1. Participants

Ten asymptomatic volunteers participated in the study (seven male, three female, average age 26 years). Subjects were included if they had no shoulder or back pain in the previous year, had never received treatment for shoulder or back pain and were over 18 years old. An experienced physiotherapist performed a physical examination to confirm normal pain-free shoulder and back range of motion and the absence of pain on resisted isometric trunk extension and shoulder internal and external rotation. Prior to testing the protocol was explained to all subjects and written informed consent was obtained. The study was approved by The University of Sydney Human Research Ethics Committee.

2.2. Instrumentation

Surface electrodes are commonly used to record activity from latissimus dorsi during trunk tasks, demonstrated in the recent systematic review previously cited with all but one study using surface electrodes (Price et al., 2024). Although evidence suggests surface electrodes may overestimate latissimus dorsi activity (Ginn and Halaki, 2015), both surface and indwelling electrodes were used in this study. With the participant lying in the prone position and the arms in 90° shoulder abduction, bipolar indwelling electrodes were inserted into the right latissimus dorsi 4 cm inferior to the inferior angle of the scapula in an infero-medial direction with surface electrodes placed over the same location (Park and Yoo, 2013, Ginn and Halaki, 2015). Indwelling electrodes were manufactured in the laboratory from 0.14 mm diameter Teflon insulated stainless steel wire with 2 mm on the ends stripped of the insulation. Two wires were threaded through a single 23-gauge needle to be used as a cannula for insertion and bent back to form a hook with approximately 3 mm separation between the tips of the two wires. Prior to the placement of the electrodes the skin was prepared using abrasive gel (Nuprep, DO Weaver and Co, Aurora, US) for exfoliation, followed by cleansing with alcohol and the application of antiseptic solution (Betadine, Faulding Healthcare Pty Ltd, Virginia, Australia) and topical anaesthesia with Xylocaine 2 % jelly (AstraZeneca Pty Ltd, NSW, Australia). Electrode placement within the latissimus dorsi was guided by a digital ultrasonic diagnostic imaging system using an aseptic technique (Mindray, DP-9900). After insertion of the indwelling electrode the needle was withdrawn and the wires were taped to the skin to prevent them being removed accidentally while still allowing adequate translation during testing. To ensure electrodes were inserted into latissimus dorsi submaximal contractions of shoulder flexion and extension were performed to confirm high activity during shoulder extension and not flexion. Paired Ag/AgCl 10 mm diameter surface electrodes (Dual Electrodes, Noraxon, USA) were then placed bilaterally over the same locations, oriented parallel to muscle fibre direction with a fixed centre-centre distance of 20 mm, ensuring an inter-electrode impedance $<$5 kOhm verified by an Ohmmeter. The electrodes were connected to a 16-channel telemetry EMG system (TELEmyo DTS EMG sensors, Noraxon, USA, Baseline noise: $<$1uV RMS, Input impedance $>$ 100 MOhm, Common Mode Rejection (CMR) $>$ 100 dB) with a gain of 1000, and a first order band-pass filter bandwidth 10–500 Hz. The EMG signals were transmitted to a receiver (Telemyo DTS belt receiver, Noraxon, USA, 16-bit resolution), sampled at 3000 Hz using the MR3 software (Version 3.12.70 Noraxon, USA) and stored for later off-line analysis.

2.3. Experimental procedure

Three maximal isometric trunk tasks (extension, right lateral flexion and right rotation) and two maximal isometric shoulder tasks (extension and internal rotation) were completed in random order three times each with at least 30 seconds rest between repetitions and with an isometric hold of five seconds. The shoulder isometric tasks have previously been shown to have a 95 % chance of producing maximal levels of latissimus dorsi activity (Boettcher et al., 2008, Ginn et al., 2011).

Trunk extension and right lateral flexion were completed with the participant lying with their torso off the end of the bed up to the level of the anterior superior iliac spine: in prone for trunk extension (Fig. 1a) and in left side-lying for lateral flexion (Fig. 1b). The lower body was supported on the bed by two researchers and the participant was required to lift the trunk to horizontal while keeping their arms relaxed across their chest and maintain that position against an external downward pressure provided manually by a third researcher. Right trunk rotation was completed in sitting while wearing a harness attached to a fixed point (Fig. 1c). The participant relaxed their hands on their knees and was instructed not to use their upper limbs as they rotated their trunk as hard as possible to the right. Resisted isometric right shoulder extension and internal rotation were performed in sitting with maximal resistance applied at the distal forearm. For shoulder extension, the shoulder was placed in 30° abduction with the elbow extended and the arm internally rotated (Fig. 1d) and for shoulder internal rotation the shoulder was positioned at 90° abduction in the scapula plane with the elbow flexed to 90° and the shoulder held in the mid rotation position (Fig. 1e) (Boettcher et al., 2008).

2.4. Data analyses

EMG signals were high pass filtered (designed 4th order, 10 Hz Butterworth filter; applied two-pass zero-phase method to achieve overall 8th order), rectified, then low pass filtered (designed 4th order, 3 Hz Butterworth filter; applied two-pass zero-phase method to achieve overall 8th order) to provide an EMG linear envelope (EMG-LE) using Matlab (Version 9 R2022b, The MathWorks, Natick, MA). The maximum value of the EMG-LE for each trial was obtained. Statistical analysis was performed using Statistica V10 (Copyright StatSoft. Inc. 1984–2011, USA). A within subject two factor (factor 1: task with 5 levels; factor 2: trial with 3 levels) analysis of variance (ANOVA) was used to compare the EMG activity recorded using surface and indwelling electrodes. Tukey post-hoc test was used to identify differences between tasks. Normal distribution of the data was confirmed using Shapiro-Wilk test.

3. Results

Maximal isometric shoulder extension produced the highest latissimus dorsi activity level in the majority of participants. Mean ± standard deviation of latissimus dorsi activity during maximal isometric exertion tasks is shown in Fig. 2. ANOVA task main effect was significant for both surface ($F_{4,36} = 10.73$, $p < 0.001$) and indwelling ($F_{4,36} = 10.65$, $p < 0.001$) electrodes. The main effect for trial and interaction were not

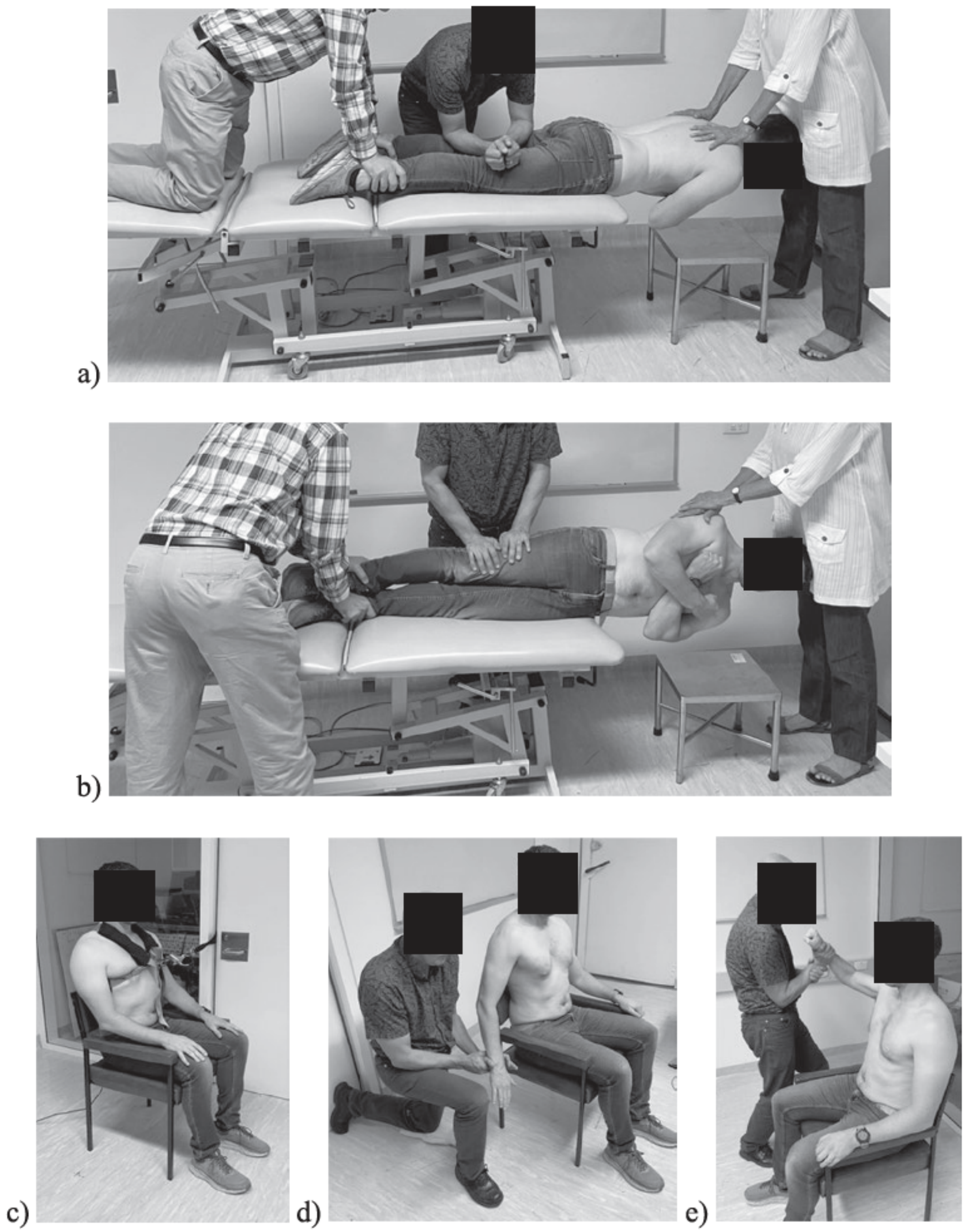

Fig. 1. A) Trunk extension in prone, b) right lateral flexion in left side-lying, c) right trunk rotation in sitting, d) shoulder extension in sitting, e) shoulder internal rotation in sitting.

significant for both surface ($F_{2,18} = 2.37$, $p = 0.122$; $F_{8,72} = 0.92$, $p = 0.504$) and indwelling ($F_{2,18} = 0.28$, $p = 0.758$; $F_{8,72} = 1.31$, $p = 0.250$) electrodes respectively. Post-hoc testing revealed that the latissimus dorsi activity during shoulder extension was significantly higher than all other maximal isometric tasks using both surface ($p < 0.015$) and indwelling ($p < 0.043$) electrodes, being approximately 1.5 times greater than the next highest task: right trunk rotation. Latissimus dorsi activity during right (ipsilateral) rotation was significantly greater than during shoulder internal rotation ($p = 0.031$) when recorded using indwelling electrodes but not when recorded using surface electrodes ($p = 0.079$) and similar to all other tasks ($p > 0.394$). No other significant differences were observed between tasks ($p > 0.079$).

4. Discussion

The results of this study indicate that trunk movements do not produce maximum activity in latissimus dorsi and support the use of shoulder extension as the task to achieve maximal latissimus dorsi activity (Ginn et al., 2011). Both surface and indwelling electrodes recorded higher latissimus dorsi activity levels during shoulder extension compared to the trunk tasks. For normalisation purposes, a maximal level of activity must be elicited in order to provide the most accurate activity profile for the muscle. Comparison with a task producing a submaximal activation would result in misrepresentation of the contribution by reporting it to be active at a higher % MVC level than it actually is. Therefore, since trunk tasks do not produce maximal latissimus dorsi activity their use to normalise EMG data from latissimus dorsi is not valid when evaluating its contribution relative to its maximal

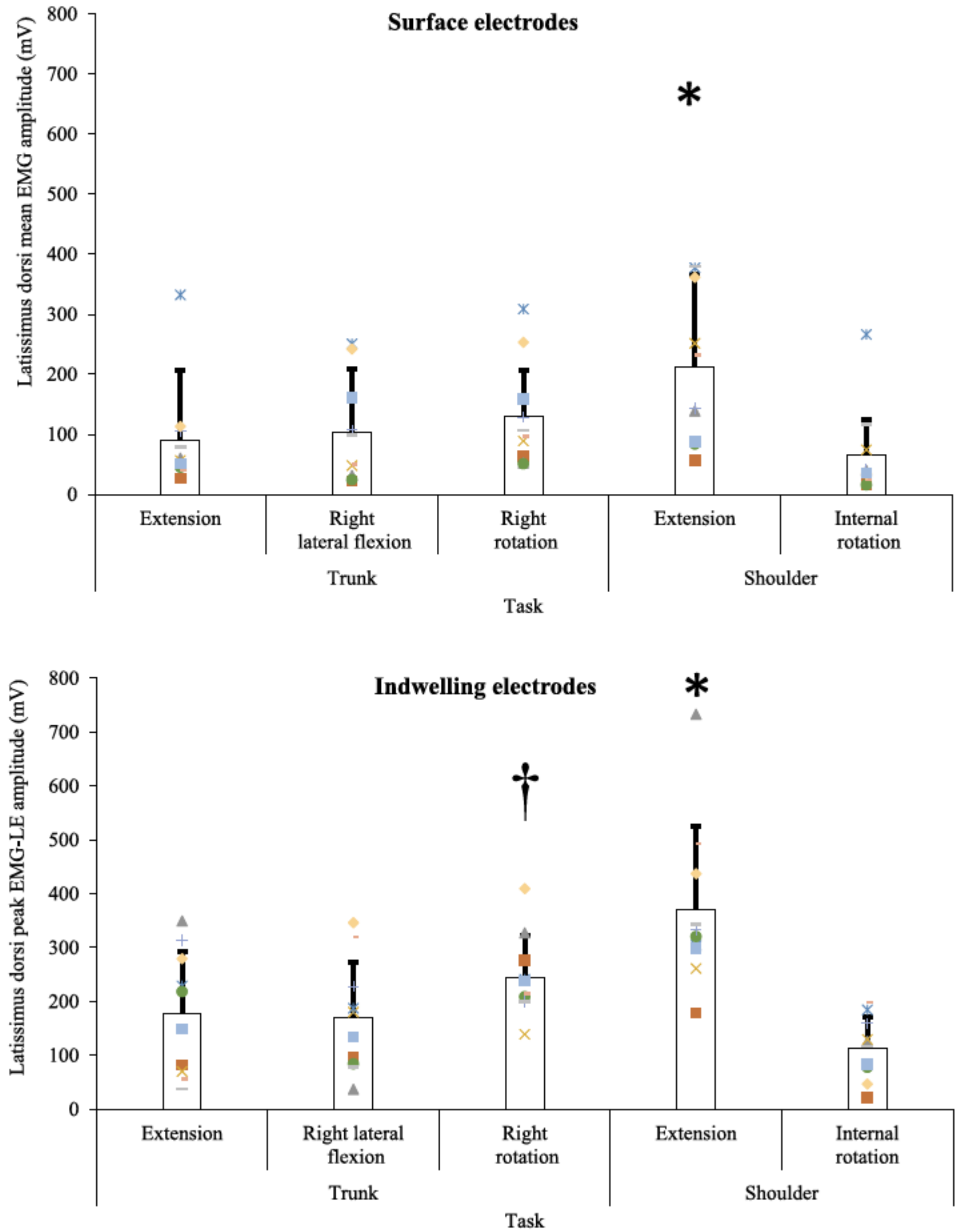

Fig. 2. Mean ± standard deviation of the peak EMG-linear envelope (EMG-LE) amplitude (mV) of the latissimus dorsi as recorded by the surface electrodes (top) and indwelling electrodes (bottom) during maximal isometric tasks. * represents significantly different to all other tasks. † represents significantly different to shoulder internal rotation.

capacity.

As stated previously many EMG studies investigating latissimus dorsi activity during trunk tasks have used trunk movements to normalise the data (Price et al., 2024). As such the EMG recorded during maximal trunk tasks is submaximal resulting in these studies over-estimating latissimus dorsi's contribution to trunk movement and stability tasks. In addition, the use of submaximal tasks makes the interpretation in these studies of the contribution of different muscles problematic (Besomi et al., 2020).

Although latissimus dorsi activity levels during maximum trunk tasks were significantly less than during maximum shoulder extension they were moderate, ranging from 46 % to 66 % of the activity generated during shoulder extension. This suggests latissimus dorsi may still have a significant role in trunk movement or control. Further research investigating latissimus dorsi activity during trunk tasks is needed to determine the extent to which latissimus dorsi contributes to trunk movement and control.

The results of this study indicate maximal trunk tasks were unable to produce maximal activity in latissimus dorsi. Failure to include this key methodological consideration in future EMG studies investigating the level of involvement of latissimus dorsi in trunk tasks is likely to over-estimate the contribution of latissimus dorsi to trunk movements and stability thus exaggerating its role in back pain rehabilitation.

Ethical approval

Approval was granted by The University of Sydney Human Ethics Committee with protocol number, 2021/922.

Funding

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

CRediT authorship contribution statement

Declan Price: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Karen A. Ginn:** Conceptualization, Formal analysis, Resources, Writing – review & editing, Validation, Visualization. **Mark Halaki:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Methodology, Formal analysis, Data curation. **Victor Kwasi:** Methodology, Investigation. **Darren Reed:** Writing – review & editing, Visualization, Supervision, Software, Resources, Methodology, Investigation, 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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Chapter 4: The validity of surface electrodes to record latissimus dorsi activity during submaximal trunk movement and stability tasks.

Journal of Electromyography and Kinesiology 83 (2025) 103013

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

The validity of surface electrodes to record latissimus dorsi activity during submaximal trunk movement and stability tasks

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ARTICLE INFO

Keywords:
Electromyography
Latissimus dorsi
Surface
Indwelling
Electrode

ABSTRACT

Introduction: The latissimus dorsi, a large superficial muscle connecting the pelvis, trunk and humerus, has the potential to contribute to trunk movement and stability. Surface electrodes are most typically used to record latissimus dorsi muscle activity during trunk tasks. However, there is the risk of crosstalk from nearby muscles, potentially leading to inaccurate muscle activity estimations. Therefore, this study aimed to determine the validity of using surface electrodes to record latissimus dorsi activity levels during submaximal trunk tasks by comparing the readings to indwelling electrodes simultaneously recorded at the same location.
Methods: Thirteen asymptomatic participants had indwelling electrodes inserted below the inferior angle of the scapula and surface electrodes placed over the same location. The participants completed submaximal trunk movements and stability tasks in various positions.
Results: There were no significant differences in latissimus dorsi activity recorded between surface and indwelling electrodes in all submaximal trunk movement tasks. However, during the trunk stability tasks the surface electrodes recorded significantly higher activity than the indwelling electrodes.
Conclusion: Surface electrodes are recommended as a valid option to record latissimus dorsi activity during submaximal trunk movement tasks. For tasks that challenge trunk stability, indwelling electrodes are recommended to avoid crosstalk from underlying muscles.

1. Introduction

The latissimus dorsi is an expansive muscle on the posterior trunk connecting the pelvis, spine, ribs and humerus through its bony and fascial attachments (Palastanga and Soames, 2018). As it spans multiple joints in the trunk, it is thought to be able to produce movement and provide stability to the trunk (Ng et al., 2001, Park and Yoo, 2014, Park et al., 2015, Perez and Nussbaum, 2002, Sheikhzadeh et al., 2008, Vera-Garcia et al., 2010).

Electromyography (EMG) is widely used to record the electrical activity of a muscle, providing a method to deduce the functional contribution or role a muscle plays in a movement or task. Surface electrodes are often the preferred choice of electrodes compared to indwelling electrodes as they are cheap, easy to apply and non-invasive (Chowdhury et al., 2013, Ginn and Halaki, 2015). However, surface electrodes are susceptible to crosstalk from nearby muscles when the target muscle is thin, deep, in close proximity to other muscles or if the electrode displaces with movement of the skin (Besomi et al., 2019, Hackett et al., 2014, Lowery et al., 2003). In such cases, indwelling electrodes are necessary to ensure accurate recordings from a specific muscle.

A recent systematic review pooled the data of 39 previous EMG studies that recorded the activity levels of latissimus dorsi during trunk movement and stability tasks (Price et al., 2024b). All but one of these studies used surface electrodes, with the most common placement location being 4 cm inferior to the inferior angle of the scapula, lateral to T9 (54 % of studies). While the latissimus dorsi, being a large superficial muscle, is well suited for surface electrode recordings, it is also a relatively thin muscle in parts, which makes it susceptible to crosstalk from underlying muscles (Besomi et al., 2019, Bogduk et al., 1998). Crosstalk was reported in a study using surface electrodes to measure latissimus dorsi activity during isometric and dynamic shoulder tasks, where the underlying erector spinae muscle was identified as the source of the interference (Ginn and Halaki, 2015). This suggests previous studies investigating latissimus dorsi activity during trunk tasks using surface electrodes may have inadvertently recorded from underlying muscles

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https://doi.org/10.1016/j.jelekin.2025.103013
Received 21 January 2025; Received in revised form 4 April 2025; Accepted 7 May 2025
Available online 10 May 2025
1050-6411/

and potentially incorrectly estimated the contribution of latissimus dorsi during some trunk tasks.

To gain a correct understanding of the role latissimus dorsi has during trunk tasks, accurate muscle recordings are essential. Therefore, the aim of this study was to determine whether surface electrodes can accurately measure latissimus dorsi activity by comparing their readings to those of indwelling electrodes at the same location during submaximal ($\leq$50 % maximum voluntary contraction (MVC)) isometric and dynamic trunk tasks.

2. Method

2.1. Participants

Thirteen asymptomatic volunteers (nine male, four female, average age 24, range 19–37 years old) who had not experienced shoulder or back pain within the past year, had never sought treatment for such pain, and were over 18 years old were enlisted into the study. A skilled physiotherapist conducted a physical assessment to ensure the absence of pain and normal range of motion in the shoulders and back, as well as the absence of discomfort during resistance tests for shoulder rotation and back extension. Following an explanation of the experiment to the participants their written informed consent was obtained. The research received approval from The University of Sydney Human Research Ethics Committee.

2.2. Instrumentation

Indwelling and surface electrodes were inserted and placed respectively at the most common location used in previous studies i.e. 4 cm inferior to the inferior angle of the scapula bilaterally, while the participant lay prone (Ginn and Halaki, 2015, Park and Yoo, 2013, Price et al., 2024b). The indwelling electrodes were manufactured in the laboratory and made from two 0.14 mm diameter Teflon insulated stainless steel wires, with 2 mm exposed at each end with one wire bent back at approximately 3 mm and the other at approximately 6 mm to form a hook. Before electrode placement, the skin was prepared using abrasive gel (Nuprep, DO Weaver and Co, Aurora, US) for exfoliation, followed by cleaning with alcohol, application of antiseptic solution (Betadine, Faulding Healthcare Pty Ltd, Virginia, Australia), and topical anaesthesia with Xylocaine 2 % jelly (AstraZeneca Pty Ltd, NSW, Australia). The wires were inserted aseptically in an infero-medial direction using a 23-gauge needle as a cannula and guided by a digital ultrasonic diagnostic imaging system (Mindray, DP-9900) to ensure appropriate placement within the latissimus dorsi. The needle cannula was then removed keeping the wires in-situ with the external wire then taped to the skin to prevent accidental displacement during movement while allowing adequate translation. Following the insertion of the indwelling electrodes, paired Ag/AgCl 10 mm diameter surface electrodes (Dual Electrodes, Noraxon, USA) were placed bilaterally directly over the inserted ends of the indwelling electrodes, oriented parallel to muscle fibre direction with a fixed centre-centre distance of 20 mm, ensuring an inter-electrode resistance $<$ 5 kOhm verified by an Ohmmeter. All electrodes were connected to a 16-channel telemetry EMG system (TELEmyo DTS EMG sensors, Noraxon, USA) with a gain of 1000 and a first order band-pass filter bandwidth of 10–500 Hz. EMG signals were transmitted to a receiver (Telemyo DTS belt receiver, Noraxon, USA, 16-bit resolution), sampled at 3000 Hz using MR3 software (Version 3.12.70 Noraxon, USA), and stored for later off-line analysis (Matlab version 9, R2022b, The MathWorks, Natick, MA). Following the placement of the electrodes, submaximal contractions of shoulder flexion and extension were performed to confirm high latissimus dorsi activity levels during shoulder extension and low levels during shoulder flexion.

2.3. Normalisation

The maximum EMG value obtained during maximally resisted isometric shoulder extension and internal rotation was used to normalise the data during analysis as these tasks have been shown to produce the highest latissimus dorsi activity (Ginn et al., 2011, Price et al., 2024a). Both tasks were completed with the participant in a seated position. For shoulder extension the shoulder was positioned at 30° abduction with the elbow extended and for shoulder internal rotation, the shoulder was at 90° abduction in the scapular plane, with the elbow flexed to 90° (Ginn et al., 2011). Maximal isometric resistance was applied at the distal forearm for five seconds and each task was completed in random order three times with at least 30 s rest between repetitions (Boettcher et al., 2008).

2.4. Experimental procedure

Trunk movement tasks and trunk stability tasks were investigated in this study. Trunk movement tasks consisted of dynamic and isometric, resisted and unresisted trunk extension, flexion, right rotation and right lateral flexion. Trunk stability tasks included leg and arm elevation in four-point kneeling and a plank.

2.4.1. Isometric tasks in sitting

Trunk extension, flexion, right rotation and right lateral flexion were completed in sitting while wearing a harness attached to a fixed point via a force transducer (Fig. 1). Prior to electrode insertion a maximal voluntary exertion (MVE) for each task was obtained. Participants performed two maximal isometric tasks against a force transducer (XTRAN load cell S1W, Applied Measurement Australia PTY LTD, Melbourne, Australia) connected to an amplifier (DA100 BIOPAC Systems Inc, Goleta, CA USA) and an analogue to digital converter (MP150, BIOPAC Systems Inc, Goleta, CA, USA) and visualised using the AcqKnowledge Software (Version 3.9.0, BIOPAC Systems Inc, Goleta, CA, USA). The average of two repetitions was used to calculate the MVE. After electrode insertion, the participant, with the aid of a visual representation of their force target level on a computer screen, isometrically resisted against the force transducer to ramp up to 50 % of the task MVE over a period of four seconds. This force was then held for three seconds before gradually returning to a resting position over another four second period. The participant's hands were placed on their knees, with verbal feedback to ensure they were not using their arms to generate force. The force transducer was attached to the harness at the back for trunk flexion and at the front for trunk extension, lateral flexion and trunk rotation. Each task was repeated twice with at least 30 s rest between repetitions.

2.4.2. Isometric tasks in lying position

Trunk extension, flexion and right lateral flexion were performed isometrically lying on a bed. For trunk extension the participant lay prone with their torso off the end of the bed up to the level of the anterior superior iliac spine (Fig. 2a). The body was secured to the bed by the researchers holding the participant's legs and pelvis and the participant was required to move the trunk to a horizontal level and maintain the position for five seconds. Trunk flexion involved the participant sitting in a semi-recumbent position on the bed with their ankles held down onto the bed by a researcher (Fig. 2b). The participant was required to flex their trunk to about 30° off the bed and maintain the position for five seconds. Right trunk lateral flexion was completed in left side-lying on the bed up to the level of the anterior superior iliac spine (Fig. 2c). The pelvis and legs were held down by the researchers and the participant was required to maintain a horizontal position for five seconds. In all these tasks the arms were held loosely across the chest and each task was repeated twice with at least 30 s rest between them.

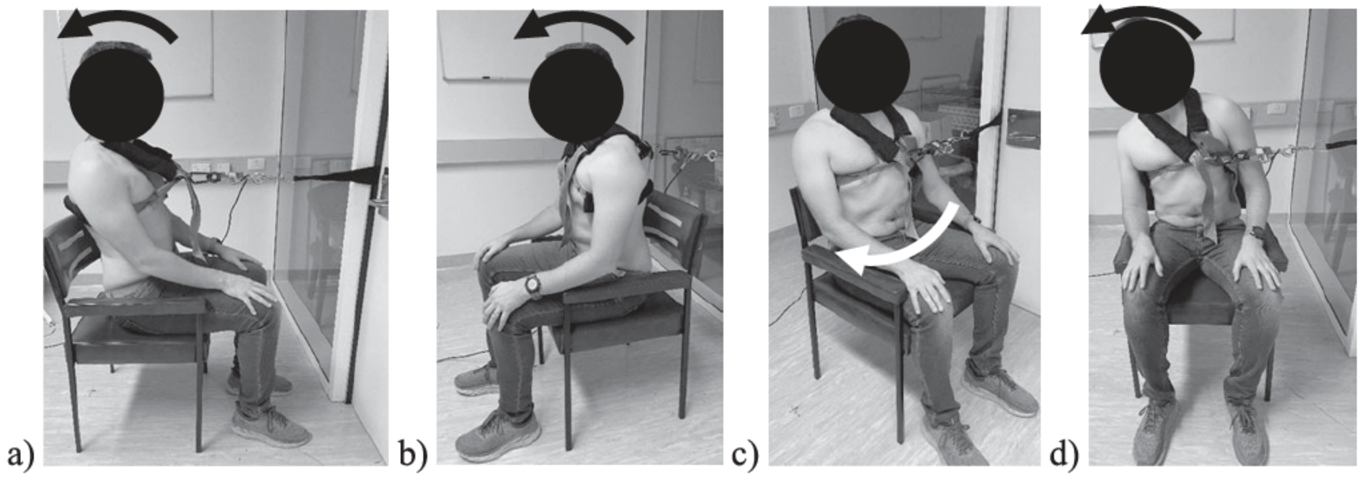

Fig. 1. Isometric tasks in seated position: a) trunk extension, b) trunk flexion, c) right trunk rotation, d) right trunk lateral flexion.

Fig. 2. Isometric tasks in lying position: a) prone extension, b) semi-recumbent flexion, c) left side-lying right lateral flexion.

2.4.3. Dynamic tasks in standing

Dynamic trunk extension, flexion, right rotation and right lateral flexion were completed in standing without any external load applied (Fig. 3). Hands were placed by their sides and verbal feedback was given to ensure the arms remained relaxed as they performed the movement with a total travel time of six seconds. Each movement, consisting of moving to the end of range and returning to the start position, was repeated twice with at least 30 s rest between repetitions.

2.4.4. Trunk stability tasks

Three common trunk stability tasks were performed on the floor. Two involved kneeling in the four-point kneeling position and either extending the right leg in isolation (Fig. 4a) or extending the right leg together with flexion of the left arm (Fig. 4b). The third task involved assuming the plank position resting on the toes and elbows (Fig. 4c). Participants were instructed to hold the position for five seconds with verbal feedback given to ensure they maintained a neutral spine position during each task. Each task was completed twice with 30 s rest between tasks.

2.5. Data analyses

EMG signals were high pass filtered (designed 4th order, 10 Hz Butterworth filter; applied two-pass zero-phase method to achieve overall 8th order), rectified, then low pass filtered (designed 4th order, 3 Hz Butterworth filter; applied two-pass zero-phase method to achieve

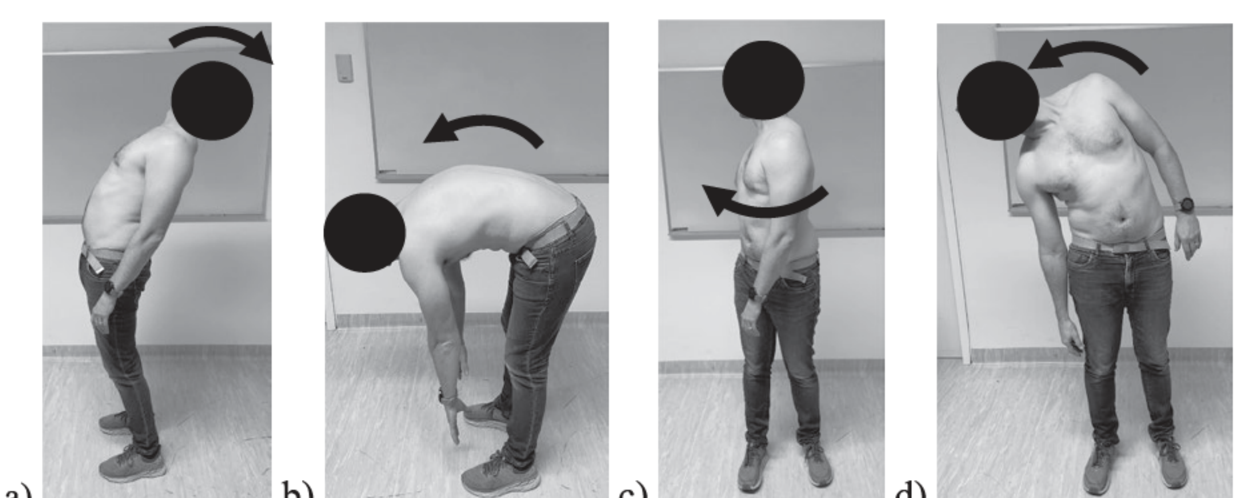

Fig. 3. Dynamic trunk tasks in standing: a) extension, b) flexion, c) right rotation, d) right lateral flexion.

Fig. 4. Trunk stability tasks: a) four-point kneeling right leg extension, b) four-point kneeling right leg extension and left shoulder flexion, c) plank.

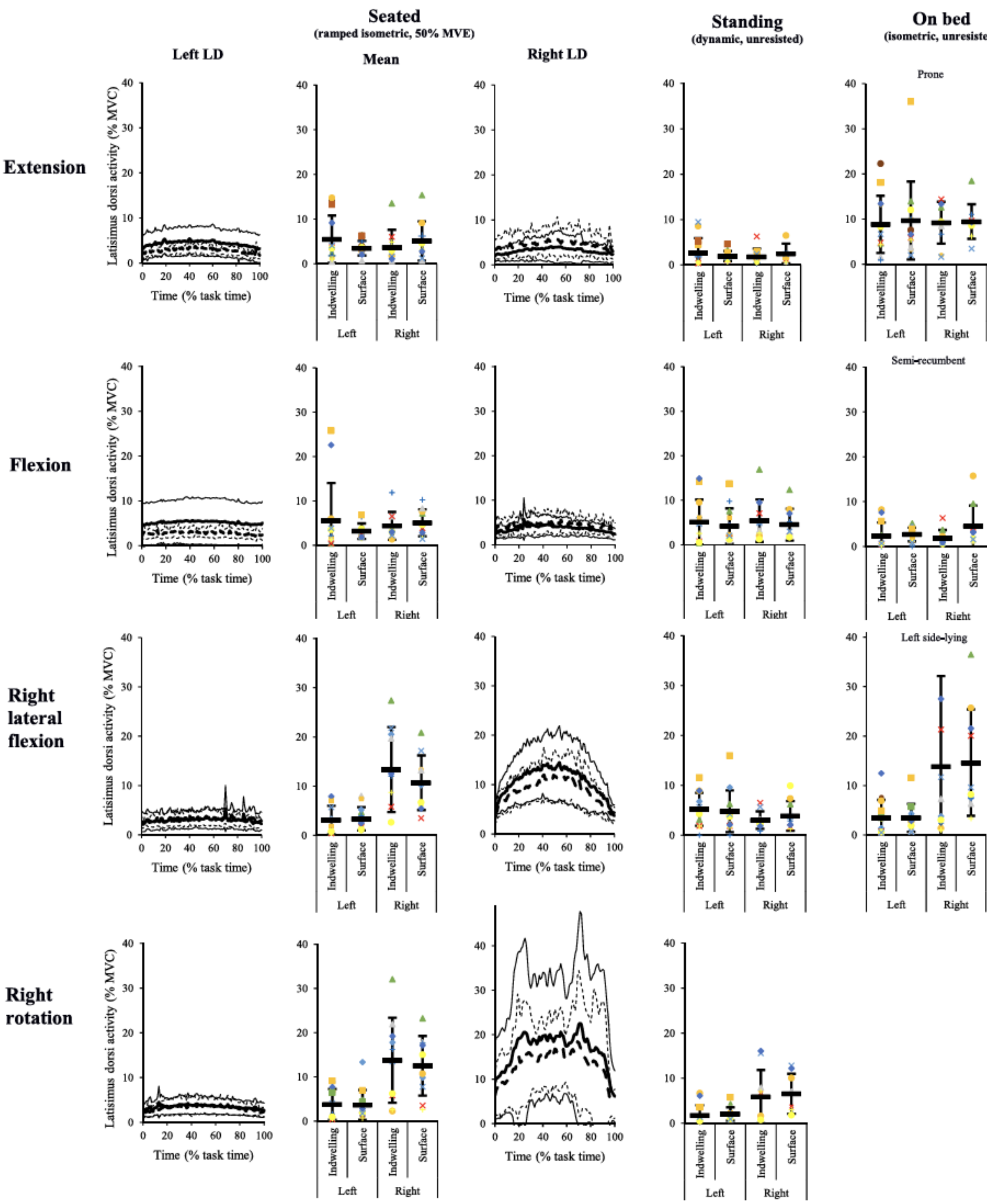

Fig. 5. Mean and standard deviation of latissimus dorsi activity as recorded using surface and indwelling electrodes during dynamic and isometric trunk movement tasks. Thick solid line indwelling electrode, thick dotted line surface electrode, thin solid line indwelling electrode SD, thin dotted line surface electrode SD.

overall 8th order) to provide an EMG linear envelope (EMG-LE). The data were then normalised to the maximum value measured during the maximally resisted isometric shoulder tasks for each EMG signal and presented as % MVC. A two second window was selected for each submaximal isometric tasks and the signals averaged across the window.

Shapiro-Wilk Test was used to evaluate normality of the data. The majority of the tasks presented a normal distribution. Given ANOVAs are robust for deviations from normality (Schmider et al., 2010), it was deemed appropriate to use. Repeated measures analysis of variance (ANOVA) with two factors (electrode type and trial) was used to compare the activity measured by the indwelling and surface electrodes across the two trials (Statistica, V10 Statsoft Inc, Tulsa OK, USA). Tukey post hoc test was used to identify differences when significant interactions were present. Significance was set at $p = 0.05$. The isometric tasks and dynamic tasks were also time normalised to 101 points and the average across the two trials for each task was calculated at each normalised time point to represent the activity levels across time for each dynamic task. A Bland-Altman analysis was completed to evaluate the agreement between the two electrode types.

3. Results

EMG signals were lost due to technical issues from the right indwelling electrode in three participants for all activities and from the left indwelling electrode in one participant for two activities (isometric flexion on the bed, dynamic right lateral flexion in standing).

3.1. Isometric and dynamic trunk tasks

Bilateral latissimus dorsi activity levels (mean ± SD) recorded using surface and indwelling electrodes during dynamic and isometric trunk movement tasks are illustrated in Fig. 5. There were no significant differences between the level of latissimus dorsi activity recorded using surface and indwelling electrodes in any of the dynamic and isometric trunk tasks ($0.081 \leq p \leq 0.894$, Cohen's $d = 0.03$ to 0.77). The levels recorded between trial one and trial two were not significantly different ($0.060 \leq p \leq 0.950$) with no significant interaction effect ($0.059 \leq p \leq 0.787$). In general, the Bland-Altmann analysis corroborated these results but revealed some additional insights. Significant offset error (significant mean difference) was found for the right side during extension 50 % MVE and flexion while supine as well as systematic bias (significant regression) between surface and indwelling electrode recodings in a number of tasks (Table 1).

3.2. Trunk stability tasks

Latissimus dorsi activity levels (mean ± SD) recorded using surface and indwelling electrodes during trunk stability tasks are illustrated in Fig. 6. During the trunk stability tasks, significantly higher (up to three times) latissimus dorsi activity levels were recorded from the surface electrodes compared to indwelling electrodes with significant effect sizes during leg and arm elevation in four-point kneeling: left latissimus dorsi ($p = 0.003$, Cohen's $d = 1.25$), right latissimus dorsi ($p = 0.002$, Cohen's $d = 1.67$); leg extension in four-point kneeling: right latissimus dorsi ($p = 0.013$, Cohen's $d = 1.27$); and during the plank: left latissimus dorsi ($p = 0.003$, Cohen's $d = 1.26$) and right latissimus dorsi ($p = 0.009$, Cohen's $d = 1.07$). The Bland-Altman analysis supported these finding with both significant offset error (significant mean difference) and systematic bias (significant regression) (Table 1). No significant differences were observed during four-point kneeling leg extension in the left latissimus dorsi ($p = 0.483$) with a Cohen's d score of 0.21 indicating a small size. The levels recorded during both trials were not significantly different ($0.239 \leq p \leq 0.991$) with no significant interaction effect ($0.269 \leq p \leq 0.678$).

Table 1
Summary of the *Bland-Altman results for trunk tasks.*

Task	Side	Mean Difference (% MVC)	Limits of Agreement (% MVC)	Intercept (% MVC)	Slope	Coefficient of Determination (R^2)
Extension						
Standing	Left	0.7	[-5.6, 7.0]	2.5	1.4	**0.66***
	Right	0.7	[-6.4, 4.9]	0.1	0.4	0.03
50 % MVE	Left	2.0	[-8.1, 12.1]	4.4	1.4	**0.67***
	Right	**−1.4***	[-6.4, 3.6]	0.9	0.1	0.03
Prone	Left	0.9	[-17.6, 15.9]	3.4	0.5	0.12
	Right	0.3	[-9.5, 8.9]	3.3	0.3	0.07
Right lateral flexion						
Standing	Left	0.4	[-6.2, 6.9]	1.8	0.3	0.09
	Right	0.9	[-8.2, 6.5]	2.7	1.0	0.19
50 % MVE	Left	0.3	[-6.5, 5.9]	1.4	0.3	0.05
	Right	2.7	[-9.3, 14.7]	3.5	0.5	**0.30***
Left sidelying	Left	0.0	[-8.6, 8.6]	1.5	0.4	0.06
	Right	0.8	[−23.2, 21.6]	8.7	0.6	**0.44***
Right rotation						
Standing	Left	0.3	[-4.9, 4.3]	1.5	0.6	0.15
	Right	0.7	[-9.5, 8.2]	2.5	0.3	0.10
50 % MVE	Left	0.1	[-5.7, 5.9]	0.03	0.01	0.00
	Right	1.2	[-10.5, 13.0]	3.6	0.4	**0.23***
Flexion						
Standing	Left	0.9	[-8.2, 10.0]	0.5	0.3	0.07
	Right	0.9	[-5.1, 6.9]	0.7	0.3	0.17
50 % MVE	Left	2.4	[-13.2, 18.0]	4.7	1.6	**0.84***
	Right	0.7	[-5.8, 4.4]	0.8	0.02	0.00
Supine	Left	0.3	[-5.6, 4.9]	2.5	0.9	0.38
	Right	**−2.7***	[-11, 5.6]	0.9	1.1	**0.54***
Trunk stability tasks						
4pt kneeling right leg	Left	0.9	[-9.4, 7.7]	2.2	0.2	0.05
	Right	**−5.1***	[-15.3, 5.1]	0.6	1.3	**0.53***
4pt kneeling right leg and left arm	Left	**−5.8***	[-16.8, 5.2]	2.2	0.7	0.20
	Right	**−7.9***	[-18.8, 3.1]	1.3	1.0	**0.44***
Plank	Left	**−6.8***	[-20.1, 6.4]	0.5	1.3	**0.65***
	Right	**−10.9***	[-30.7, 8.9]	2.5	0.9	**0.65***

* bold text indicates significant ($p < 0.05$) mean difference or regression.

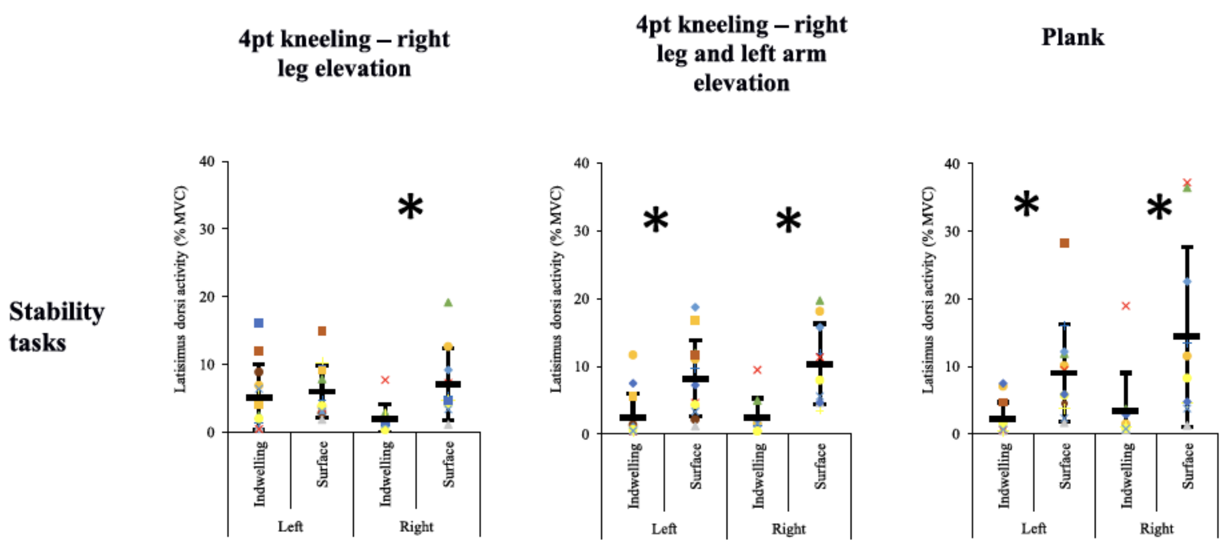

Fig. 6. Mean and standard deviation of latissimus dorsi activity as recorded using surface and indwelling electrodes during trunk stability tasks. * indicates significant ($p<0.05$) differences between indwelling and surface recordings.

4. Discussion

The aim of this study was to determine if surface electrodes accurately measure latissimus dorsi activity by comparing their readings to those of indwelling electrodes during trunk tasks when recording simultaneously from the same location. The results found no significant differences in latissimus dorsi activity levels recorded using surface or indwelling electrodes during submaximal trunk movement tasks. This result was consistent across all examined trunk movements (extension, flexion, rotation and lateral flexion) and body postures (standing, sitting, prone, supine and side-lying). Therefore, these findings indicate that surface electrodes are as valid as indwelling electrodes in recording latissimus dorsi activity during submaximal trunk movement tasks. As surface electrodes are cheap, easy to apply, non-invasive and involve little risk, they would be an appropriate choice of electrode for investigating latissimus dorsi activity during submaximal trunk movement tasks.

Only one other study has compared surface and indwelling electrodes during trunk tasks (Ginn and Halaki, 2015). The only trunk task the authors investigated was isometric trunk extension in prone at maximum exertion using similar normalisation procedures and electrode placement to the current study. The surface electrodes recorded significantly higher activity than the indwelling electrodes. This increased activity was attributed to the underlying erector spinae muscle group from which activity had been recorded simultaneously using indwelling electrodes. This suggests indwelling electrodes may be more appropriate for investigating latissimus dorsi activity during maximally loaded trunk extension tasks. Further research is required to determine if this is applicable to other maximally loaded trunk tasks.

Latissimus dorsi exhibited low levels of activity (<20 % MVC) during all trunk movement tasks examined in the current study. These findings are consistent with previous studies investigating similar tasks (trunk extension in prone, trunk movements in standing) while using comparable shoulder normalisation methods and load levels to the current study (De Ridder et al., 2013, Park et al., 2015, Siu et al., 2016). This is in contrast to other studies which normalised the EMG data to levels recorded during maximally resisted trunk tasks, which reported higher latissimus dorsi activity levels during similar trunk movement tasks as the current study (ipsilateral trunk rotation at moderate load (30–59 % MVE)) (Kumar et al., 2002, Stevens et al., 2007a, Talebian et al., 2010). Recent research has shown that maximally resisted isometric trunk tasks generate significantly less latissimus dorsi activity than maximal isometric shoulder extension and, therefore, when used for EMG normalisation purposes, are likely to overestimate the contribution of latissimus dorsi (Price et al., 2024a). As such, the results from the current study and previous studies, which used shoulder extension as the normalisation method, are more likely to give an accurate representation of latissimus dorsi activity levels.

During the submaximal trunk stability tasks investigated in four-point kneeling, latissimus dorsi activity levels recorded from the surface electrodes were consistent with previous studies which used similar shoulder normalisation methods (Callaghan et al., 1998, Drake et al., 2006, Kavcic et al., 2004, Stevens et al., 2007b). However, these surface electrodes activity levels were up to three times higher than the levels recorded by the indwelling electrodes in the current study during these tasks and the Bland-Altman analysis corroborating these results. This discrepancy may be due to crosstalk from surrounding muscles (Ginn and Halaki, 2015). These results indicate that indwelling electrodes are more appropriate when investigating latissimus dorsi activity during trunk stability tasks to ensure crosstalk contamination is avoided and latissimus dorsi activity is not overestimated. Although the current study was not designed to identify the source of potential crosstalk, there is strong evidence indicating erector spinae as the source of latissimus dorsi crosstalk contamination during shoulder tasks (Ginn and Halaki, 2015). Future studies are required to determine if this is the case during trunk tasks.

Some data were lost in the current study due to technical difficulties with the wires, such as the fascia being too thick to penetrate and the wires shorting with no signal recorded. While this resulted in latissimus dorsi activity being available for analysis from only ten participants on one side, the effect sizes for the tasks with no significant differences between electrode type were, in general, small to very small. In addition, all the trunk stability tasks examined exhibited large effect sizes and significant differences between electrode types were found despite the small participant number, suggesting adequate power was reached.

A potential limitation of indwelling electrodes is that they have a smaller recording zone compared to surface electrodes and may require multiple electrode locations to be representative of the activation of large muscles such as latissimus dorsi (Besomi et al., 2019). The single location to record latissimus dorsi activity used in this study was the most commonly used insertion site found in the literature and there is evidence to suggest indwelling electrodes inserted at this location are as representative of the whole muscle as surface electrodes during shoulder tasks (Ginn and Halaki, 2015). Future studies are required to determine if indwelling electrodes are also representative of the whole of latissimus dorsi during trunk tasks.

5. Conclusion

This study found that surface and indwelling electrodes recorded similar latissimus dorsi activity levels during all the submaximal trunk movement tasks investigated. Therefore, when investigating latissimus dorsi activity during submaximal trunk movements, surface electrodes are appropriate as they accurately represent latissimus dorsi activity levels and have lower risks than indwelling electrodes. However, for tasks designed to challenge trunk stability the recording of latissimus dorsi activity levels using surface electrodes may overestimate the contribution of latissimus dorsi. In such cases, indwelling electrodes should be used to ensure accurate recordings of latissimus dorsi activity.

6. Ethics

Approval was granted by The University of Sydney Human Ethics Committee with protocol number 2021/922.

CRediT authorship contribution statement

Declan Price: Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Data curation, Conceptualization. **Karen A. Ginn:** Visualization, Validation, Supervision, Methodology. **Mark Halaki:** Writing – review & editing, Validation, Supervision, Software, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Victor Kwasi:** Writing – review & editing, Supervision, Resources, Methodology. **Darren Reed:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Funding

None declared. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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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Chapter 5: Revisiting the contribution of latissimus dorsi to trunk movements.

Revisiting the contribution of latissimus dorsi to trunk movements

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Word count (excluding abstract, tables, figures and references): 2195

Abstract word count: 184

Number of Figures: 5

Keywords: electromyography, latissimus dorsi, trunk, movement

Abstract

Introduction: Latissimus dorsi has the anatomical potential to contribute to trunk movement due to its expansive attachments arising from the pelvis and trunk. Previous EMG studies have reported high latissimus dorsi activation during trunk extension, rotation and lateral flexion. However, many studies have used trunk-based normalisation tasks and surface electrodes. Both have been shown to be problematic for measuring latissimus dorsi activity levels. This study aimed to quantify latissimus dorsi activity during trunk movements using validated shoulder-based EMG normalisation tasks and indwelling electrodes.

Method: Ten asymptomatic volunteers performed trunk extension, flexion, lateral flexion and rotation at submaximal and maximal loads. Indwelling electrodes were inserted into the right latissimus dorsi, and EMG signals were normalised to maximal isometric shoulder extension and internal rotation.

Results: During all submaximal tasks, latissimus dorsi activity was less than 20% maximal voluntary contraction (MVC) and even during maximally resisted trunk tasks only achieved activity levels of between 31% and 43% MVC.

Conclusions: The low to moderate levels of latissimus dorsi activation observed in pain-free individuals even during maximal load conditions suggest it is not a primary contributor to trunk movement.

1. Introduction

The latissimus dorsi is a broad, expansive muscle spanning two-thirds of the posterior trunk. It originates from the pelvis, the lower six thoracic vertebrae and all lumbar vertebrae via the thoracolumbar fascia and extends to the lower four ribs and attaches to the humerus (Palastanga and Soames, 2018). Due to these extensive attachments from the pelvis to the humerus, the latissimus dorsi is well positioned to contribute to trunk movement. Previous electromyography (EMG) studies have reported moderate to high activation levels of the latissimus dorsi during trunk rotation, lateral flexion and extension under moderate and maximal loading conditions (Drake et al., 2006, Ng et al., 2001, Ng et al., 2002, Perez and Nussbaum, 2002, Sheikhzadeh et al., 2008, Van Oosterwijck et al., 2017, Vera-Garcia et al., 2010).

To accurately compare muscle activity across tasks and between studies, the raw EMG data must be normalised, typically by using a task that has been shown to elicit maximal activation of the muscle (Besomi et al., 2020). In EMG studies investigating latissimus dorsi activity during trunk tasks, various normalisation methods have been used, often involving combinations of trunk movements to generate a maximal contraction from latissimus dorsi (Price et al., 2024b). However, evidence shows that trunk tasks do not reliably elicit maximal latissimus dorsi activation and therefore, previous studies using trunk-based normalisation methods may have overestimated latissimus dorsi's contribution (Price et al., 2024a). Maximal activation is more reliably achieved through shoulder extension, internal rotation and/or adduction as these tasks have been shown to produce maximal activity levels in latissimus dorsi in a majority of participants (Boettcher et al., 2008, Ginn et al., 2011, Park and Yoo, 2013).

Most EMG studies investigating latissimus dorsi activity during trunk tasks have used surface electrodes to record its activity (Price et al., 2024b). Surface electrodes may be appropriate for submaximal tasks, but at higher loads they risk interference from nearby muscles, such as the erector spinae, reducing their accuracy (Price et al., 2025b).

Therefore, the aim of this study was to investigate latissimus dorsi activity during trunk tasks previously used in the literature while using indwelling electrodes and validated normalisation techniques. This approach was intended to more accurately determine the extent to which the latissimus dorsi contributes to trunk tasks.

2. Methods

2.1 Participants:

Ten asymptomatic volunteers (seven male, three female) over 18 years old (mean age 26 years (SD ±5)) who had not experienced shoulder or back pain within the past year and had never sought treatment for shoulder or back pain were recruited into the study. A physical assessment was completed by a skilled physiotherapist to ensure there was no pain and full range of motion at the shoulders and back and no pain during resisted shoulder rotation and back extension. The experiment was then explained to the participant and their written informed consent was obtained. The study received approval from The Univerisity of Sydney's Human Research Ethics Committee.

2.2 EMG setup

Bipolar indwelling electrodes were inserted into the right latissimus dorsi, 4 cm inferior to the inferior angle of the scapula in an infero-medial direction while the participant lay prone with the shoulders abducted (Ginn and Halaki, 2015). Electrodes were manufactured in the laboratory from two 0.14 mm diameter Teflon insulated stainless steel wires with 2 mm on the ends stripped of the insulation and the two wires bent back at different levels to form a hook.

The wires were threaded through a 23-gauge needle, which was used as a cannula to insert the electrodes. Prior to insertion the skin was prepared with the application of alcohol, antiseptic solution (Betadine, Faulding Healthcare Pty Ltd, Virginia, Australia) and anaesthetic gel (Xylocaine 2% jelly, AstraZeneca Pty Ltd, NSW, Australia). Electrode placement within the latissimus dorsi was guided by a digital ultrasonic diagnostic imaging system (Mindray, DP-9900). The needle was then removed with the wires remaining in the muscle and the external wires were taped to the skin to prevent the wires from being pulled out and to allow adequate translation of the wires during testing. The electrodes were connected to a 16-channel telemetry EMG system (TELEmyo DTS EMG sensors, Noraxon, USA) with a gain of 1000 and a first order band-pass filter bandwidth of 10-500 Hz. EMG signals were transmitted to a receiver (Telemyo DTS belt receiver, Noraxon, USA, 16-bit resolution), sampled at 3000 Hz using MR3 software (Version 3.12.70 Noraxon, USA), and stored for later off-line analysis (Matlab version 9, R2022b, The MathWorks, Natick, MA). Following the insertion of the electrodes, submaximal contractions of shoulder flexion and extension were performed to confirm low latissimus dorsi activity levels during shoulder flexion and high levels during shoulder extension.

2.3 Normalisation

The raw EMG signals were normalised to maximally resisted isometric shoulder extension at 30° abduction and maximally resisted isometric shoulder internal rotation at 90° abduction in the scapular plane, as they have been shown to produce maximal levels of activity from the latissimus dorsi (Boettcher et al., 2008, Ginn et al., 2011, Price et al., 2024a). These values were expressed as a percentage of the maximal voluntary contraction (MVC). The tasks were completed in sitting with a resistance applied at the distal forearm. The participants were verbally encouraged to push as hard as possible against a matched resistance by the researcher and held for 3-5 seconds while ensuring good posture and correct technique. Each task was repeated three times in random order with at least 60 seconds rest between repetitions.

2.4 Experimental procedure

The exercise protocol consisted of submaximal and maximal trunk extension, flexion, right lateral flexion, and right rotation in three positions: standing, sitting (isometric, 50% and 100% maximal voluntary exertion (MVE)), and lying (isometric, with and without external load). These tasks were investigated as they have been reported to produce moderate to high levels of latissimus dorsi activity in a previous systematic review investigating latissimus dorsi's contribution to trunk tasks (Price et al., 2024b).

In standing, participants performed dynamic trunk flexion, extension, right lateral, and right rotation without external resistance (Figure 1). Each movement was completed over three seconds, followed by a return to the starting position over three seconds. Participants ensured their arms remained relaxed throughout the task.

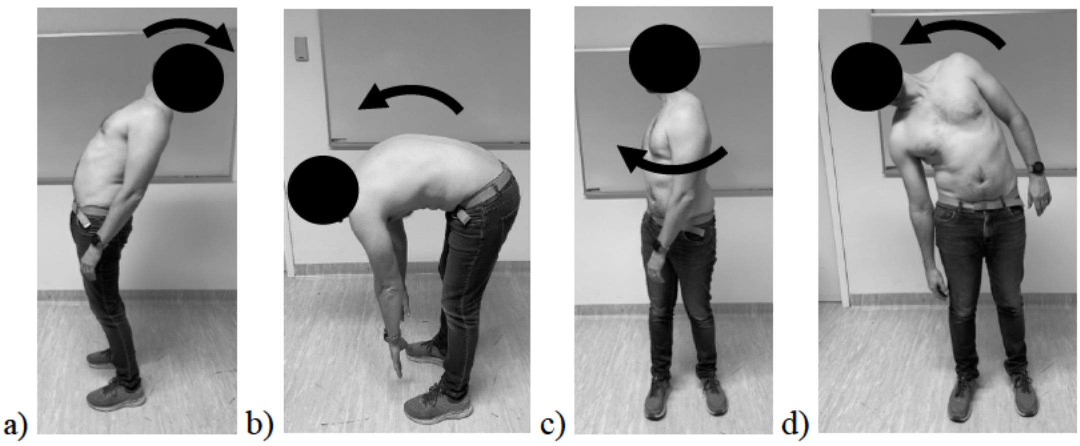
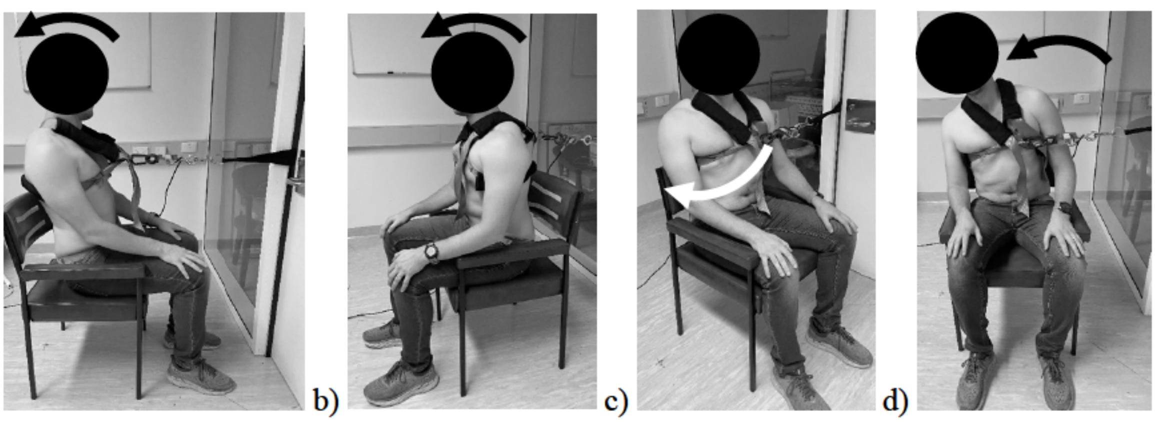


Figure 1. *Dynamic tasks in standing: a) extension, b) flexion, c) right rotation, d) right lateral flexion.*

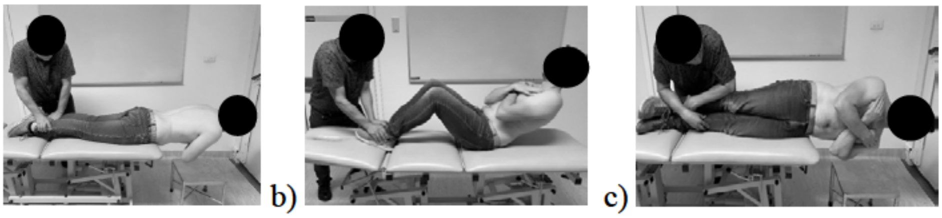
Isometric trunk flexion, extension, right rotation, and right lateral flexion were performed in sitting while wearing a harness on their torso connected to a fixed point via a rope and force transducer (XTRAN load cell S1W, Applied Measurement Australia PTY LTD, Melbourne, Australia) (Figure 2). Participants exerted an isometric force against the rope to match the target of 50% maximal voluntary exertion (MVE). The force signal was amplified (DA100 BIOPAC Systems Inc, Goleta, CA, USA), converted to a digital signal (MP150, BIOPAC Systems Inc, Goleta, CA, USA) and displayed on a screen using the AcqKnowledge Software (Version 3.9.0, BIOPAC Systems Inc, Goleta, CA, USA) for the participant to follow. The tasks involved a four second ramp up time to 50% MVE, three second hold, and a four second ramp down time. The MVE values were generated from the average of two maximal exertions in the same movement direction obtained prior to electrode insertion. For extension, lateral flexion, and rotation the rope was attached to the harness anteriorly and for flexion the rope was attached to the harness posteriorly. Throughout the tasks the participant had their hands resting on their knees and a researcher observed the participant to ensure they were pushing through their trunk and not using their arms. Seated trunk rotation was also performed at 100% MVE with a hold time of five seconds without any ramp up and down time.



a) b) c) d)

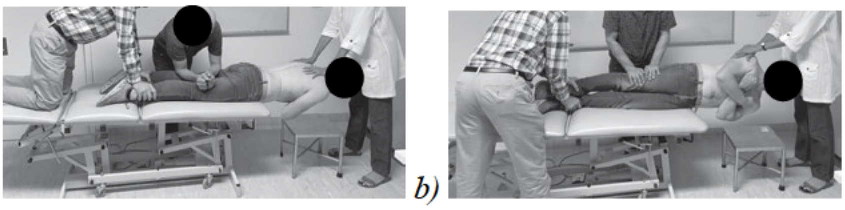
Figure 2. *Isometric tasks in seated position: a) extension, b) flexion, c) right rotation, d) right lateral flexion.*

The tasks performed in lying involved extension in prone, flexion in crook-lying and right lateral flexion in left side-lying (Figure 3). In extension and lateral flexion, participants were secured to the bed at the pelvis up to the level of their anterior superior iliac spine. They were instructed to raise to a horizontal position and hold for five seconds. These tasks were repeated with external resistance applied by the researchers until the participant's maximal effort was reached (Figure 4). For trunk flexion, the participant lay in crook-lying with their feet manually secured to the bed. They lowered their torso to 30° off the bed and maintained this position for five seconds. In each of these tasks the participants were instructed to keep their arms held relaxed across their chest. Each task was repeated twice in random order with at least 60 seconds rest between repetitions.



a) b) c)

Figure 3. *Isometric tasks in lying position: a) extension in prone, b) flexion in crook-lying, c) right lateral flexion in left side-lying.*



a) b)

Figure 4. *Maximal isometric extension in prone (a) and right lateral flexion in left side-lying (b).*

2.5 Data analyses

EMG signals were high pass filtered (10 Hz, 8th order Butterworth), rectified, and low pass filtered (3 Hz, 8th order Butterworth) using Matlab (version 9.1). The data were then normalised to the maximum level obtained in the normalisation test. The average EMG was calculated across the entire movement for dynamic tasks, and over a two second window for the hold phase of the isometric tasks with the mean of the two trials used.

3. Results

Latissimus dorsi was activated at low (< 20% MVC) to moderate (30–42% MVC) levels during all submaximal and maximal trunk tasks (Figure 5). Trunk extension, ipsilateral rotation, and ipsilateral lateral flexion at maximal resistance were the only tasks where latissimus dorsi was active above 30% MVC.

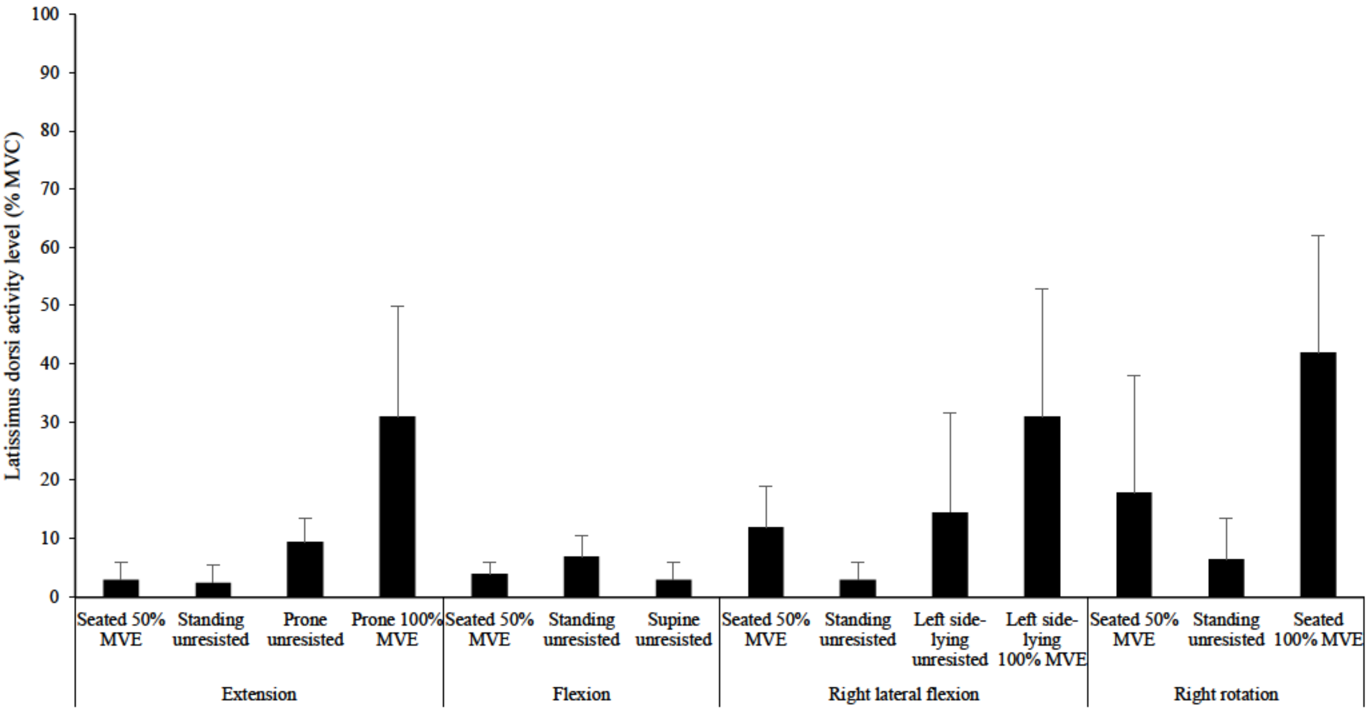


Figure 5. *Mean and standard deviation of the right latissimus dorsi activity during dynamic and isometric trunk extension, flexion, right lateral flexion and right rotation.*

4. Discussion

This study assessed the contribution of latissimus dorsi to trunk movement by measuring its activity during isometric and dynamic trunk tasks performed across different positions and loads. During all submaximal tasks, latissimus dorsi activity was less than 20% MVC, and even during maximally resisted trunk tasks only achieved activity levels of between 31% and 43% MVC. These consistently low to moderate activity levels suggest that latissimus dorsi plays a limited role in trunk movement.

The limited activation of latissimus dorsi during trunk tasks may be explained by its anatomical characteristics. Despite its broad size, latissimus dorsi is relatively thin and may lack the structural capacity to generate substantial force across the lumbar spine (Bogduk et al., 1998). Other trunk muscles, such as the erector spinae, are more likely to be preferentially recruited to perform trunk movements due to their greater cross-sectional area and more favourable line of action.

In contrast to the current findings, a recent systematic review (Price et al., 2024b) reported substantially higher latissimus dorsi activation during trunk tasks performed at similar loads, particularly under maximal effort conditions where variability and peak values were high. For instance, during ipsilateral rotation, activity ranged from 26–82% MVC, with a pooled mean of 60% MVC from the meta-analysis, compared to 42% MVC in the current study. In trunk extension and ipsilateral lateral flexion, latissimus dorsi activity in the current study was 31% MVC for both tasks. In contrast, the review reported ranges of 10–79% MVC for extension and 15–85% MVC for ipsilateral lateral flexion, with most studies exceeding the values observed here. At submaximal loads, differences were less pronounced, particularly when EMG was normalised to shoulder tasks. For example, during prone extension, studies using shoulder-based normalisation reported 6–26% MVC with a pooled result of 18% MVC, compared to 10% in the current study. In contrast, during ipsilateral rotation, studies using trunk-based normalisation showed a much greater range of activation, from 10–101% MVC, whereas the current study reported 18% MVC.

These discrepancies between previous studies and the current study likely reflect methodological differences, particularly in normalisation procedures and electrodes used. Many previous studies used trunk tasks for normalisation that are unlikely to have elicited maximal latissimus dorsi activation, potentially exaggerating relative EMG values (Besomi et al., 2020, Price et al., 2024a). Additionally, all but one of the previous studies used surface electrodes, which, while comparable to indwelling electrodes at submaximal loads (Price et al., 2025b), may overestimate latissimus dorsi activity at high loads due to crosstalk from underlying muscles (Ginn and Halaki, 2015).

A potential limitation of the current study is the use of a single indwelling electrode to record latissimus dorsi activity levels as it may not capture the full range of regional activation across such a broad muscle (Besomi et al., 2019, Wickham and Brown, 2012). However, previous studies suggest that indwelling electrodes in the same location as the current study are as representative of the whole of latissimus dorsi activity as surface electrodes (Brown et al., 2007, Ginn and Halaki, 2015, Price et al., 2025b). A similar sample size of 10-15 participants has been used in previous descriptive studies (Ginn and Halaki, 2015, Lee et al., 2011, McGill et al., 1999, Reed et al., 2010) to capture a representative profile of muscle activity during a range of tasks.

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Chapter 6: Latissimus dorsi’s contribution to trunk stability in standing is minimal.

Latissimus dorsi's contribution to trunk stability in standing is minimal

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Conflict of interest: None declared.

Ethics: Approval was granted by The University of Sydney Human Ethics Committee with protocol number, 2017/924.

Funding: None declared. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Word count (excluding abstract, tables, figures and references): 2367

Abstract word count: 185

Number of Figures: 2

Keywords: electromyography, latissimus dorsi, trunk, stability

Abstract

Introduction: The latissimus dorsi has been proposed to contribute to trunk stability due to its extensive attachments to the trunk and via the thoracolumbar fascia. While electromyography evidence is limited, previous studies investigating latissimus dorsi activity during trunk stability tasks have reported contralateral activation prior to limb movement, suggesting a possible postural role, though surface EMG may be overestimating activity due to cross talk. This study investigated latissimus dorsi activation during submaximal isometric upper and lower limb tasks in standing and to determine whether contralateral arm support on the pelvis affects activation.

Method: Fifteen asymptomatic volunteers performed right-sided isometric shoulder and hip flexion and extension at 50% maximal voluntary exertion in standing with the left arm either by the side or fixed on the pelvis. Indwelling electrodes recorded left sided latissimus dorsi activity.

Results: Latissimus dorsi activation was minimal (≤5% maximal voluntary contraction) during all tasks. A small but statistically significant difference was observed during unsupported hip flexion ($p=0.03$); however, this difference was not meaningful.

Conclusions: Latissimus dorsi does not meaningfully contribute to trunk stability during submaximal, isometric limb tasks in standing in healthy individuals

1. Introduction

The latissimus dorsi is a broad posterior trunk muscle with direct attachments to the lower ribs and pelvis, and indirect connections to the lumbar vertebrae via the thoracolumbar fascia (Palastanga and Soames, 2018). These expansive attachments and its span across multiple spinal segments provide a rationale for the latissimus dorsi contributing to trunk stability by generating tension through the thoracolumbar fascia and stiffening the spine when contracted.

Trunk (or core) stability refers to the control of trunk and pelvic motion to optimise force transfer to and from the limbs (Cholewicki and VanVliet, 2002, Kibler et al., 2006, Stevens et al., 2007b). This is achieved through coordinated and balanced activation of deep and superficial trunk muscles, in response to the load, speed and direction of movement of the limbs during a task (Hodges et al., 1999, Lee et al., 2009, 2011, McGill et al., 2003). Such control limits excessive movement of the vertebral joints, protecting neurovascular structures from shear forces while providing a stable base for limb movement (Cholewicki and VanVliet, 2002, Lee et al., 2009, McGill et al., 2003, Panjabi, 1992a). In rehabilitation, particularly for individuals with low back pain, exercise strategies often aim to restore or improve trunk stability, either by addressing the muscular system globally or by targeting specific trunk muscles (Hill et al., 2011, Panjabi, 1992a). Understanding how individual trunk muscles contribute to trunk stability within larger coordinated activation patterns can guide exercise prescription and rehabilitation strategies.

Trunk stability exercises commonly involve limb movements that impose rotational destabilising forces on the trunk, such as unilateral shoulder flexion or extension in standing or four-point kneeling, which require activation of trunk muscles to counteract these forces to maintain trunk stability (Lee et al., 2009, 2011). As stated before, the latissimus dorsi may contribute to trunk stability by tensioning the thoracolumbar fascia, thus transmitting forces across the lumbopelvic region. Stabilising the distal attachment of latissimus dorsi by placing the hand on the pelvis could potentially increase its ability to tension the thoracolumbar fascia and thus its contribution to trunk stability.

While anatomical continuity with the thoracolumbar fascia supports a potential stabilising role, evidence of latissimus dorsi's involvement in trunk stability during upright submaximal tasks is limited. Surface electromyography (EMG) studies have reported contralateral latissimus dorsi activation during upper limb movements, interpreted as anticipatory postural adjustments (Esposti and Baldissera, 2013, Pereira et al., 2014). However, surface EMG recordings from latissimus dorsi are prone to cross talk from adjacent muscles, which can misrepresent the true contribution of latissimus dorsi to trunk stability (Ginn and Halaki, 2015, Price et al., 2025b).

This study aimed to determine whether latissimus dorsi contributes to trunk stability by using indwelling EMG to examine latissimus dorsi activation during voluntary, submaximal, isometric upper and lower limb tasks in standing, and to determine whether fixing the distal attachment of latissimus dorsi influences its activation levels. It was hypothesised that the contralateral latissimus dorsi would show increased activation during isometric shoulder flexion and that fixing the hand on the pelvis would increase its activation levels.

2. Method

2.1 Participants

Fifteen asymptomatic volunteers participated in this study (9 male and 6 female, mean age 22.9 ± 4.15 years). Subjects were included if they had no shoulder or back pain in the previous year, had never received treatment for shoulder or back pain, and were over 18 years old. An experienced physiotherapist performed a physical examination to confirm normal pain-free shoulder and back range of motion and the absence of pain on resisted isometric shoulder rotation. Prior to testing, the protocol was explained to all subjects and written informed consent obtained. The study was approved by The University of Sydney's Human Research Ethics Committee.

2.2 Instrumentation

The participants were familiarised with the exercise protocols prior to electrode insertion. Bipolar indwelling electrodes were inserted into the left latissimus dorsi (non-moving limb), 4 cm below the inferior angle of the scapula and angled infero-medially as described by Ginn and Halaki (2015). The electrodes were constructed in the laboratory using two 0.14 mm Teflon-coated stainless-steel wires with 2 mm of insulation removed from the ends to create an exposed tip. Each wire was bent to form a hook after being threaded through a 23-gauge needle, which served as the insertion cannula. The skin was prepared before the procedure by applying alcohol, antiseptic solution (Betadine, Faulding Healthcare Pty Ltd, Virginia, Australia), and a topical anaesthetic gel (Xylocaine 2% jelly, AstraZeneca Pty Ltd, NSW, Australia). Using a digital ultrasonic diagnostic imaging system (Mindray, DP-9900), the electrodes were guided into position maintaining an aseptic technique. Following insertion, the needle was removed, and the exposed wires were secured to the skin with tape to prevent dislodgement while still allowing for sufficient movement during testing. The indwelling electrodes were connected to a 16-channel telemetry EMG system (TELEmyo DTS EMG sensors, Noraxon, USA) with a gain of 1000 and a first-order band-pass filter (10–500 Hz). EMG signals were transmitted to a receiver (Telemyo DTS belt receiver, Noraxon, USA) at a sampling rate of 3000 Hz, recorded using MR3 software (Version 3.12.70, Noraxon, USA), and stored for subsequent analysis in MATLAB (Version 9, The MathWorks, Natick, MA).

2.3 Normalisation

Latissimus dorsi EMG data were normalised using two isometric tests, performed in random order: maximal resisted isometric shoulder internal rotation at 90° abduction in the scapula plane while seated, and maximal resisted isometric shoulder extension at 30° abduction while seated. Both tasks have been shown to produce maximal latissimus dorsi activation (Boettcher et al., 2008, Ginn et al., 2011, Price et al., 2024a). For each task resistance was applied at the wrist where the participant was verbally encouraged to push as hard as possible against a matched resistance by the researcher. This was held for 3-5 seconds while maintaining good technique and position. Each test was repeated three times with at least 60 seconds rest between repetitions.

2.4 Experimental procedure

Four right-sided isometric tasks (shoulder flexion, shoulder extension, hip flexion and hip extension) were performed in standing with each task completed twice with two variations: one with the left upper limb placed on the pelvis (fixed condition), and the same task with the left upper limb hanging freely by the side (not fixed condition). These tasks mimic common functional demands requiring trunk stability and are commonly used in trunk rehabilitation. Right shoulder flexion was performed in standing with the right arm by the side, elbow extended and the thumb facing forward. A pulley handle was attached to a rigid frame and a load cell (XTRAN load cell S1W, Applied Measurement Australia PTY LTD, Melbourne, Australia) behind the participant and then pulled forward by the participant (Figure 1a). Right shoulder extension was performed in standing with the right arm in 30° flexion, elbow extended, palm facing backward and a pulley handle attached to a rigid frame and the load cell in front of the participant (Figure 1b). Right hip flexion and extension were performed while standing on the left leg on a small block. The right leg was extended with a strap around the ankle connected to a pulley at floor level attached to a rigid frame and the load cell behind for hip flexion and in front for hip extension (Figure 1c and d). Maximum load (100% maximum voluntary effort (MVE)) measured in Newtons (N) for shoulder and hip flexion and extension was determined by taking the average of two maximal isometric contractions completed prior to electrode insertion. Each task was then performed with a ramp up time of four seconds to 50% of this maximum effort (50% MVE), a hold time of three seconds, and a ramp down time of four seconds. The load cell signal was amplified (DA100 BIOPAC Systems Inc, Goleta, CA, USA) converted to a digital signal (MP150, BIOPAC Systems Inc, Goleta, CA, USA) and displayed to the participant to match the target force using the AcqKnowledge Software (Version 3.9.0, BIOPAC Systems Inc, Goleta, CA, USA). This submaximal load was chosen as it reflects typical functional loads. Mean 50% MVE isometric loads were 515.3 N (262.3 N to 882.9 N) for shoulder extension, 433.6 N (223.3 N to 956 N) for shoulder flexion, 511.5 N (247.5 N to 826.1 N) for hip extension, and 546.5 N (333.5 N to 845.4 N) for hip flexion.

Each task was performed in random order with two repetitions and with at least 30 seconds rest between tasks. During each task, correct technique was monitored to ensure no compensatory shoulder, trunk, or lower limb movements occurred. If compensatory movements occurred, the task was repeated.

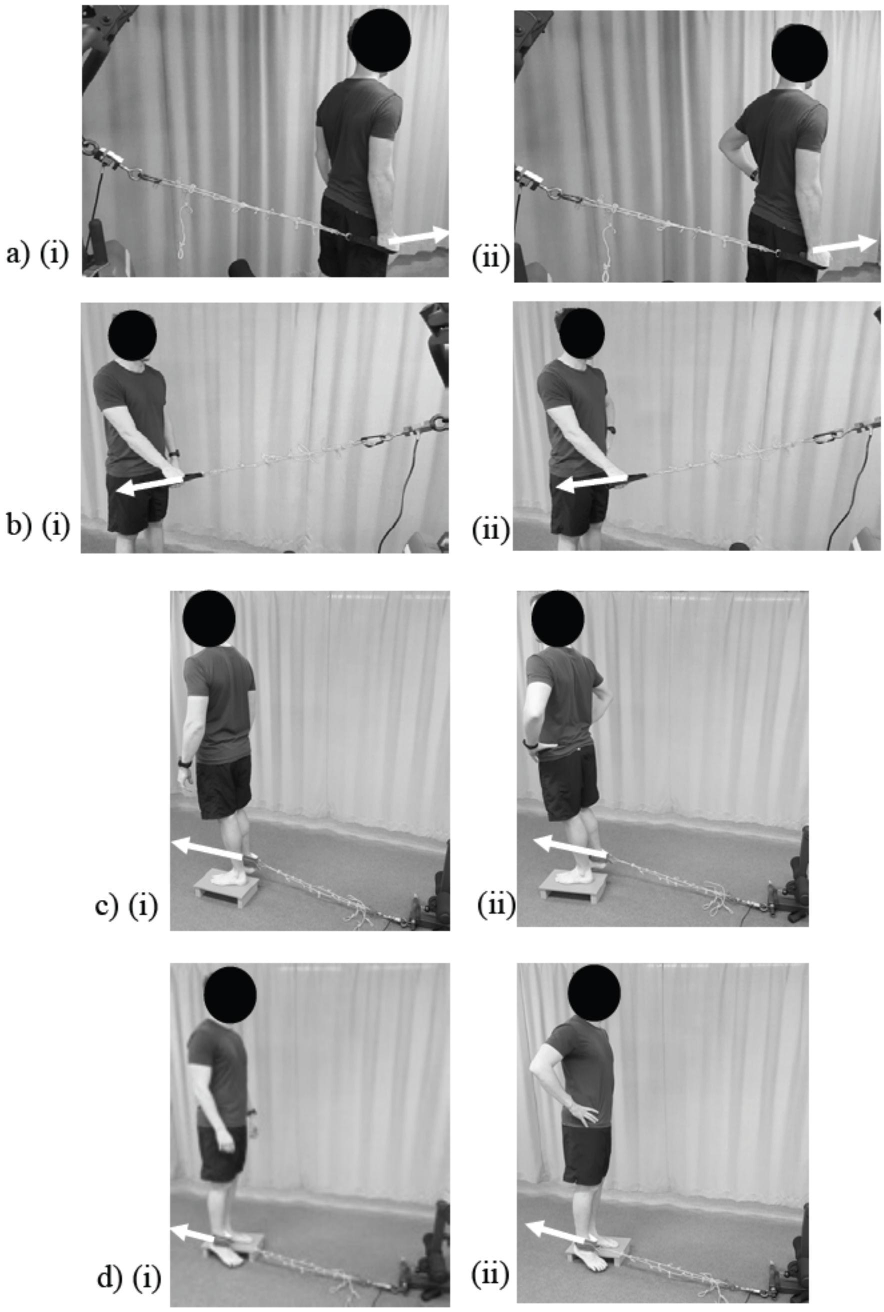

Figure 1. Isometric a) right shoulder flexion, b) right shoulder extension, c) right hip flexion, and d) right hip extension with the left upper limb by the side (i) and fixed on the pelvis (ii)

2.5 Data analysis

Electromyography signals were initially high-pass filtered using a 4th order Butterworth filter with a 10 Hz cutoff, applied in a two-pass zero-phase manner to achieve an effective 8th order filter. The signals were then rectified and subsequently low-pass filtered with a filter cut-off of

10 Hz using the same approach, to produce an EMG linear envelope (EMG-LE). The resulting data were normalised to the peak value obtained from the corresponding normalisation trials. Mean activation levels for each task were determined by averaging across a two second window from each of the two trials during the three second isometric hold at 50% MVE. All statistical analysis was completed using Jamovi (Version 2.6.44.0). Data were screened for normality using the Shapiro-Wilk test applied to the difference scores between paired conditions: fixed vs not fixed. For each comparison, if the difference scores were normally distributed ($p \geq 0.05$), a paired samples t-test was used. If normality was not met ($p < 0.05$), the Wilcoxon signed-rank test was used as a non-parametric alternative.

3. Results

The mean (% MVC ± SD) activation levels of the left latissimus dorsi during the fixed and not fixed tasks are shown in Figure 2. The left latissimus dorsi was active at very low levels during all tasks in both fixed and not fixed positions (≤5% MVC). No data were lost to electrode failure or other technical issues during these tasks.

The only statistically significant difference was observed between the fixed and not fixed hip flexion task, with greater activity in the not fixed condition ($W = 22$, $p = 0.030$, rank biserial correlation = -0.63).

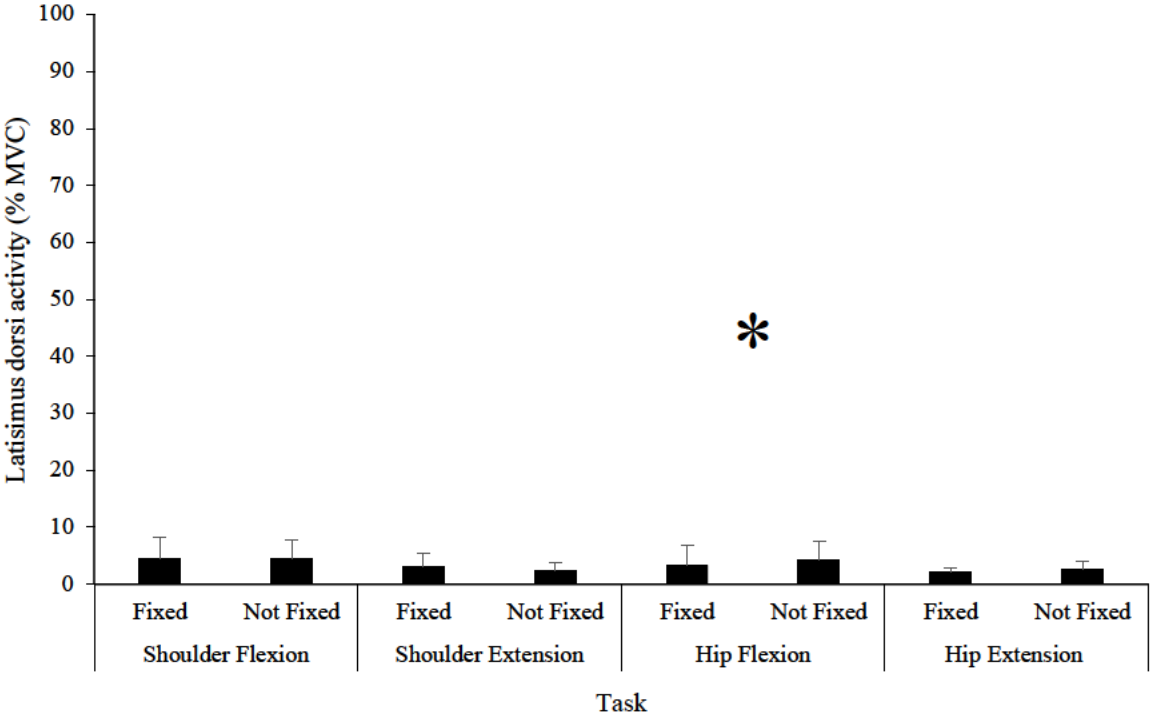

Figure 2. Mean left latissimus dorsi activation (% MVC ± SD) during fixed and not fixed hip and shoulder flexion and extension in standing. * Indicates a significant difference between fixed vs not fixed conditions.

4. Discussion

To our knowledge, this is the first study to examine the contribution of latissimus dorsi to trunk stability during isometric limb tasks in standing using indwelling EMG. Latissimus dorsi activation remained consistently low (≤5% MVC) across all right-sided isometric tasks, indicating a very limited contribution to maintaining trunk stability during submaximal upper and lower limb efforts in standing.

Fixing the upper limb by placing the hands on the pelvis was hypothesised to facilitate greater latissimus dorsi activation by fixing the distal attachment, thereby enhancing force transmission to the trunk. It was thought this would position the latissimus dorsi to contribute more effectively to trunk stability by exerting force through its attachment to the thoracolumbar fascia, thereby increasing its capacity to transmit force across the lumbopelvic region, thereby supplementing the stabilising actions of the trunk flexors and extensors. However, the only observed difference between conditions was a small (1% MVC) but statistically significant reduction during the fixed condition compared to the not fixed condition during hip flexion. Therefore, stabilising the distal attachment in this manner did not increase latissimus dorsi activation during submaximal isometric limb efforts in standing and thus, did not increase its contribution to trunk stability.

Previous studies examining the timing of latissimus dorsi activation during upper limb movements reported anticipatory activation of the contralateral latissimus dorsi during shoulder flexion, suggesting a feedforward mechanism contributing to trunk stability (Esposti and Baldissera, 2013, Pereira et al., 2014). However, while EMG amplitude does not directly correlate to force production (Dick et al., 2024), the minimal activity observed in the current study suggests that latissimus dorsi does not play a substantial trunk stabilising role under typical functional demands in healthy individuals. At the submaximal loads examined in the current study other trunk muscles, such as the internal and external obliques, transverse abdominis and/or multifidus, may be preferentially recruited for trunk stability (Hodges et al., 1999, Lee et al., 2009, 2011).

Future research incorporating dynamic, higher-load, or external destabilising tasks is warranted to determine whether latissimus dorsi contributes to trunk stability under more demanding conditions. Simultaneous EMG recordings from surrounding trunk muscles would also clarify the contribution of latissimus dorsi to trunk stability relative to other muscles, and integration with EMG-driven musculoskeletal modelling could further quantify its force contribution and role in trunk stability.

A potential limitation of using indwelling electrodes is that they sample activity from a relatively small region of the muscle, which may limit generalisability to the whole muscle (Besomi et al., 2019). However, previous studies investigating regional activation patterns in the latissimus dorsi using surface electrodes during shoulder movements have shown no substantial functional differences across the regions (Park and Yoo, 2014, Wickham and Brown, 2012). As such, the location of the electrode in the current study was chosen as it is a commonly used site in the literature and has been shown to be as representative as surface electrodes for evaluating latissimus dorsi muscle function (Ginn and Halaki, 2015, Price et al., 2024b). Previous descriptive studies (Ginn and Halaki, 2015, Lee et al., 2011, McGill et al., 1999, Reed et al., 2010) used a similar sample size of 10-15 participants to provide a representative estimate of muscle activity levels during various movements.

5. Conclusion

Latissimus dorsi demonstrated minimal activation during all submaximal isometric limb tasks in standing, with no increase in activation observed with the contralateral upper limb fixed. These findings provide clarity on the functional relevance of latissimus dorsi and suggest it does not meaningfully contribute to trunk stability during typical functional or rehabilitation tasks in healthy individuals.

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Chapter 7: Discussion

7.1 Overview

This thesis aimed to clarify the functional role of the latissimus dorsi during trunk movement and stability tasks using electromyography (EMG). The findings from the studies in this thesis consistently demonstrated low to moderate activation levels during trunk movements, even at maximal effort, and minimal activation during submaximal trunk stability tasks in both standing and four-point kneeling positions. Furthermore, no differences were observed when fixing the distal end of the latissimus dorsi by supporting the upper limb on the pelvis in standing.

To address the aim of quantifying the contribution of latissimus dorsi to trunk tasks, this thesis also examined two key methodological considerations in EMG research: electrode type and normalisation method. Surface electrodes were found to be acceptable for investigating latissimus dorsi activity during submaximal trunk movement tasks but tended to overestimate activity during stability tasks, most likely due to crosstalk. Additionally, trunk-based maximum voluntary contractions (MVCs), commonly used for latissimus dorsi normalisation during trunk tasks, elicited significantly less activity in latissimus dorsi than shoulder extension and were therefore considered invalid, likely leading to overestimation of latissimus dorsi activation levels when applied. This highlights the importance of employing accurate EMG methodology when assessing muscle function to inform exercise prescription in both gym-based settings and rehabilitation programs.

These findings challenge the commonly held view of the latissimus dorsi as a major trunk mover and stabiliser. The evidence suggests that its role as a trunk mover and stabiliser has been overemphasised, potentially leading to clinical reasoning and rehabilitation strategies that unnecessarily focus on this muscle. Given its minimal activation during submaximal trunk tasks, training it for stability at low loads may be unwarranted. Instead, clinicians should prioritise muscles with demonstrated roles in trunk movement and stability, such as the transversus abdominis, internal and external obliques, and multifidus.

7.2 Systematic review

A systematic review with Meta-Analysis was completed to evaluate the current understanding of latissimus dorsi's contribution to trunk movement and stability. The review (Chapter 2) revealed highly variable EMG results for latissimus dorsi, particularly at high loads, largely attributable to methodological heterogeneity, including differences in electrode placement, load magnitude, and MVC normalisation. Combined with small sample sizes, the absence of indwelling electrodes, and low GRADE (Grading of Recommendations, Assessment, Development and Evaluations) scores, these factors weakened the strength of evidence and made it difficult to draw firm conclusions about its role in trunk movement. The low GRADE ratings reflected limited confidence in the strength and applicability of the evidence, suggesting that clinical guidance drawn from these studies should be applied with caution.

In contrast, consistent low activation was reported during controlled, low-load tasks such as contralateral trunk rotation and limb movements in four-point kneeling. These findings, supported by moderate-quality evidence, reinforce the conclusion that latissimus dorsi is not a major contributor under submaximal conditions. The variability across studies underscored the need for standardised EMG methodology, which this thesis addressed.

7.3 Normalisation

The systematic review identified wide variability in EMG normalisation methods used when investigating trunk movement and stability tasks. The first experimental study (Chapter 3) therefore aimed to determine the most effective task for eliciting maximal latissimus dorsi activity. Comparisons of multiple MVC approaches, including commonly used trunk and shoulder tasks, demonstrated that isometric shoulder extension was the most valid and reliable task for eliciting maximal latissimus dorsi activation, making it the preferred method for EMG normalisation during trunk-based tasks.

Normalisation is critical for interpreting EMG data, as it enables comparison of muscle activity across tasks, participants, and studies by reducing variability caused by anatomical and physiological differences between individuals, muscles, and recording conditions (Besomi et al., 2020). The most widely accepted method is MVC-based normalisation, in which muscle activation during a task is expressed as a percentage of the activity generated during a MVC of that muscle. This approach is considered ideal because it is repeatable, provides meaningful reference for interpreting muscle activation relative to an individual's maximal effort, and allows for consistent comparisons across tasks and studies. Although the MVC should ideally replicate the experimental task in terms of joint angle, muscle length, contraction type, and velocity, this is not always feasible. In such cases, a standardised isometric MVC in a reproducible position is acceptable, provided maximal effort is achieved. In this study, a standardised shoulder extension task was selected for its capacity to elicit maximal resistance and activation.

In the systematic review, 97% of studies (38/39) normalised EMG to an MVC, with 55% (21/38) using trunk-based tasks such as trunk flexion, extension, rotation, or lateral flexion. In contrast, studies investigating shoulder tasks typically used shoulder extension, adduction, or internal rotation, which elicit high levels of muscle activity (Boettcher et al., 2008, Park and Yoo, 2013). Although some studies reported high activation from trunk-based MVCs (Ng et al., 2001, Sheikhzadeh et al., 2008, Vera-Garcia et al., 2010), these findings were inconsistent. If the participants do not achieve a true maximal effort, normalisation is effectively based on a submaximal task, inflating activation values during experimental tasks. This may misrepresent the muscle's true contribution and misguide rehabilitation.

In this thesis, shoulder extension elicited the highest activation across all participants and electrode types, establishing it as the superior normalisation method. Shoulder internal rotation, although hypothesised to be similarly effective, instead produced values comparable to trunk tasks. Interestingly, when comparing studies in the systematic review that examined the same tasks but used different normalisation methods (shoulder vs. trunk), no significant differences in %MVC were observed at low loads (Price et al., 2024b), likely because latissimus dorsi is only minimally active in these conditions.

One study (Vera-Garcia et al., 2010) compared latissimus dorsi activity during maximally resisted trunk and shoulder tasks and reported similar activation (73–85% MVC) across several maximally resisted trunk and shoulder tasks. While our findings supported this pattern of similar activation levels for shoulder internal rotation and trunk movements, the absolute values were lower, with shoulder extension consistently producing the greatest activation. Thus, maximally resisted shoulder extension is recommended as the most valid and reliable normalisation task for latissimus dorsi EMG.

Clinically, inappropriate normalisation can lead to overestimating latissimus dorsi’s contribution and misdirecting rehabilitation strategies. These findings support Besomi et al.'s (2020) recommendation that normalisation tasks should closely match the muscle's primary function. Therefore, for future latissimus dorsi studies, shoulder extension MVCs, and not trunk-based MVCs, are recommended.

Despite its advantages, MVC-based normalisation also has limitations: it can be difficult to ensure that only the target muscle contributes to the recorded activity, electrode placement may not perfectly reflect experimental conditions, and variability in participants’ ability to achieve true maximal efforts can affect reliability. Apart from MVC-based normalisation, there are several other methods for interpreting EMG data. These include normalising to a submaximal reference contraction, peak or mean EMG obtained from during the task, and normalising to a standardised dynamic activity to name a few. However, submaximal tasks are not appropriate to use as there is no physiological ceiling and cannot therefore express activation as a proportion of maximal capacity. MVC normalisation was selected as they provide a physiological reference value and allow for direct comparison of activation across conditions and between muscles, which was important for the current work.

7.4 Electrode

Having identified the most appropriate normalisation method, the next methodological consideration was determining the most suitable electrode type for recording latissimus dorsi activity (chapter 3). This thesis found that both surface and indwelling electrodes reliably recorded latissimus dorsi activity during submaximal movement tasks, but indwelling electrodes were superior during trunk stability tasks.

Surface electrodes have traditionally been the default choice, as reflected in the systematic review where all but one study used them. However, evidence suggests they may overestimate latissimus dorsi activity due to crosstalk from nearby muscles, particularly the underlying erector spinae (Ginn and Halaki, 2015). In this study, surface electrodes recorded higher activity during trunk extension, similar to values recorded by indwelling electrodes in the erector spinae, raising concerns about crosstalk and signal validity.

A direct comparison was therefore conducted with surface and indwelling electrodes placed 4 cm inferior to the inferior angle of the scapula (Fig 6.) (the most common site in the literature) during a variety of trunk tasks. These included:

- Isometric trunk extension, flexion, right rotation, and right lateral flexion at 50% MVE (sitting)
- Unrestrained dynamic trunk movements (standing)
- Isometric trunk tasks in prone, supine, and side-lying positions
- Trunk stability tasks such as limb movements in four-point kneeling and the plank

Results showed no significant differences between electrode types during submaximal isometric and dynamic trunk movements (≤50% load) across positions. In all other tasks, including those where latissimus activation was anticipated, surface and indwelling signals were closely matched.

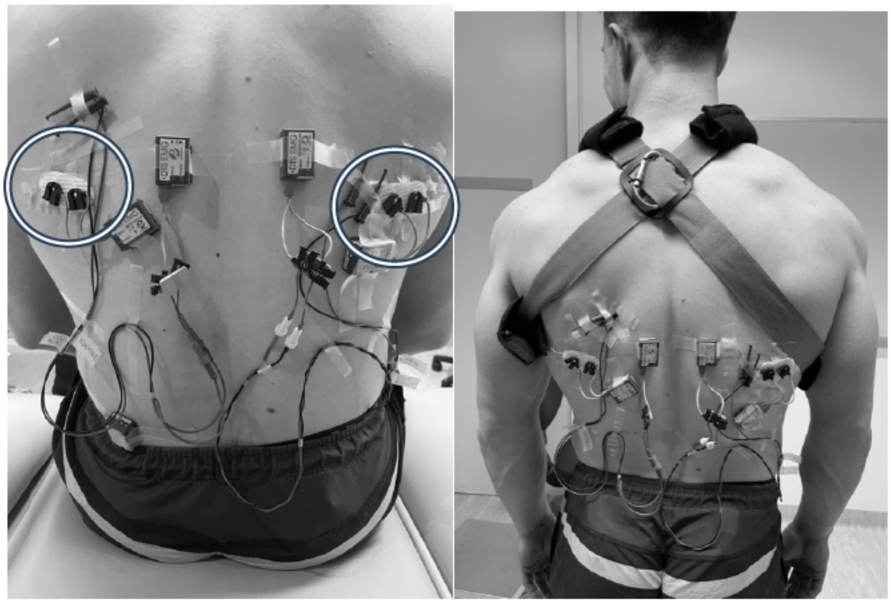

Figure 6. Locations of indwelling and surface electrodes, 4 cm inferior to the inferior angle of the scapula. Photo by author.

However, significant differences were observed during trunk stability tasks, where surface electrodes recorded activity up to three times higher than indwelling electrodes. In four-point kneeling, surface electrodes suggested elevated activity, while indwelling electrodes detected minimal activation. These findings indicate that surface electrodes may overestimate activity during trunk stability tasks, while remaining acceptable for submaximal trunk movements. Based on these findings, studies using surface electrodes can still be compared with those using indwelling electrodes for trunk movement tasks, provided that similar loads and normalisation methods are employed.

Electrode placement is also critical to ensure accurate EMG recording, which can be influenced by the depth of the muscle and its proximity to other muscles. In the systematic review, 54% of studies (21/39) placed surface electrodes lateral to T9 or 4 cm inferior to the inferior angle of the scapula. These descriptions were treated as equivalent in the review, and results suggest this region is appropriate for reliable measurement.

While indwelling electrodes reduce crosstalk and provide more accurate recordings, they are invasive and may require multiple placements in large muscles including latissimus dorsi (Besomi et al., 2019, Wickham and Brown, 2012). However, prior surface EMG studies have demonstrated relatively uniform activation across different regions of latissimus dorsi during shoulder tasks (Brown et al., 2007, Park and Yoo, 2014). For example, Brown et al. (2007) found consistent activation across six subdivisions, while Park and Yoo (2014) reported no differences between medial and lateral compartments. These findings support the use of a single electrode site to represent the whole muscle. Furthermore, indwelling and surface electrodes placed at the same location have shown produced comparable results during shoulder tasks (Ginn and Halaki, 2015).

While surface electrodes are commonly used due to their non-invasive nature, minimal discomfort, and suitability for high-force contractions (Besomi et al., 2019) they present limitations, particularly in muscles like the latissimus dorsi. Due to its relatively thin profile and proximity to other muscles, the latissimus is prone to crosstalk, and its position may shift relative to the electrodes during dynamic tasks. In contrast, indwelling electrodes, although invasive, are recommended when accuracy is critical, particularly in stability or high-load tasks, as they reduce crosstalk and can move with the muscle (Besomi et al., 2020). Use of real-time ultrasound may further improve placement precision. Clinicians using surface EMG should be aware of these limitations and interpret latissimus dorsi activity with caution.

7.5 Trunk movement

Having established the appropriate methodologies for accurately recording and analysing latissimus dorsi activity, the study in chapter 5 assessed the muscle's contribution to trunk movement. The experimental design replicated common isometric and dynamic trunk tasks identified in the systematic review, while addressing methodological limitations of prior research. Specifically, indwelling electrodes were employed for both submaximal and maximal tasks to minimise crosstalk that may overestimate activity with surface EMG, and raw EMG signals were normalised to a maximally resisted shoulder extension in sitting, providing a valid representation of latissimus dorsi activity. Trunk rotation, lateral flexion, flexion, and extension were examined in multiple body positions (seated, standing, prone, supine, and side-lying) and under varying loads (unresisted, 50% MVE, and 100% MVE).

Across these conditions, latissimus dorsi exhibited low to moderate activation. Activity remained below 20% MVC during submaximal conditions and reached moderate levels (31-42% MVC) only under maximal loads. These findings suggest that latissimus dorsi plays only a limited role in trunk movement, particularly at submaximal loads, likely because it is not anatomically suited to generate substantial torque across the lumbar spine (Bogduk et al., 1998). Although the latissimus dorsi broadly spans from the pelvis to the humerus, it is relatively thin and poorly positioned mechanically compared to the erector spinae, which is more advantageously aligned for force generation. This supports the interpretation that latissimus dorsi contributes indirectly, perhaps via fascial connections or stabilising roles, rather than acting as a primary torque generator.

Two submaximal tasks showed elevated latissimus dorsi activity above baseline: ipsilateral trunk rotation and ipsilateral lateral flexion in sitting (10-15% MVC). Under maximal effort, these tasks elicited activation of 31-42% MVC, indicating that latissimus dorsi may assist with ipsilateral rotation and lateral flexion, though only modestly under submaximal demands. Interestingly, isometric trunk flexion and extension in sitting at 50% MVE produced similar activation levels. While latissimus dorsi involvement in extension is expected, the activity recorded in flexion is less easily explained. Because arm use was strictly controlled, this activation may represent a stabilising function rather than a torque-producing role.

Based on the systematic review, it was hypothesised that latissimus dorsi would be highly active during maximal effort trunk extension, ipsilateral rotation, and ipsilateral lateral flexion. However, this hypothesis was not supported. The low to moderate levels observed here (chapter 5) were notably lower than those reported in earlier studies using similar movements and loads. The systematic review also revealed wide variability of latissimus dorsi activity at maximal loads, with less variability at submaximal loads. For example, prior studies reported activation ranges of 19-79% MVC for trunk extension (Ginn and Halaki, 2015, Perez and Nussbaum, 2002, Vera-Garcia et al., 2010), 15-85% MVC for ipsilateral lateral flexion (Park and Yoo, 2013, Perez and Nussbaum, 2002, Vera-Garcia et al., 2010), and 26-82% for ipsilateral rotation (O'Brien and Potvin, 1997, Perez and Nussbaum, 2002, Stevens et al., 2007a, Talebian et al., 2010, Vera-Garcia et al., 2010) at maximal loads. The current study's findings (chapter 5) compared with this literature, show that ipsilateral rotation at maximum effort had the greatest variability across studies, while submaximal tasks were more consistent.

Several methodological factors likely explain these discrepancies and high variability. A key methodological difference was EMG normalisation. Studies reporting higher latissimus dorsi activity during maximal ipsilateral rotation all used trunk-based MVCs (Ng et al., 2001, Ng et al., 2002, Sheikhzadeh et al., 2008, Talebian et al., 2010). While trunk MVCs may be valid for trunk muscles, they may not elicit maximal activation in the latissimus dorsi, potentially inflating relative values. Other studies used a combination of both trunk and shoulder tasks and reported similarly lower levels, more comparable to the present findings (O'Brien and Potvin, 1997, Perez and Nussbaum, 2002). In some cases, it is often unclear which tasks produced the highest activity levels and were therefore used to normalise the data. Perez et al. (2002) used one arm brachiation and they stated that it often exceeded the trunk MVC values but did not specify in which tasks. This methodological consideration is important, as relying solely on trunk movements for MVCs may overestimate latissimus dorsi activity, potentially affecting conclusions about its relative contribution during tasks.

Differences in task execution, such as dynamometer use, participant positioning, or unintended arm involvement, may also have influenced activation, particularly at submaximal loads where resistance is harder to quantify (e.g. prone body weight tasks). At maximal efforts the body position is less critical, as the applied resistance should elicit maximal activation regardless of position. Finally, earlier studies often utilised surface EMG, which is prone to crosstalk from adjacent muscles such as the erector spinae, likely contributing to overestimation of latissimus dorsi involvement. Together, these methodological issues suggest that previous reports of high latissimus dorsi activity may reflect artefacts rather than genuine muscle contribution.

Overall, these findings challenge prior assertions that latissimus dorsi is a primary trunk mover. Instead, the evidence indicates that it functions predominantly as a shoulder muscle, with only limited trunk involvement except under maximal loading. From a clinical perspective, this suggests that latissimus dorsi should not be a primary target in trunk movement training. Greater emphasis should instead be placed on muscles with established torque-producing roles, such as the erector spinae.

7.6 Trunk stability

Latissimus dorsi has traditionally been considered a contributor to trunk and pelvic stability due to its extensive attachments both within and external to the trunk. Trunk stability exercises are commonly prescribed for back pain management on the premise that increased muscle activation enhances segmental stiffness across the lumbar spine and SIJ. One proposed mechanism is the posterior oblique sling, linking the opposite gluteus maximus and latissimus dorsi via the TLF (Procopio et al., 2025, Vleeming et al., 1995, Willard et al., 2012). This thesis examined latissimus dorsi recruitment during upper and lower limb movements in four-point kneeling (chapter 4) and standing (chapter 6), using indwelling electrodes normalised to shoulder extension MVCs to provide accurate activation values.

Results showed that latissimus dorsi activity was consistently very low (≤5% MVC) during all limb movements in both standing and four-point kneeling. Additionally, placing the hands on the pelvis to create a closed kinetic chain did not alter latissimus dorsi recruitment. These findings suggest that latissimus dorsi is unlikely to contribute meaningfully to trunk stability under the submaximal loading conditions typically prescribed in rehabilitation. While greater recruitment may occur under high-load conditions, this could not be confirmed within the scope of the present study.

It was hypothesised that the contralateral latissimus dorsi activity would increase during limb movements in standing to provide trunk stabilisation, and similarly in four-point kneeling during contralateral leg extension. However, no significant change in activity was observed in either condition. Likewise, placing the hands on the pelvis to provide a stable upper-limb anchor did not affect activity.

Previous studies reporting higher activity may have been influenced by methodological limitations such as surface EMG crosstalk or task-specific demands (Callaghan et al., 1998b, Drake et al., 2006, Stevens et al., 2007b). For example, in four-point kneeling, previous reports showed latissimus dorsi activity up to three times higher than in the present study (chapter 4) (Callaghan et al., 1998b, Drake et al., 2006, Stevens et al., 2007b). While the current results remained consistently low across tasks, previous studies showed increased activity with greater loads, likely reflecting methodological artefacts, due to the use of surface electrodes or the choice of MVC technique, rather than true recruitment.

Taken together, these findings challenge traditional models positioning the latissimus dorsi as a key trunk stabiliser via the TLF (Vleeming et al., 1995, Willard et al., 2012). While anatomical studies support a plausible stabilising role (Procopio et al., 2025), functional activation data do not support this under typical rehabilitative loads. The latissimus dorsi's broad attachments and oblique fibre orientation limit its capacity to generate localised lumbar torque and provide segmental spinal stiffness, as argued by Bogduk (1998). Its primary function may instead be force transmission between the upper and lower limbs during high-load, whole body tasks, such as throwing, lifting or rowing, consistent with increased activation under maximal conditions. The posterior oblique sling is therefore better understood as a mechanism of force transfer rather than lumbar stabilisation (Procopio et al., 2025, Vleeming et al., 1995, Willard et al., 2012). Anatomical studies reinforce this role, showing that latissimus dorsi contraction can alter passive properties in distal joints such as the hip, confirming that its effects are not purely local but transmitted via the fascia (Caldeira et al., 2024, Procopio et al., 2025). Other muscles attaching to the TLF, such as the multifidus, obliques, and transversus abdominis, are structurally and functionally better suited for segmental control and spinal stiffness (Hodges et al., 1999, Lee et al., 2009, 2011).

From a clinical perspective, these findings indicate that common submaximal stability exercises, such as limb movements in four-point kneeling are unlikely to meaningfully engage the latissimus dorsi unless performed at very high loads. Although these exercises likely stabilise the lumbar spine through other mechanisms or muscles, clinicians should avoid expecting significant latissimus dorsi involvement. Rehabilitation should instead prioritise coordinated activation of multiple trunk muscles tailored to the individual's goals. This aligns with the consensus that effective back pain management requires integrated, system-level strategies rather than attempts to isolate a single muscle. In athletic populations, however, training latissimus dorsi under heavy load may still be relevant, given its role in force transfer.

Overall, these findings support classifying the latissimus dorsi primarily as a shoulder muscle rather than a trunk stabiliser. This distinction is particularly important in clinical practice, where exercises such as limb movements in four-point kneeling or resisted trunk extension are often prescribed to 'activate' the latissimus dorsi. Clinicians should not expect meaningful activation of the latissimus dorsi during low-load trunk stability tasks but may consider its role in high-load, whole body movements where force transfer is required.

7.7 Future research and limitations

Further research is required to address several methodological and conceptual gaps highlighted by the included studies in this thesis. These include whether a single electrode site truly reflects activity across the entire latissimus dorsi muscle, how the timing of latissimus dorsi activation influences trunk function, how recruitment patterns change with different loading levels, and which neighbouring muscles may contribute to crosstalk in both surface and indwelling EMG recordings. Addressing these questions will be essential to improve the validity and interpretability of future investigations into latissimus dorsi function.

A potential limitation of this thesis was the use of a single indwelling electrode to record latissimus dorsi activity, which, although providing high specificity, samples only a small region of a broad muscle where regional variability has been reported (Besomi et al., 2019, Park and Yoo, 2014, Wickham and Brown, 2012). While this site was the most commonly used in prior literature and shown to be as representative during shoulder tasks (Brown et al., 2007, Ginn and Halaki, 2015, Price et al., 2025a, Price et al., 2024b), multiple electrode sites may be required for trunk tasks. Simultaneously recording activity from neighbouring thoracolumbar fascia muscles, including the internal oblique or transversus abdominis, could clarify how latissimus dorsi integrates within the broader trunk stability system.

In addition to activation magnitude, the timing of muscle recruitment is also an important consideration. Future studies could examine whether latissimus dorsi activates prior to, or in coordination with, other muscles, which would suggest a potential stabilising function. Similarly, investigating co-activation with gluteus maximus could provide further insight into their functional relationship via the TLF.

Given that this research found low activity at submaximal loads and greater activity at maximal effort, future work should examine activity across progressively increasing loads to determine whether activation increases linearly or only above certain thresholds. While EMG provides a representation for muscle activity, it does not directly measure torque or force output (Dick et al., 2024). Integrating EMG with EMG-driven musculoskeletal modelling could further quantify latissimus dorsi force contribution, joint loading, and load-sharing across the kinetic chain. This approach would bridge the gap between neural activity and mechanical function.

Future studies should also explore latissimus dorsi function across a broader range of tasks, particularly dynamic and sport-specific movements involving trunk-limb coupling such as throwing, rowing, running or swimming. Perturbation-based or multiplanar tasks may provide more realistic assessments of trunk stability. Moreover, extending this work to clinical populations, such as individuals with low back pain, may reveal altered recruitment patterns or compensations not present in healthy young adults. Such work could clarify the role of latissimus dorsi within functional kinetic chains and inform both performance training and clinical intervention.

7.8 Conclusion

This thesis provides strong evidence that latissimus dorsi plays a limited role in trunk movement and stability under submaximal loads and only a moderate role under maximal conditions. These findings challenge long-held assumptions that it is a major trunk stabiliser and emphasises the importance of task specificity, electrode choice, and normalisation methodology in EMG research and clinical practice.

These results suggest that rehabilitation and training programs targeting trunk stability may overestimate the relevance of latissimus dorsi. Focus should shift away from isolating it in trunk stability training and instead towards muscles with established segmental stabilising roles. While the thesis has limitations, it provides a strong methodological foundation for further biomechanical and EMG exploration by validating electrode selection and normalisation approaches.

Without careful attention to these methodological factors, there is a risk of misinterpreting muscle function and implementing ineffective interventions. Future research should examine latissimus dorsi function during progressively loaded and dynamic tasks, explore its coordination with other trunk stabilising muscles, and investigate activation timing. By clarifying its limited role under submaximal conditions, this thesis contributes to a more accurate understanding of the function of trunk musculature and informs more targeted approaches in both research and clinical practice.

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Appendix 1 – Ethics approval

THE UNIVERSITY OF SYDNEY

Research Integrity & Ethics Administration
HUMAN RESEARCH ETHICS COMMITTEE

Monday, 31 January 2022

Dr Darren Reed
School of Medical Sciences: Biomedical Sciences; Faculty of Medicine and Health
Email: darren.reed@sydney.edu.au

Dear Darren,

The University of Sydney Human Research Ethics Committee (HREC) has considered your application.

I am pleased to inform you that after consideration of your response, your project has been approved.

Details of the approval are as follows:

Project No.:	**2021/922**
Project Title:	**Role of latissimus dorsi in trunk movement and control**
Authorised Personnel:	**Reed Darren; Price Declan; Ginn Karen; Halaki Mark; Kwasi Victor;**
Approval Period:	**31/01/2022 to 31/01/2026**
First Annual Report Due:	**31/01/2023**

Documents Approved:

Date Uploaded	Version Number	Document Name
23/12/2021	Version 2	consent form version 2 clean
23/12/2021	Version 2	Participant information Statement version 2 clean
28/10/2021	Version 1	advertisement
28/10/2021	Version 1	Risk Assessment
28/10/2021	Version 1	Safe Work Practice

Condition/s of Approval

- Research must be conducted according to the approved proposal.
- An annual progress report must be submitted to the Ethics Office on or before the anniversary of approval and on completion of the project.
- You must report as soon as practicable anything that might warrant review of ethical approval of the project including:
  - Serious or unexpected adverse events (which should be reported within 72 hours).
  - Unforeseen events that might affect continued ethical acceptability of the project.
- Any changes to the proposal must be approved prior to their implementation (except where an amendment is undertaken to eliminate *immediate* risk to participants).
- Personnel working on this project must be sufficiently qualified by education, training and experience for their role, or adequately supervised. Changes to personnel must be reported and approved.
- Personnel must disclose any actual or potential conflicts of interest, including any financial or other interest or affiliation, as relevant to this project.
- Data and primary materials must be retained and stored in accordance with the relevant legislation and University guidelines.

- Ethics approval is dependent upon ongoing compliance of the research with the *National Statement on Ethical Conduct in Human Research*, the *Australian Code for the Responsible Conduct of Research*, applicable legal requirements, and with University policies, procedures and governance requirements.

- The Ethics Office may conduct audits on approved projects.

- The Chief Investigator has ultimate responsibility for the conduct of the research and is responsible for ensuring all others involved will conduct the research in accordance with the above.

This letter constitutes ethical approval only.

Please contact the Ethics Office should you require further information or clarification.

Sincerely,

[redacted]

Associate Professor Helen Mitchell
Chair
Human Research Ethics Committee (HREC 1)

The University of Sydney of Sydney HRECs are constituted and operate in accordance with the National Health and Medical Research Council's (NHMRC) National Statement on Ethical Conduct in Human Research (2018) and the NHMRC's Australian Code for the Responsible Conduct of Research (2018)

Appendix 2 – Consent forms

School of Medical Sciences
Faculty of Medicine and Health

ABN 15 211 513 464

Dr Darren Reed

Room N348, Anderson Stuart Building
Camperdown Campus
The University of Sydney
Telephone: +61 2 86278869
Email: darren.reed@sydney.edu.au

PARTICIPANT CONSENT FORM

I, ...[PRINT NAME], give consent to my participation in the research project

THE ROLE OF LATISSIMUS DORSI IN TRUNK MOVEMENT AND STABILITY – AN ELECTROMYOGRAPHIC STUDY

In giving my consent I acknowledge that:

1. The procedures required for the project and the time involved (including any inconvenience, risk, discomfort or side effect, and of their implications) have been explained to me, and any questions I have about the project have been answered to my satisfaction.

2. I have read the Participant Information Statement and have been given the opportunity to discuss the information and my involvement in the project with the researcher/s.

3. I understand that I can withdraw from the study at any time, without affecting my relationship with the researcher(s) or the University of Sydney now or in the future.

4. I understand that my involvement is strictly confidential and no information about me will be used in any way that reveals my identity.

5. I understand that being in this study is completely voluntary – I am not under any obligation to consent.

6. I consent to:

i)	Digital video/photo	YES	☐	NO	☐
ii)	Receiving Feedback	YES	☐	NO	☐

If you answered YES to the “Receiving Feedback Question (ii)”, please provide your details i.e. mailing address, email address. Please note any photos or videos taken during the experiment will be de-identified.

Feedback Option

Address: ____

____

Email: ____

Signed: ....

Name: ....

Date: ....

Appendix 3 – Participant information sheet

THE UNIVERSITY OF SYDNEY

School of Medical Sciences
Faculty of Medicine and Health

ABN 15 211 513 464

Dr Darren Reed

Room N348, Anderson Stuart Building
Camperdown Campus
The University of Sydney
Telephone: +61 2 86278869
Email: darren.reed@sydney.edu.au

THE ROLE OF LATISSIMUS DORSI IN TRUNK MOVEMENT AND STABILITY – AN ELECTROMYOGRAPHIC STUDY

PARTICIPANT INFORMATION STATEMENT

(1) What is this study about?

You are invited to take part in a research study into latissimus dorsi muscle activation patterns during common trunk and limb movements. The latissimus dorsi is an important shoulder muscle, located at the back of the shoulder and covering a large area of the back. Its role in shoulder function is well established but it also has extensive attachments to the trunk and its role in trunk function is still unclear. To address muscle dysfunction, normal function must first be established. Electromyography is one of the most effective ways to understand muscle recruitment and muscle function. Traditionally surface electrodes have been used to measure activity from latissimus dorsi, however these have shown to be invalid when measuring activity during shoulder movements. Therefore, this project will investigate the activation level and patterns of latissimus dorsi during trunk and limb movements using surface and indwelling electromyography to determine if surface electrodes are valid in measuring latissimus dorsi activity levels during trunk movements and to determine its role in the normal functioning of the trunk.

This Participant Information Statement tells you about the research study. Knowing what is involved will help you decide if you want to take part in the research. Please read this sheet carefully and ask questions about anything that you don't understand or want to know more about.

Participation in this research study is voluntary.

By giving your consent to take part in this study you are telling us that you:

- ✓ Understand what you have read.
- ✓ Agree to take part in the research study as outlined below.
- ✓ Agree to the use of your personal information as described.

(2) Who is running the study?

Declan Price is conducting this study as the basis for the Doctor of Philosophy at The University of Sydney. This will take place under the supervision of the following staff from the Faculty of Medicine and Health:
Dr Darren Reed - Senior Lecturer in the School of Medical Sciences
Professor Karen Ginn - School of Medical Sciences
Dr Victor Kwasi (neurosurgeon) - School of Medical Sciences
Associate Professor Mark Halaki - School of Health Sciences.
Declan will be responsible for the co-ordination of the research team and general running of the study. Fine wire electrode insertion will be performed by the supervisory team.

(3) What will the study involve for me?

If you agree to participate in this study, you will be requested to perform a range of trunk and limb movements during which we will record the muscle activity (electromyographic recordings) of your latissimus dorsi and gluteus maximus (the buttock muscle) on both sides. To make this recording a small electrode will be inserted by a needle into the latissimus dorsi muscle on both sides, after which the needle will be removed and a thin wire will remain. Surface electrodes will be used over gluteus maximus and over the indwelling electrode into latissimus dorsi. At the end of the experiment all electrodes will be removed.

A digital camera may be used to capture images of the setup and experimental methodology. Any photos taken and used for publication purposes or public display will have faces blacked out and permission obtained from the participant.

(4) How much of my time will the study take?

You will need to attend *one testing session in the Shoulder Lab, located in the Medical Foundation Building* (K25), room 220, for approximately 2 hours. The following day Declan Price will contact you to confirm if there is any residual redness or irritation at the electrode insertion site.

(5) Who can take part in the study?

You are eligible to participate if you have not experienced shoulder or back pain or dysfunction in the last two years, have never required treatment of your shoulder or back and demonstrate normal range of motion and co-ordination during screening.

(6) Do I have to be in the study? Can I withdraw from the study once I've started?

Being in this study is completely voluntary and you do not have to take part. Your decision whether to participate will not affect your current or future relationship with the researchers or anyone else at the University of Sydney. If you decide to take part in the study and then change your mind later, you are free to withdraw at any time.

(7) Are there any risks or costs associated with being in the study?

You may experience some discomfort or minor bruising associated with the insertion of the electrode. Local anaesthetic cream will minimize the discomfort associated with electrode placement. There is also a risk of infection at the insertion site where the skin is pierced. All needles and intramuscular electrodes will be sterilized prior to insertion and the sites of electrode placement will be cleansed with antiseptic and covered at the end of the experiment, to keep this risk of infection to a minimum. Some people react to needle insertion by feeling faint or nauseous. If this occurs the experiment will be stopped and the researchers will ensure that you fully recover before you leave. Previous adverse reaction to needles is an indication you should not participate in this experiment.

(8) Are there any benefits associated with being in the study?

While we intend that this research study furthers medical knowledge and may improve treatment of shoulder or back pain in the future, we cannot guarantee that you will receive any direct benefits from being in the study.

(9) What will happen to information about me that is collected during the study?

By providing your consent, you are agreeing to us collecting personal information about you for the purposes of this research study. Your information will be stored securely and your identity/information will be kept strictly confidential, except as required by law. Study findings may be published, but you will not be individually identifiable in these publications.

(10) Can I tell other people about the study?

Yes, you are welcome to tell other people about the study.

(11) What if I would like further information about the study?

When you have read this information, Declan Price, Dr Darren Reed or Prof Karen Ginn will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact: Declan Price declan.price@sydney.edu.au Dr Darren Reed on 86278869, darren.reed@sydney.edu.au or Prof Karen Ginn, karen.ginn@sydney.edu.au

(12) Will I be told the results of the study?

You have a right to receive feedback about the overall results of this study. You can tell us that you wish to receive feedback by ticking the relevant box on the consent form. This feedback will be in the form of a one-page lay summary. You will receive this feedback after the study is finished.

(13) What if I have a complaint or any concerns about the study?

Research involving humans in Australia is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this study have been approved by the HREC of the University of Sydney. As part of this process, we have agreed to carry out the study according to the *National Statement on Ethical Conduct in Human Research (2007).* This statement has been developed to protect people who agree to take part in research studies.

If you are concerned about the way this study is being conducted or you wish to make a complaint to someone independent from the study, please contact the university using the details outlined below. Please quote the study title and protocol number.

The Manager, Ethics Administration, University of Sydney:

- **Telephone:** +61 2 8627 8176
- **Email:** human.ethics@sydney.edu.au
- **Fax:** +61 2 8627 8177 (Facsimile)

This information sheet is for you to keep