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The effect of dynamic mobilization exercises and therapeutic trunk exercises on superficial epaxial and hypaxial muscle activity in horses

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ABSTRACT

Background: Equine back rehabilitation commonly integrates dynamic mobilization exercises (DME), including DME to the chest (DMEChest) and DME to the hip (DMEHip), and therapeutic trunk (TTE) exercises, including pelvic rounding (Rounding), and lateral tail pulls (LatTail). However, limited evidence supports their use for selectively activating trunk muscles.
Aims/objectives: To quantify and compare superficial epaxial and hypaxial muscle activity during selected DMEs and TTEs using surface electromyography (sEMG). Increased muscle activity was hypothesized across exercises, specifically in external abdominal oblique (EAO) during lateral bending (DMEHip, LatTail), and longissimus dorsi (LD) and rectus abdominus (RA) during spinal flexion (DMEChest, Rounding) exercises.
Methods: Bilateral sEMG data, from the EAO, RA, and LD (T14 and L1) of $n = 7$ horses executing DMEChest, DMEHip, LatTail, and Rounding, were band-pass filtered (40-450 Hz), full-wave rectified, and amplitude normalized. Average rectified value (ARV) was calculated and grouped by movement direction (ipsilateral, contralateral) for DMEHip and LatTail. Linear mixed models assessed associations between exercise and normalized ARV, with horse as a random effect.
Results: Compared to other exercises, estimated marginal mean ARV (%) [95 % CI] was significantly greater ($P < 0.05$) during ipsilateral DMEHip for EAO (207.0, [178.7, 235.4]), RA (172.1, [140.8, 203.4]) and LD at T14 (136.8, [126.4, 147.3]), and during both ipsilateral DMEHip (120.4, [114.9 -125.9]) and Rounding (123.0 [117.5, 128.5]) for LD at L1.
Conclusions: Findings support the use of DMEs and TTEs for the targeted activation of EAO, RA and LD, particularly during DMEHip and Rounding where the greatest increases in muscle activity were observed.

1. Introduction

Back pain is a leading cause of impairment, affecting up to 94 % of the ridden horse population [1] and up to 33 % of the human population [2]. Despite its high prevalence, definitive diagnosis for back pain is often arduous, and evidence-based rehabilitation programs remain contentious [3–7]. In humans, nociception associated with back injury leads to structural and functional adaptations, including inhibition and atrophy of deep spinal stabilizers, with increased local adipose and connective tissue infiltration [8–11]. These pathological changes underpin contemporary human rehabilitation strategies for back pain, which reduce inhibitory “drivers” (i.e. pain) [12] and reactivate deep stabilizing musculature [13] before initiating trunk strengthening and endurance training [8]. Although species-specific evidence remains limited, these principles are widely applied in the management of equine back pain through dynamic mobilization exercises (DMEs) aimed at improving stabilization, as well as therapeutic trunk exercises (TTE). Typically, DMEs use a reward (e.g. carrot) to guide the horse through spinal flexion (e.g. chin-to-chest, chin-to-fetlocks) and lateral bending (e.g. chin-to-hip), requiring coordinated trunk and limb girdle stabilization via deep musculature [14]. Commonly prescribed TTEs include lateral tail pulls and caudal pelvic rounding reflexes, that aim to activate postural muscles through pressure applied at specific anatomical regions. Some evidence supports DMEs to activate deep spinal muscle (e.g.

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multifidus) activity and hypertrophy [14–17]. However, evidence supporting the relative efficacy of individual DMEs and TTEs for activating superficial epaxial and hypaxial muscles, which they purportedly target [14,16], is limited. This gap in knowledge restricts the development of targeted, evidence-based rehabilitation programs for horses with back pain.

Surface electromyography (sEMG) provides a non-invasive method for quantifying superficial muscle activity and is increasingly used in equine biomechanics research [18–20]. Recent studies have used sEMG to quantify epaxial and hypaxial muscle activity during selected DMEs and TTEs [21,22]. These studies reported increased hypaxial activity during DMEs to the hip [21,22] and carpus [21], and increased epaxial [21] and hypaxial [22] activity during pelvic rounding, without significant increases in activity during DMEs to the chest [21]. These studies provide important preliminary data on the effect of selected DMEs and TTEs on unilateral muscle activity. However, effective movement depends on coordinated bilateral and antagonistic muscle function. Therefore, further research is required to build on these findings by simultaneously assessing the activity of paired, bilateral muscle groups.

The aim of this study is to use sEMG to quantify and compare bilateral epaxial (longissimus dorsi (LD)) and hypaxial (external abdominal obliques (EAO) and rectus abdominis (RA)) muscle activity in horses executing commonly prescribed static DMEs and TTEs. Based on previous studies, it is hypothesized that EAO, RA and LD activity will significantly increase across all DMEs and TTEs evaluated here. A secondary hypothesis is that LD and RA will exhibit the greatest increases in activity during exercises where spinal flexion is encouraged (i.e. pelvic rounding and DME to the chest), and that EAO activity will exhibit the greatest increases during exercises where lateral bending is encouraged (i.e. DME to the hip and lateral tail pull).

2. Materials and methods

2.1. Horses

The study protocol was approved by The University of Queensland's Production and Companion Animal Ethics Committee (Project ID: 2023/AE000262; Approval date, 11 April 2023). Seven ($n = 7$) Standardbred geldings, with an average age of 14.2 years (range 9-20 years) and weight of 520 kg (range 482-562 kg) were included in this study. Horses were part of the university herd and had no clinical history of back pain or spinal pathology at the time of the study. A physiotherapeutic assessment was undertaken by two highly experienced titled animal physiotherapists (L.H., L.G.), which included spinal palpation and functional assessment. The physiotherapists deemed horses as suitable for inclusion in the study, based on the absence of lameness at in-hand walk and trot on a hard surface and their ability to execute tight circles on both reins and six steps of rein back in-hand.

2.2. Equipment set-up and skin preparation,

Delsys Trigno (Delsys Inc, Natick, MA, USA) wireless sensors with combined sEMG and inertial measurement unit (IMU) capabilities were employed. In accordance with best practice guidelines and previously published studies, sEMG sensors were attached bilaterally, and parallel to the muscle fiber orientation over LD: 10 cm directly abaxial to T14 and L1 vertebrae, EAO: over rib 16 and 30 cm from the midline [22], and RA: caudal to the pectoral muscles and in line with the 8th rib [23]. The sensors that were positioned to acquire bilateral sEMG data from T14 and L1 locations were also used to collect IMU data for quantifying thoracolumbar back motion. Each sensor site was prepared by removing all overlying hair using clippers and a wet razor, and then the skin was thoroughly cleaned with isopropyl alcohol [19]. Sensors were then attached directly to dry skin using Delsys Adhesive Surface Interface Strips (Delsys Inc., Natick, MA, USA) and positioned parallel to the direction of the muscle fibers. Sensors were further secured using flexible kinesiology tape that was placed over the top of each sensor and attached to the skin on either side with 0 % stretch/tension. This was a precautionary measure to catch the RA sensors should they become detached due to their ventral location but was applied over all other sensors for consistency. Three GoPro cameras (GoPro Inc., USA) were positioned directly above, behind and to the right side of the horse, recording continuously during data collection. Video footage served as a reference only.

2.3. Data collection protocol

Horses completed a training session per day over a period of 2 days (during June 2023), prior to the data acquisition session. Training sessions consisted of a 60-second walk in hand and 6 steps of rein back. Each horse was then trained to execute the DMEs and TTEs that would be evaluated in the study. The exercises consisted of a caudal rotation rounding reflex of the pelvis (Rounding) (Fig. 1a), baited DMEs to each hip (i.e. where the muzzle is encouraged towards the hip (DMEHip)) (Fig. 1b and 1c), and chest (i.e. where the muzzle is encouraged towards the chest (DMEChest)) (Fig. 1f), and lateral tail pulls (LatTail) to the left and right (Fig. 1d and 1e). All horses were in a square standing position with a neutral neck position prior to commencing each exercise. Data acquisition sessions took place on a separate day, following the completion of the two training sessions. sEMG (1259 Hz) and IMU (148 Hz) data were synchronously recorded during each exercise using EMGWorks Acquisition software (version 4.8.0, Delsys Inc., USA). Each exercise was performed by the same experienced physiotherapist (L.G.) over a 5-second period. Each exercise was repeated in triplicate, with a 20-second rest period between each exercise. Clear verbal 'start' and 'stop' cues were provided by the researcher at the computer terminal (L.H.) to the researcher executing the exercises (L.G.). All exercises were performed in the following order using the protocols outlined below.

2.3.1. Pelvic rounding (Fig. 1a)

With the physiotherapist positioned on the left, close to the left hind limb, digital pressure was applied bilaterally along the intramuscular groove between biceps femoris and semitendinosus muscles, inducing lumbosacral flexion, which was held for 2 seconds.

2.3.2. DME to the right and left hip (DMEHip) (Fig. 1b and 1c, respectively)

With the physiotherapist standing by the right shoulder, the horse was encouraged to bend laterally, as far as possible towards the right tuber coxae without side-stepping, by following a reward (carrot). The exercise was repeated to the left (Fig. 1c) with the physiotherapist standing by the horse's left shoulder and encouraging lateral bending towards the left tuber coxae. Each direction of movement was held for 2 seconds.

2.3.3. Lateral tail pulls to the right and left (LatTail) (Fig. 1d and 1e, respectively)

The physiotherapist stood 70 cm to the right of the horse, in line with the right hind limb, and held the tail below the dock. A lateral pull was gradually applied until the right tensor facia lata visibly contracted. The exercise was repeated to the left (Fig. 1e) with the physiotherapist standing in line with the left hind limb and gradually applying a lateral pull until the left tensor facia latae visibly contracted. Tail pulls were sustained for 2 seconds, then released.

2.3.4. DME chin to chest (DMEChest) (Fig. 1f)

The physiotherapist stood to the left of the horse's shoulder. The horse was encouraged to follow a reward (carrot) from a neutral head position towards the chest and to hold the position for 2 seconds.

Fig. 1. Dynamic mobilization exercises (DME) and therapeutic trunk exercises (TTE) in the order they were undertaken. a) Caudal pelvic rounding, b) DME to the hip (DMEHip) to the right c) DMEHip to the left, d) Lateral tail pulls to the right, e) Lateral tail pulls to the left, f) DME chin to chest (DMEChest).

2.4. Data processing and analysis

Data files were converted to mat. format and imported into MATLAB (version 2022b, Matworks, USA) for post-processing of sEMG and IMU data. IMU data were used to estimate thoracolumbar flexion/extension and lateral bending movements to demarcate the beginning (start event) and end (end event) of each movement cycle/trial. Differential pitch (flexion/extension) and yaw (lateral bending) angle-time signals were calculated in accordance with Mackechnie-Guire & Pfau [24] by subtracting the relevant gyroscope signals (X and Z, respectively) of the L1 sensor from the T14 sensor. Differential angle-time signals were smoothed using a low pass, Butterworth 4th order filter with a 5 Hz cut-off frequency [25,26]. Start and end events for each movement were defined using filtered differential flexion/extension or lateral bending angle-time signals, depending on the primary movement for each measured exercise (i.e. flexion/extension for Rounding and DMEChest, and lateral bending for DMEHip and LatTail). Start and end events were defined by ascent and descent through a 0°/s threshold, respectively, and then time-normalized. Events were visually checked against video footage from each trial and through independent verification by two researchers (L.H., L.S.G.). sEMG signals were DC-offset removed, band-pass filtered using a Butterworth 4th order filter with a 40-450 Hz cut-off frequency [27] and were full-wave rectified. IMU-derived start and end events were applied to sEMG signals from the same trial. Average rectified value (ARV) was calculated from full wave rectified sEMG signals using start and end events to define the time domain. Values were checked for potential outliers by setting limits to ±2 SD outside of the mean ARV values within each subject, muscle and task [28], and none were identified using this method. However, one ARV value (μV) from EAO was approximately two times greater than the other values in the dataset and was manually excluded as an outlier, as agreed by two researchers (L.H., L.S.G.), because it skewed the outlier detection method and did not reflect muscular effort for the studied exercise (DMEHip). ARV data were normalized relative to a reference voluntary contraction (RVC) [18,29], defined as the mean DMEChest ARV value within each horse and muscle. This RVC was selected based on evaluation of the sEMG data acquired here, and the results of a previous study [21], both of which showed minimal changes in the amplitude of sEMG signals from trunk muscles during DMEChest. Thus, this RVC offered consistent, submaximal contraction for normalization, which permitted an examination of the proportional difference in muscle activity between exercises and horses.

2.9. Statistical analysis

To evaluate bilateral muscle activity across the different exercises, normalized ARV data derived from unilateral exercises; DME to the left hip (DMEHipL), DME to the right hip (DMEHipR), lateral tail pull to the left (LatTailL), and lateral tail pull to the right (LatTailR), were grouped according to whether the left or right-side muscle was ipsilateral or contralateral to the direction of the exercise. For example: data from DMEHipL and left-side muscles, and DMEHipR and right-side muscles were grouped as “Ipsilateral DMEHip”. Similarly, ARV data from DMEHipL and right-side muscles and DMEHipR and left-side muscles were grouped as “Contralateral DMEHip”. The same convention was applied to data from unilateral LatTail exercises. For bilateral exercises (i.e. Rounding and DMEChest) paired t-tests revealed no statistical difference ($P > 0.05$) between left and right-side ARV data within each muscle/exercise. Thus, normalized, within-muscle ARV data were grouped for Rounding and DMEChest exercises. This resulted in a six-category exercise variable: DMEChest, Ipsilateral DMEHip and LatTail, Contralateral DMEHip and LatTail, and Rounding.

Statistical analyses were conducted using Stata 19 (Stata Statistical Software: Release19, College Station, TX StataCorp LLC (2025)). Possible associations between exercise and muscle activity were explored by fitting separate linear mixed models (LMM) for each exercise with normalized ARV as the outcome variable, the six-category exercise variable as a fixed effect and horse as the random effect. Comparison models were fitted with repetition included as an additional categorical fixed effect. This did not influence the coefficients of interest, so this variable was not included in the final models. Estimated marginal mean (EMM) normalized ARV values and associated 95 % confidence intervals (CIs) were then derived from the model. Comparisons between each pair of exercises were made to estimate the predicted differences and associated 95 % CIs.

3. Results

A total of 1499 observations were analysed across horse, muscle, exercise and repetition. Normalized ARV data across muscles and exercises are graphically represented using box plots in Fig. 2. LMM results from individual muscles are summarized in Table 1 and reveal that, across muscles, the greatest EMM ARV (%) was observed for EAO, RA and LD at T14 during ipsilateral DMEHip, and for LD at L1 during Rounding.

3.1. *External abdominal obliques*

LMM results for EAO are presented in Table 2, with pairwise comparisons revealing significantly greater normalized ARV for ipsilateral DMEHip compared to all other exercises ($P < 0.001$). Rounding ARV was significantly greater than DMEChest and contralateral DMEHip and LatTail ($P < 0.05$). For unilateral exercises, ARV during ipsilateral DMEHip and LatTail were significantly greater than contralateral ($P < 0.001$). When unilateral exercises were compared, ARV was significantly greater during ipsilateral DMEHip than LatTail ($P < 0.05$), but no significant differences were observed between contralateral DMEHip and LatTail ($P > 0.05$).

Table 1

Estimated marginal mean normalized ARV (%) and associated 95 % confidence intervals from all four linear mixed models for each muscle and exercise.

Exercise	Muscle			
	External abdominal oblique	Rectus abdominis	Longissimus dorsi T14	Longissimus dorsi L1
DME to the chest	100.0 (71.6 - 128.4)	99.7 (68.4 - 131.0)	100.0 (89.6 - 110.4)	100.0 (94.5 - 105.5)
DME to the hip ipsilateral	207.0 (178.7 - 235.4)	172.1 (140.8 - 203.4)	136.8 (126.4 - 147.3)	120.4 (114.9 - 125.9)
DME to the hip contralateral	117.0 (88.4 - 145.6)	99.4 (68.1 - 130.8)	112.3 (101.9 - 122.7)	113.8 (108.3 - 119.2)
Lateral tail pull ipsilateral	169.7 (141.3 - 198.1)	107.5 (76.2 - 138.8)	105.1 (94.6 - 115.5)	108.8 (103.3 - 114.2)
Lateral tail pull contralateral	120.5 (92.1 - 148.9)	87.9 (56.6 - 119.2)	98.4 (88.0 - 108.9)	103.0 (97.6 - 108.5)
Pelvic caudal rounding	164.1 (135.3 - 193.0)	103.9 (72.1 - 135.7)	109.9 (99.3 - 120.4)	123.0 (117.5 - 128.5)

3.2. *Rectus abdominis*

LMM results for RA are presented in Table 3, with pairwise comparisons revealing that normalized ARV from ipsilateral DMEHip was significantly greater than all other exercises ($P < 0.001$). No other significant differences in ARV were observed between exercises for RA ($P > 0.05$).

3.3. *Longissimus dorsi*

LMM results for LD at T14 are presented in Table 4, with pairwise

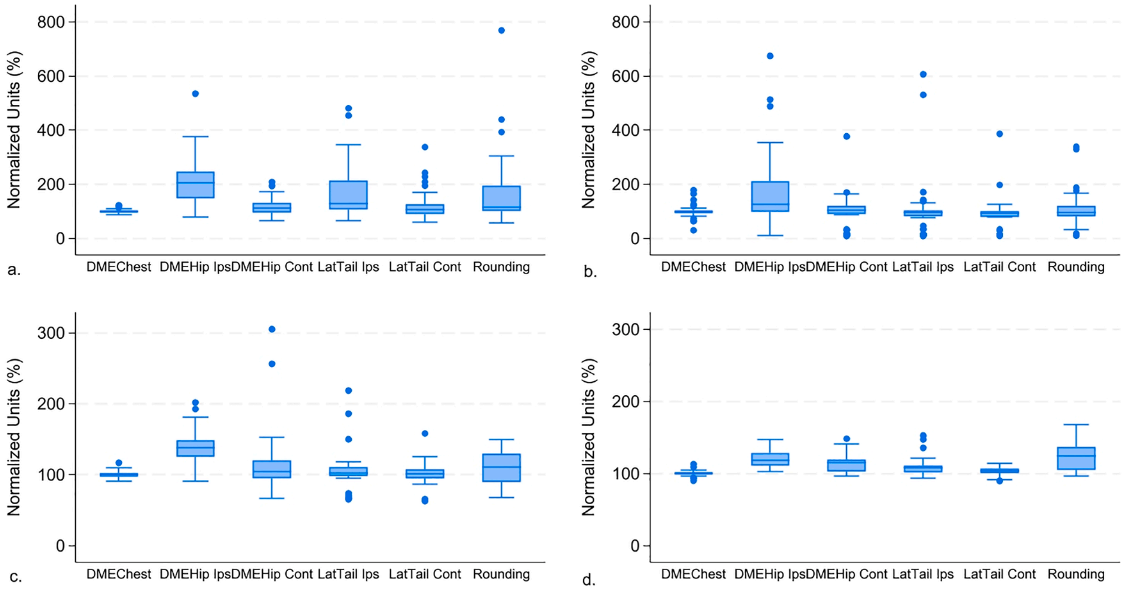

Fig. 2. Boxplots of normalized ARV (%) data from $n = 7$ horses derived from (a) external abdominal oblique (EAO), (b) rectus abdominis (RA), (c) longissimus dorsi at T14 (LD T14), and (d) longissimus dorsi at L1 (LD L1) muscles during DME to the chest (DMEChest), DME to the hip (DMEHip) on the ipsilateral side (DMEHip Ips) and contralateral side (DMEHip Cont), lateral tail pulls (LatTail) on the ipsilateral side (LatTail Ips) and contralateral side (LatTail Cont), and caudal pelvic rounding (Rounding).

Table 2

Linear mixed model pairwise comparisons matrix for normalized ARV (%) from the external abdominal oblique between exercises (exercise 1 – exercise 2), presented as estimated marginal mean difference and associated 95 % confidence interval.

External abdominal obliques

Exercise	DME to the chest (Exercise 2)	DME to the hip ipsilateral	DME to the hip contralateral	Lateral tail pull ipsilateral	Lateral tail pull contralateral	Caudal pelvic rounding
DME to the chest (Exercise 1)	-	-	-	-	-	-
DME to the hip ipsilateral	107.0 (75 – 138.3)***	-	-	-	-	-
DME to the hip contralateral	17.0 (−14.5 – 48.5)	−90.1 (−121.6 – −58.5) ***	-	-	-	-
Lateral tail pull ipsilateral	69.7 (−38.4 – 101.0) ***	−37.3 (−68.6 – −6.0) *	52.7 (21.2 – 84.2) **	-	-	-
Lateral tail pull contralateral	20.5 (−10.8 – 51.8)	−86.5 (−117.8 – −55.2) ***	3.5 (−28.0 – 35.0)	−49.2 (−80.5 – −17.9) *	-	-
Caudal pelvic rounding	64.1 (32.4 – 95.9) ***	−42.9 (−74. – −11.2) **	47.2 (15.3 – 79.1) *	−5.6 (−37.3 – 26.1)	43.7 (11.9 – 75.4) *	-

Significance is denoted by.

[*] $P < 0.05$;.

[**] $P < 0.01$;.

[***] $P < 0.001$.

Table 3

Linear mixed model pairwise comparisons matrix for normalized ARV (%) from the rectus abdominis between exercises (exercise 1 – exercise 2), presented as estimated marginal mean difference and associated 95 % confidence interval.

Rectus abdominis

Exercise	DME to the chest (Exercise 2)	DME to the hip ipsilateral	DME to the hip contralateral	Lateral tail pull ipsilateral	Lateral tail pull contralateral	Caudal pelvic rounding
DME to the chest (Exercise 1)	_	_	_	_	_	_
DME to the hip ipsilateral	72.4 (38.1 – 106.8) ***	_	_	_	_	_
DME to the hip contralateral	−0.3 (−34.6 – 34.1)	−72.7 (−107.0 – −38.3) ***	_	_	_	_
Lateral tail pull ipsilateral	7.7 (−26.6 – 42.1)	−64.7 (−99.0 – −30.3) ***	8.0 (−26.3 – 42.4)	_	_	_
Lateral tail pull contralateral	−11/8 (−46.2 – 22.5)	−84.2 (−118.6 – −49.9) ***	−11.5 (−45.9 – 22.8)	−19.6 (−53.9 – 14.8)	_	_
Caudal pelvic rounding	4.2 (−30.6 – 39.0)	−68.2 (−103.0 – −33.4) ***	4.5 (−30.3 – 39.2)	−3.6 (−38.4 – 31.2)	16.0 (−18.8 – 50.8)	_

Significance is denoted by * $P < 0.05$; ** $P < 0.01$;.

[***] $P < 0.001$.

Table 4

Linear mixed model pairwise comparisons matrix for normalized ARV (%) from the longissimus dorsi (at T14) between exercises (exercise 1 – exercise 2), presented as estimated marginal mean difference and associated 95 % confidence interval.

Longissimus dorsi T14

Exercise	DME to the chest (Exercise 2)	DME to the hip ipsilateral	DME to the hip contralateral	Lateral tail pull ipsilateral	Lateral tail pull contralateral	Caudal pelvic rounding
DME to the chest (Exercise 1)	_	_	_	_	_	_
DME to the hip ipsilateral	36.8 (26.4 – 47.3) ***	_	_	_	_	_
DME to the hip contralateral	12.3 (1.9 – 22.8) *	−24.5 (−34.9 – −14.1) ***	_	_	_	_
Lateral tail pull ipsilateral	5.1 (−5.4 – 15.5)	−31.8 (−42.2 – −21.4) ***	−7.3 (−17.7 – 3.2)	_	_	_
Lateral tail pull contralateral	−1.6 (−12.0 – 8.9)	−38.4 (−48.8 – −28.0) ***	−13.9 (−24.3 – −3.5) **	−6.6 (−17.1 – 3.8)	_	_
Caudal pelvic rounding	9.9 (−0.7 – 20.4)	−27.0 (−37.6 – −16.4) ***	−2.5 (−13.0 – 8.1)	4.8 (−5.8 – 15.4)	11.4 (0.9 – 22.0) *	_

Significance is denoted by.

[*] $P < 0.05$;.

[**] $P < 0.01$;.

[***] $P < 0.001$.

comparisons revealing that normalized ARV from ipsilateral DMEHip

was significantly greater than Rounding ($P < 0.001$). Similarly, LD at

T14 ARV was significantly greater for ipsilateral DMEHip ($P < 0.001$) and contralateral ($P < 0.05$), when compared with DMEChest. When unilateral exercises were compared, significantly greater LD at T14 activity was observed during ipsilateral DMEHip compared to both ipsilateral and contralateral LatTail ($P < 0.001$). Significantly greater ARV was observed during contralateral DMEHip when compared with contralateral LatTail ($P < 0.01$), but no significant differences were observed between contralateral DMEHip and ipsilateral LatTail.

LMM results for LD at L1 are presented in Table 5. Pairwise comparisons revealed that LD at L1 ARV was significantly greater ($P < 0.001$) across all exercises compared to DMEChest, except for contralateral LatTail, which was not significantly different ($P > 0.05$). LD at L1 ARV was significantly greater ($P < 0.001$) during Rounding when compared to LatTail (ipsilateral and contralateral) and contralateral DMEHip but was not significantly different when compared to ipsilateral DMEHip ($P > 0.05$). Like LD at T14, when unilateral exercises were compared, significantly greater L1 activity was observed during ipsilateral DMEHip compared to both ipsilateral and contralateral LatTail ($P < 0.001$).

4. Discussion

Despite their frequent clinical use in equine back rehabilitation programs [14,15], evidence supporting the effect of DMEs and TTEs on superficial trunk muscle activation remains limited. In recognition of this, we used sEMG to quantify and compare bilateral EAO, RA, and LD (at T14 and L1) activity across four commonly prescribed DMEs and TTEs. Findings demonstrated significant exercise-specific increases in EAO, RA and LD activity, quantified using normalized ARV. Across exercises, the greatest increases in ARV were observed for ipsilateral EAO, RA and the thoracic region (T14) of LD during DMEHip. During unilateral exercises (DMEHip and LatTail), EAO, RA and LD activity were significantly greater on the ipsilateral side (i.e. the side of the direction of the exercise/movement) than the contralateral side. For bilateral, sagittal plane exercises (Rounding and DMEChest), the greatest increase in muscle activity was observed in the lumbar (L1) region of LD during Rounding. Overall, these findings partially support the hypotheses, as increased muscle activity was observed across exercises, with the most pronounced responses occurring in the EAO during DMEHip and in LD (at L1) during Rounding. However, the most pronounced increases in LD (at T14) and RA activity were observed during DMEHip, which does not support the hypothesis that this would occur during exercises that encourage spinal flexion (DMEChest, Rounding).

To our knowledge, only two studies have used sEMG to evaluate superficial trunk muscle activity during DMEs and TTEs [21,22]. Consistent with these studies, our results demonstrate marked increases in ipsilateral RA and EAO activity during DMEHip compared with DMEChest [21,22], and minimal changes in muscle activity during DMEChest exercises [21]. In contrast to Coll et al. [21], who reported no significant differences in lumbar LD activation during this exercise. The discrepancy in lumbar LD activity likely reflects methodological differences between studies, particularly our application of high-pass filtering prior to signal normalization, which attenuates low-frequency noise contamination and conforms to best practice guidelines for equine sEMG signal processing [19,27].

4.1. Unilateral exercises: DMEHip and lateral tail pull

The unilateral exercises studied here include DMEHip and LatTail. These exercises rely on coordinated agonist-antagonist muscle interactions to facilitate controlled lateral bending [30], which we quantified here for the first time using bilateral sEMG data. During DMEHip, significant increases in ipsilateral muscle activation were observed across all three muscles studied, with the greatest relative increase observed in the ipsilateral EAO, which likely reflects its agonistic role in trunk lateral bending [21,22,30]. Interestingly, when compared to the other exercises, the only significant increases in RA activity were observed during ipsilateral DMEHip. Although contralateral EAO and RA activity increased during DMEHip, these changes did not reach significance. Together, these findings suggest that DMEHip may be associated with increased activation of ipsilateral EAO and RA, with possible antagonistic engagement of the contralateral musculature, which may support recommendations for performing the exercise on both sides.

During unilateral exercises, changes in LD activity differed between the thoracic (T14) and lumbar (L1) regions studied here. Compared to the other exercises, significantly greater bilateral LD activity was observed at both T14 and L1 locations during DMEHip, with comparatively greater activity observed at T14. This finding is consistent with regional anatomical and architectural differences in LD that influence muscle function and activation along its length [31–33]. Fascicle length decreases from the cranial to caudal direction, with thoracic fascicles being approximately twice as long as lumbar fascicles, and with fiber orientation transitioning from predominantly unipennate to bipennate and parallel to the spine [31]. Segmental mobility also varies due to osteoarticular morphology that permits greater mobilisation in the thoracic region [34–36]. Although not quantified here, previous kinematic data have demonstrated that DMEHip induces lateral bending of the mid-caudal thoracic spine [21,36,37]. Since lateral bending is coupled with axial rotation and is most pronounced between T11-T14 [36,38], greater muscular demand in this mobile region is expected.

Table 5

Linear mixed model pairwise comparisons matrix for normalized ARV (%) from the longissimus dorsi (at L1) between exercises (exercise 1 – exercise 2), presented as estimated marginal mean difference and associated 95 % confidence interval.

Longissimus dorsi L1						
Exercise	DME to the chest (Exercise 2)	DME to the hip ipsilateral	DME to the hip contralateral	Lateral tail pull ipsilateral	Lateral tail pull contralateral	Caudal pelvic rounding
DME to the chest (Exercise 1)	–	–	–	–	–	–
DME to the hip ipsilateral	20.4 (16 – 24.7) ***	–	–	–	–	–
DME to the hip contralateral	13.8 (9.5 – 18.0) ***	−6.6 (−10.9 – −2.3) **	–	–	–	–
Lateral tail pull ipsilateral	8.8 (4.5 – 13.0) ***	−11.6 (−15.9 – −7.3) ***	−5.0 (−9.3 – −0.7) *	–	–	–
Lateral tail pull contralateral	3.0 (−1.2 – 7.3)	−17.3 (−21.6 – −13.1) ***	−10.7 (−15.0 – −6.4) ***	−5.7 (−10.0 – −1.4) **	–	–
Caudal pelvic rounding	23.0 (18.7 – 27.3) ***	2.6 (−1.7 – 7.0)	9.3 (4.9 – 13.6) ***	14.3 (9.9 – 18.6) ***	20.0 (15.6 – 24.3) ***	–

Significance is denoted by.

[*] $P < 0.05$;.

[**] $P < 0.01$;.

[***] $P < 0.001$.

Further, longer thoracic fascicles and greater segmental mobility likely facilitate increased lateral bending in this region, whereas shorter lumbar fascicles contribute more to stabilization [31,32]. Thus, the observed increases in LD activity at T14 and L1 locations are consistent with these regional and functional differences and suggest that DMEHip may be more effective in activating thoracic regions of LD. However, further work is required to support this interpretation.

Across all muscles, activity was significantly greater during ipsilateral DMEHip than during ipsilateral LatTail. Ipsilateral EAO and lumbar (L1) LD activity were also significantly greater during both DMEHip and LatTail when compared to DMEChest and contralateral LatTail. Although lateral tail pull has been described as a pelvic stability exercise due to pelvic muscle activation [14,39], the broader muscle engagement observed here suggests that it may be more accurately described as a lumbopelvic stabilizing exercise. However, further research is required to investigate the synchronized activation of lumbopelvic musculature during LatTail to confirm this theory.

Taken together, these findings suggest that DMEHip may be associated with greater increases in EAO, RA, and LD activity at thoracic and lumbar regions than LatTail, particularly on the ipsilateral side. This interpretation is broadly consistent with previous reports of increased epaxial activation during DMEHip [21] and evidence of bilateral LD activation during lateral bending [40,41]. The rapid, lateral bending motion that is induced by DMEHip, and involves multiple spinal segments [34,36], likely necessitates increased antagonistic activation of the contralateral LD to control intervertebral motion [30]. In contrast, the slower, progressive force applied during LatTail, combined with anatomical characteristics of the lumbar spine that limit range of motion (ROM) in this region [34], may explain the comparatively lower contralateral LD activity observed. Overall, these findings suggest that DMEHip could be useful in rehabilitation programs that target bilateral activation of thoracic and lumbar LD. In contrast, LatTail may be more appropriate for facilitating unilateral activation of EAO and lumbar musculature, albeit to a lesser extent than DMEHip. However, further research is required to investigate superficial trunk muscle activity in horses with back pain during unilateral exercises to substantiate this interpretation.

4.2. Bilateral, sagittal plane exercises: caudal pelvic rounding and DMEChest

Across all muscles, ARV during DMEChest was either non-significant or significantly lower when compared across exercises, which is consistent with findings by Coll et al. [21]. These results suggest that DMEChest may not optimally target activation of the superficial trunk muscles evaluated here. However, the effect of DMEChest on other muscle groups warrants investigation, especially as kinematic studies have demonstrated increased cervical ROM, particularly at C6 – 7, during this exercise [37], which may indicate increased muscle activity in this region. Compared to DMEChest, significantly greater activity was observed during Rounding for EAO and LD at the L1 location. Further, across exercises, the greatest predicted normalized ARV for LD at L1 was observed for Rounding. This finding is consistent with Coll et al., [21], who reported increased EAO activity during Rounding. In addition, Elosegui et al., [39] reported significant increased activation of gluteus medius, biceps femoris and gracilis muscles during Rounding. It is therefore possible that the pronounced EAO activity observed during Rounding necessitates increased antagonistic co-activation of LD in the lumbar region to control lumbopelvic motion [30], but further studies are required to confirm this. Taken together, these findings suggest that Rounding may be more accurately described as a dual-function task, serving both as a lumbopelvic stabilization and mobilization exercise, rather than as a purely hypaxial strengthening activity [15]. The results may support the use of Rounding when rehabilitation objectives involve targeted, bilateral activation of the lumbar LD and EAO. Again, further research is warranted to evaluate superficial trunk muscle activity in horses with back pain during Rounding and DMEChest exercises to substantiate these findings in clinical populations.

4.3. Study limitations

This preliminary study has limitations that should be considered when interpreting the findings. sEMG data were only acquired from three superficial trunk muscles and at two locations on LD. While these muscles and sensor locations were selected based on biomechanical and anatomical reasoning, further studies are required to evaluate the effect of DMEs and TTEs on additional superficial trunk muscles and locations on LD. A relatively small sample of horses without back pain was employed, which provides preliminary data from a healthy population. However, further studies are required to build on this by employing a larger sample and by studying horses with back pain to determine clinical relevance. Although all horses underwent two days of acclimatization, the degree of active movement varied according to each horse's response to the trigger. For DMEs, food was the trigger, and horses differed in their interest and subsequent motivation, which affected the speed and degree of lateral bending. However, these differences reflect anecdotal observations of horses performing these exercises in clinical/physiotherapeutic practice.

For this study, we utilized a 2-second hold for each exercise to acquire data from a period of stable stretching and movement. However, it is important to note that DMEs and TTEs are often held for a longer period of 5 – 10 seconds in clinical practice, as outlined by Stubbs and Clayton [42] and Stubbs et al. [17]. In our analyses, we used multiple pairwise comparisons that increase the risk of Type 1 error. As recommended by Rothman [43], we did not use any adjustments when reporting our results as such an approach increases the risk of Type 2 error. However, we deem the observed differences of > 30 % for muscles with greater variation in activity (EAO and RA) and > 10 % for those with less variation (LD) as not being due to chance alone, thus we have a high level of confidence in these findings. Finally, this study was limited in that the exercises were not conducted in a randomized order, which may have influenced the results. Future studies should build on this work by combining sEMG with optical motion capture to enable a more detailed analysis of muscle function within the context of movement.

5. Conclusion

This study is the first to evaluate bilateral superficial epaxial and hypaxial muscle activity during DMEs and TTEs that are commonly used within rehabilitation programs for horses with back pain. Analysis of sEMG data revealed significantly greater thoracic LD (at T14), RA and EAO activity during DMEHip on the ipsilateral side, and lumbar LD (at L1) activity during Rounding, when compared across exercises. These findings support the use of DMEs and TTEs for the targeted activation of EAO, RA and LD, particularly DMEHip and Rounding, where the greatest increases in activity were observed. Overall, this study contributes to the ongoing development of evidence-based practice in animal physiotherapy and provides a foundation for future work in horses with back pain. Longitudinal studies are required to determine whether the observed increases in muscle activity during DMEs and TTEs result in sustained functional adaptations.

Ethical Statement

The material in this manuscript has been acquired in accordance with Guidance on the operation of Animals (Scientific Procedures) Act 1986 and has been approved by The University of Queensland's Production and Companion Animal Ethics Committee. The approval number is 2023/AE000262 (approval date, 11 April 2023). The horses are part of The University of Queensland Equine Unit and are used for teaching and research purposes.

CRediT authorship contribution statement

L.M. Harrison: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **L.B. St. George:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Formal analysis, Data curation. **L.M. Goff:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization. **G. Nardese:** Writing – review & editing, Software, Formal analysis, Data curation. **T. Barnes:** Writing – review & editing, Formal analysis. **B. Ahern:** Writing – review & editing, Validation, Supervision, Methodology. **A. Sole-Guitart:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of this paper.

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