The Effect of Ground Poles and Elastic Resistance Bands on Longissimus Dorsi and Rectus Abdominus Muscle Activity During Equine Walk and Trot

Karen Shaw[1*], Tena Ursini[1], David Levine[2], Jim Richards[3], Steve Adair[1]

[1]Equine Performance and Rehabilitation Center, Department of Large Animal Clinical Sciences, University of Tennessee College of Veterinary Medicine, 2407 River Drive, Knoxville, TN, 37919, United States. kshaw13@utk.edu, tursini@utk.edu, sadair@utk.edu

[2]Department of Physical Therapy, The University of Tennessee at Chattanooga, 615 McCallie Ave Dept #3253, Chattanooga, TN, 37403, United States. David-Levine@utc.edu

[3]Allied Health Research unit, University of Central Lancashire, Fylde Road, Preston, Lancashire PR1 2HE, United Kingdom. jrichards@uclan.ac.uk

*__Corresponding Author:__ Karen Shaw, Email: kshaw13@utk.edu

Present Address: University of Tennessee, 2407 River Drive, Knoxville, TN, USA, 37919

Abstract

Core strengthening and postural stability are desired outcomes of certain therapeutic exercises performed in horses. This study aimed to quantify changes in muscle activation at a walk and trot in horses traveling over eight consecutive ground poles evenly spaced (at 30 inches for walk and 48 inches for trot) in parallel fashion in a straight line, and with hindquarter and abdominal elastic resistance bands applied at 25% stretch. Surface electromyography (sEMG) data were collected for the longissimus dorsi and rectus abdominus muscles in six horses. A 2x2 repeated measures ANOVA was performed for each muscle to test for significant differences in differences in normalized average rectified values and maximum low pass signals. Within subject effects were reported, followed by post-hoc pairwise comparisons to evaluate differences between the conditions of with or without ground poles or elastic resistance bands. The use of ground poles at a walk resulted in a significant ($p < 0.05$) increase in the maximum low pass value bilaterally in the longissimus dorsi and rectus abdominus muscles, with an increase in the average rectified value bilaterally in the rectus abdominus muscles and right longissimus dorsi muscle. The use of ground poles at a trot resulted in a significant increase in the maximum low pass value bilaterally in the rectus abdominus muscles. The hindquarter and abdominal elastic resistance bands resulted in a respective 27% and 27.2% increase in the mean average rectified value of the left and right RA muscles, however this only reached statistical significance in the left RA ($p < 0.05$). These findings provide support regarding changes in muscle activation when using ground poles to increase core and epaxial muscle engagement. While a significant effect on core muscle activation was identified with the elastic resistance bands at a trot, further research is needed in this area to further characterize their effects on muscle activation.

Keywords: surface electromyography; equine, horse; rehabilitation; therapeutic exercise; core, muscle activity; biomechanics; equine athletics; resistance bands; poles, cavalettis

1. Introduction

Human physical therapy has grown since the early 20th century and has become an integral part in the healthcare team with an emphasis on the maintenance, restoration, or enhancement of physical and functional abilities of the individual [1,2]. The principles and techniques used in human physical therapy have a strong evidence base, whereas in the equine field the scientific evidence supporting therapeutic exercise strategies is lacking. For this reason, there has been a cross-species application of many physical therapy principles. Most therapeutic exercise strategies used in horses involve the application of the principles, knowledge, and experience in human physical therapy, combined with the understanding of equine biomechanics and movement dysfunction associated with injury [1,3-10]. However, to better understand the physiological effects of these therapeutic interventions, further research is needed to support their use.

Maximizing performance and the biomechanical efficiency of movement in equine athletes often involves posture control and core muscle engagement [1,9-10]. A state of good posture has been previously defined as "a state of musculoskeletal balance that protects the supporting structures of the body against injury or progressive deformity" [2]. Posture control and core muscle strengthening is encouraged to avoid limb overload in horses recovering from injuries to their extremities, as reduced core strength and poor posture can lead to increased loading of an injured limb [1,9-10]. Posture is influenced by many factors including conformation, body condition, muscle development, muscle hypertonicity, and muscle atrophy [1]. Spinal positioning and posture control are influenced by several muscle groups including the; abdominal core muscles, hindquarter muscles, epaxial, and hypaxial muscles, which have been shown to play a significant role in movement and stabilization of the spine throughout the gait cycle [9-18]. The muscles investigated in this study were the longissimus dorsi (LD) and rectus abdominus (RA) given their contributions to core and postural stability.

Therapeutic techniques that have been purported to improve postural control in horses include assistive or adaptive equipment that provide tactile and proprioceptive stimuli, whose sensory input is integrated into functional activity. One such technique is the application of elastic resistance bands in a figure of eight conformation around the horse's trunk to provide a rhythmic stimulus to induce hindquarter protraction through suspected simulation of the iliopsoas and spinal flexor muscles [1]. Alternatively, elastic resistance bands have been applied from the girth of a saddle or surcingle, extending around the caudal aspect of the hindlimbs to facilitate hindlimb protraction and engagement of the core musculature [1]. A 4-week training regimen using elastic resistance bands around the abdomen and hindquarters resulted in alterations of back kinematics as measured by inertial measurement unit (IMU) sensors [3]. Changes seen included a reduction in mediolateral and rotational movement of the thoracolumbar region at a trot, consistent with increased dynamic stability of the spine [3]. While alterations in back kinematics have been identified with the use of an elastic resistance band training system, changes in activation of epaxial muscles of the spine, such as the LD muscles, have not yet been investigated. Additionally, while an increase in activation of abdominal musculature with the use of the abdominal elastic resistance band has been suggested, changes in core abdominal muscle recruitment with electromyography have not yet been investigated to the authors' knowledge.

Negotiating over ground poles or raised ground poles (cavalettis) is another therapeutic technique used in rehabilitation programs for training proprioceptive awareness, core muscle activation, posture development, and neuromotor control [1,5,19-22]. In addition to an altered neuromuscular response, maneuvering over obstacles can also result in a learned response, which can influence foot clearance, joint trajectories, and electromyographic activity [19,23]. The use of raised poles incorporated into a gymnastic training program has been shown to increase stride length, tracking distance, and improve multifidi muscle cross sectional area when combined with dynamic mobilization exercises [4]. While the basic locomotor rhythm in horses is mediated at the spinal level by the central pattern generators, maneuvering over obstacles requires visual input and processing in the motor cortex to produce an altered locomotor response [24]. The locomotor response initiated with ground poles includes changes in limb elevation and flight arc, increased swing phase joint flexions of the forelimbs and hindlimbs, and increased lateral stability of the stance limb likely from recruitment of the forelimb adductor and extensor musculature [5, 19-20]. Additionally, as a horse maneuvers over an obstacle such as ground poles, their balance is perturbed as the swing limbs are raised over the obstacle, which requires the body and stance limbs to maintain balance and stability [10]. Identifying therapeutic strategies to increase muscle activation of the trunk is important for increasing spinal stability by limiting the degree of spinal rotation [25].

The LD muscle was investigated in this study, as the thoracic segment is the largest of the epaxial muscles, which has a significant role in trunk stability [10,26]. The RA muscle works in accordance with the LD to generate tension and dorsal flexion in the thoracolumbar spine, helping to create a stable and rigid platform to facilitate locomotion [10,18,26]. Given the increase in forelimb and hindlimb flight arc and joint angles with ground poles and the resulting increase in spinal rotation, our hypothesis was that there would be increased LD and RA muscle activation when walking and trotting over ground poles given its role in stabilizing the axial skeleton. A significant increase in mean and maximal surface electromyographic activity of the RA muscle has been reported in 3 out of 6 horses when ridden over ground poles and raised poles [11]. Further research is needed to investigate and better characterize changes induced in muscle activation of core, epaxial, hypaxial, forelimb and hindlimb muscles with the use of ground poles at a walk and trot.

Electromyography (EMG) is a technique used to evaluate muscle activity during movement, through the measurement of motor unit action potentials (MUAP) associated with muscle activations [27-32]. Numerous EMG studies have been conducted in the horse in both clinical and nonclinical environments. Key areas of researched have included the role of muscles in pathologic conditions, and the activity of muscles involved in locomotion to determine their contribution to performance [11,14-15,18,27]. EMG has been utilized to quantify muscle activity within defined events to support riding or training practices in horses such as the use of gymnastic gridwork, interval training in racehorses, riding with hyperflexion, or the use of specific training aids [27]. Surface electromyography (sEMG) involves the placement of a non-invasive surface electrode over the superficial muscle of interest [27,32]. The myoelectrical activity of certain muscles can be measured to determine changes in muscle activation during defined events, during the use of therapeutic devices, or as a result of specific training or rehabilitation strategies [27]. Other applications for sEMG in horses include the evaluation of baseline muscle activity in static situations, the investigation of neuromuscular dysfunction, and the study of dynamic muscle recruitment patterns, adaptation to training, or the result of specific interventions on muscle activation [27]. Processing of sEMG data is performed to remove noise artifact and to acquire useable data for analysis [27-32]. Following specific filtering techniques, the sEMG signal can be normalized to a reference contraction, such as a peak activation for a defined sequence of muscle activity. Normalization enables comparison of muscle activity in the same muscle between different exercise tests or conditions [27-28]. From the normalized data, the mean average rectified value (ARV) represents "average work done," and mean maximum low pass value represents peak activity for each muscle [28-30].

The main purpose of this study was to evaluate the ARV and maximum low pass value of the LD and RA muscles at a walk and trot with two therapeutic interventions: with the use of ground poles, and with the use of elastic resistance bands. Eight consecutive ground poles were arranged in parallel fashion in a straight line, set at generally accepted distances for the walk and trot (0.76m for walk, 1.22m for trot) [5,19]. Elastic resistance bands were applied behind the hindquarter musculature and ventral abdomen, and were applied at 25% stretch. Horses additionally were taken over the ground poles with the presence of the resistance bands, with statistical analysis investigating for an interaction between the poles and resistance bands to determine if the effect of one independent variable "depended on" or "influenced" the other. The specific muscles selected were based on their functions related to posture control [12-13,25-26,33]. Earlier research has demonstrated the activity of these muscles during locomotion at a walk and trot, without the presence of therapeutic intervention [14-18].

Our aim is to assess whether the use of ground poles or a proprioceptive aid provided by hindquarter and abdominal elastic resistance bands would result in differences in surface electromyographic activity based on normalized ARV and normalized maximum low pass values of selected muscles at a walk and trot, and to determine if an interaction between the two exercise conditions existed. We hypothesized that the LD and RA muscles would have increased sEMG activity, characterized by increased normalized ARV and increased normalized maximum low pass values, when ground poles and elastic resistance bands were used.

2. Materials and Methods

2.1 Horses

This study was approved by the University of Tennessee Institutional Animal Care And Use Committee (IACUC). Six horses were included in this study. There were 5 mares and 1 gelding, aged between 3 and 20 years old, and with 4 different breeds or crosses represented (3 Thoroughbreds, 1 Quarter Horse, 1 Tennessee Walking Horse cross, 1 Saddlebred cross). All horses were trotted in hand and evaluated by two veterinarians experienced in lameness (KS, TU). Any horse with lameness on hard or soft ground greater than grade 1 on the AAEP scale was excluded. Horses that were gaited without diagonal two-beat trot or with apparent neurological deficits were also excluded. All selected horses were exposed to the experimental set-up (arena, ground poles), trained to lunge with a surcingle, and were instrumented with elastic resistance bands prior to data collection. The acclimation period to the elastic resistance bands ranged from 1 to 4 days, depending on each horse's level of earlier training or exposure. Throughout the acclimation and data collection period, subjects were administered a low-dose non-steroidal anti-inflammatory drug (phenylbutazone, 2.2mg/kg, once daily) to reduce the risk of exercise-induced soreness in the current sample population of horses that are not in a routine exercise program. Since subjects were screened and excluded for consistent lameness or asymmetry, low-dose non-steroidal anti-inflammatory drug is expected to result in minimal alteration of the gait pattern of the included horses.

2.2 Equipment and Instrumentation

Each horse was tacked with a modified saddle pad with the caudal thoracic region removed to prevent interference with the LD sensors. The saddle pad had buckles for attachment of the abdominal and hindquarter elastic resistance bands. A breast collar and surcingle were used to hold the saddle pad and resistance bands in place (Figure 1). Elastic hindquarter and abdominal bands (Equicore Concepts LLC, East Lansing, Michigan, USA) were fitted with a 25% stretch, which was calculated from 75% of the distance between attachment points of the elastic bands. There was not obvious deformation or indenting of the hamstring or abdominal musculature after the bands were applied.

For sEMG electrode placement, the skin over the muscles was shaved, then cleaned with chlorhexidine scrub and isopropyl alcohol. Pre-gelled bipolar self-adhesive AgCl electrodes (HEX Dual Electrodes, Noraxon, Scottsdale, Arizona, USA) with an inter-electrode distance of 2cm, were placed parallel to the direction of the muscle fibers in defined locations and secured with cyanoacrylate adhesive. Electrodes were manufactured with a fixed 2cm inter-electrode distance and unable to migrate (Figures 2 & 3). This inter-electrode distance falls within the range of what is utilized in other equine sEMG studies (ranging from 1 to 4cm inter-electrode distance) and is based on the European SENIAM guidelines [14,16,18-19,32,34-35]. Wireless direct transmission system (DTS) sensors (DTS Research EMG Probes, Noraxon, Scottsdale, Arizona, USA) were attached to the electrodes with 3-inch pinch end leads and secured to the skin with cyanoacrylate adhesive.

The RA muscles were instrumented with surface electrodes placed mid-length along the muscle bellies bilaterally, 2cm lateral to the midline (Figure 2) [18]. The RA electrode and sensor were located cranial to the abdominal band, to prevent interference of the EMG signal. For the LD muscles, surface electrodes were positioned approximately 2cm lateral to the midline bilaterally over the bulk of the LD muscles at the level of the dorsal spinous process T16 (Figure 3), which was identified with linear ultrasound transducer and marked with liquid correction fluid [14,16,28,36].

Figure 1: Placement of the surface electrodes over the LD (arrow) muscles bilaterally, with application of hindquarter and abdominal elastic resistance bands.

Figure 2: Placement of surface electrodes over the RA muscles bilaterally, with a fixed 2cm inter-electrode distance and adjacent wireless direct transmission system (DTS) sensors attached to the electrodes with 3-inch pinch end leads.

Figure 3: Placement of surface electrodes over the LD muscles bilaterally at T16. (Needle electrodes were placed simultaneously in the multifidus muscle at the levels of thoracic and lumbar spinous processes T12, T18, and L5. The results of the needle EMG data were not investigated in the current study.)

2.3 Data Collection Protocol

All data were collected using the Noraxon MR3.10 software. The sEMG signal was transmitted to the computer by a telemetric system (TELEmyo Direct Transmission System (DTS) Belt Receiver, Noraxon, Scottsdale, Arizona, USA). High speed camera video footage was collected for all trials at 125 frames per second (NiNOX Video Capture, Noraxon, Scottsdale, Arizona, USA), which was synchronized with sEMG, and with digital output (myoSYNC Master Sync, Noraxon, Scottsdale, Arizona, USA). The camera was set up at one end of the arena facing the direct line of movement so that horses traveling away and towards the camera would be included in the field of view.

Following instrumentation, sEMG data were gathered at sampling rate of 1500 Hz with synced video footage. If the movement condition was not met, such as a subjective observation of change in gait, stumbling, bucking, or when sEMG sensors were dislodged, data collection was extended or repeated until a minimum of five consistent three-stride segments were obtained. Typically, the handler would travel the arena length or over the sequence of poles three times down and back for the desired strides to be obtained. Data were obtained in-hand at walk and trot, on a straight line at each horse's preferred speed within the gait, following a previously reported method [3,5]. The walking and trot conditions were performed in an indoor arena with soft synthetic surface in the following non-randomized order;

1. Without bands, straight line
2. Without bands, straight line over ground poles
3. With bands, straight line
4. With bands, straight line over ground poles

Eight consecutive ground poles were arranged in a parallel fashion in a straight line, spaced to 0.76 $\pm$ 0.07 meters for walking (30 $\pm$ 3 inches) and spaced to 1.22 $\pm$ 0.07 meters for trotting (48 $\pm$ 3 inches). Pole spacing was adjusted by up to 0.07 meters (3 inches) to accommodate for individual horse variation in stride lengths at either gait [5, 19]. Poles were arranged within an indoor arena on a soft synthetic surface. Ground pole spacing was checked and adjusted every time it was knocked or moved by a horse throughout the data collection.

2.4 Validation of Muscle Activation Patterns Across Gait Cycle

A subsample of the muscle activation data were collected with synchronized kinematic data in order to evaluate the LD and RA muscle activity relative to objectively defined gait events. Four spherical markers (14mm diameter pearl markers, B&L Engineering) were placed on the lateral aspect of the coronary band on all four feet, secured with double-sided adhesive tape and cyanoacrylate adhesive. The kinematic data were collected using a 12-camera 3D motion capture system, with a sampling frequency of 100 frames/second (VICON Motion Systems Ltd, Oxford, UK). Heel strike and toe off events were determined using vertical displacement of the lateral foot markers. These data were used to check the firing sequences with known gait events during walks and trots on hard ground in one of the sample subjects. For one complete gait cycle, two muscle activations were seen in the left and right LD and RA muscles at both the walk and trot, which was consistent with previous reports [12,14,16,25-26]. Despite phasic patterns observed between left and right sided muscles, two activations remained consistently evident for all muscles within each stride examined. These trends in muscle activation for each gait cycle were compared and found to be consistent with the strides marked using sEMG synced video footage on soft ground. Since the left hind toe-off gait events for identifying individual strides were marked subjectively based on video footage, this use of motion capture using objectively defined gait events provided a confirmation of the phasic activation patterns for each muscle of interest across the gait cycle, with two complete left and right LD and RA muscle activations per stride. Since the 3D motion capture system was not available for use during the time of data collection, it was used retrospectively for a validation trial to confirm muscle activation patterns relative to objectively acquired gait events given that the same muscle activation patterns were seen in each muscle irrespective of the surface type. The left hind toe-off event corresponded with a LD or RA muscle activation peak during both walk and trot gaits, whereas the heel strike event proceeded the LD and RA muscle activations.

2.5 Data Processing and Analysis

The high-speed camera video footage was reviewed and used to mark a total of fifteen strides (five consistent three-stride segments) for each horse under each trial condition. Three-stride segments were isolated using “tags” at left hind toe-off events (same viewer, KS). Toe-off was employed for improved accuracy of visual event detection, as it was relatively easy to subjectively consistently identify using video capture.

Post-processing and analysis of sEMG data was performed in Visual3D software (C-Motion Inc., Germantown, MD, USA) version 2020.07.4. A removed mean was performed on the raw EMG signals to account for the signal offset from baseline. A 40Hz high pass filter was applied to reduce movement artifacts and to attenuate low-frequency noise from the sEMG signal [33]. The sEMG signal was then full wave rectified, followed by filtering with a 15Hz low pass filter [27-28,32-33]. To restrict the analysis to periods of muscle activation and further eliminate noise from the data, muscle activity onset and offset events within the isolated strides were marked using the rectified data. This resulted in 30 muscle activations isolated for the LD and RA muscles for each trial for the 15 strides identified from the synchronized video. The sEMG data contained within these identified muscle activations were used for further analysis. When the subjective toe-off events corresponded with a peak of activity of the LD and RA muscles, the entire muscle activation proceeding the toe-off event was included in the analysis, which consistently followed the left hind heel-strike events according to the validation trial. Entire muscle activation bursts proceeding the toe-off event were included in analysis, to prevent partial or split muscle activations. Within each horse, the maximum observed signal from each muscle across the 30 muscle activations for the rectified and enveloped EMG signals were found across all conditions, with and without resistance bands and with and without ground poles, which were used as the reference voluntary contraction (RVC) values [28]. The mean rectified and maximum enveloped data were then normalized to their respective RVC values which were compiled for further statistical analysis. Normalization was performed separately for the walk and trot activities.

2.6 Statistical Analysis

Statistical analysis was performed with SPSS 27 Software (IBM SPSS Statistics, IBM Inc., Armonk, NY, USA). A 2x2 repeated measures ANOVA was performed for each muscle to test for significant differences in the means of the normalized average rectified and maximum low pass values amongst the 6 subjects across the two factors; with and without resistance bands, and with and without ground poles. We tested for an interaction between the two conditions. Since no significant interactions existed between poles and resistance bands, the results of each condition could be evaluated independently. Descriptive statistics were performed (mean, standard deviation) in addition to within subject effects (p-value, partial eta squared). Values of $p \leq 0.05$ were considered significant. Where significant main effects were seen, post-hoc pairwise comparisons were performed to evaluate the differences between the conditions.

3. Results

3.1 Poles vs. No Poles, At A Walk (Tables 1 & 2)

The results of the electromyographic data from walking over poles are represented in Table 1 (mean, SD, p-value, and effect size) and Table 2 (post-hoc testing, poles vs. no poles). With the repeated measures ANOVA analysis, there was a significant increase in the maximum low pass values with the presence of poles in the left LD ($p = 0.045$), right LD ($p = 0.005$), left RA ($p = 0.019$), and right RA ($p = 0.015$) muscles at a walk. The percentage increase of the maximum low pass value in the left and right LD muscles in the group over poles was 51.3% and 38.0% respectively, compared to the group without poles. A relatively large increase in the maximum low pass value was seen in the left and right RA muscles of over double the maximum low pass value in the group with poles compared to without poles, 120.8% and 147.2% greater, respectively.

The presence of poles additionally resulted in a significant increase in the ARV in the right LD ($p = 0.008$), left RA ($p = 0.004$), and right RA ($p = 0.001$) muscles at a walk. The percentage increase in the ARV for the left and right RA muscles with the use of poles was 100.0% and 70.6% greater respectively compared to without poles. While the percentage increase in the mean ARV for the left and right LD muscles with the use of poles was respectively 13.5% and 27.0% greater than without poles, the increase seen in the left LD muscle did not reach statistical significance ($p = 0.087$).

3.2 Resistance Bands vs. No Resistance Bands, At A Walk (Tables 1 & 3)

The results of the electromyographic data from walking with elastic resistance bands are represented in Table 1 (mean, SD, p-value, and effect size) and Table 3 (post-hoc testing, resistance bands vs. no resistance bands). The use of resistance bands in the RA resulted in a consistent increase in the maximum low pass values and ARV, however these changes did not reach statistical significance. The maximum low pass values increased by 47.3% ($p = 0.103$) and 25% ($p = 0.541$) for the left and right RA muscles respectively. The ARV increased by 25.0% ($p = 0.336$) and 11.8% ($p = 0.576$) in the left and right RA muscles respectively when compared to without resistance bands. Additionally, the use of resistance bands in the LD muscles at the walk resulted in a non-significant reduction in both the maximum low pass value and ARV. The maximum low pass values decreased by 12.0% ($p = 0.212$) and 14.0% ($p = 0.060$) for the left and right LD muscles respectively. The ARV values decreased by 10.8% ($p = 0.138$) and 12.5% ($p = 0.058$) for the left and right LD muscles respectively when compared to without resistance bands.

3.3 Poles vs. No Poles, At A Trot (Tables 4 & 5)

The results of the electromyographic data from trotting with poles are represented in Table 4 (mean, SD, p-value, and effect size) and Table 5 (post-hoc testing, poles vs. no poles). The presence of poles at a trot resulted in a significant increase of the mean maximum low pass value of the left RA ($p = 0.013$) and right RA ($p = 0.013$) muscles. The mean maximum low pass value for the left and right RA muscles over poles was 50.9% and 60.0% greater, respectively, than the mean maximum low pass value without poles. Additionally, when comparing the ARV of the left and right RA muscles, the use of poles resulted in a 59.5% ($p = 0.060$) and 72.7% ($p = 0.072$) respective increase in ARV compared to without poles, although this was without statistical significance. The use of poles also resulted in a mean increase in the ARV of the left and right LD muscles of 20.0% (p = 0.142) and 29.8% (p = 0.094) respectively compared to the mean ARV value without poles, although this difference was not statistically significant.

3.4 Resistance Bands vs. No Resistance Bands, At A Trot (Tables 4 & 6)

The results of the electromyographic data from the trot are represented in Table 4 (mean, SD, p-value, and effect size) and Table 6 (post-hoc testing, resistance bands vs. no resistance bands). The use of elastic resistance bands resulted in a significant increase of the mean ARV of the left RA muscle (p = 0.022). For the left RA muscle, the percentage increase in the ARV in the group with resistance bands was 27.0% greater than the group without resistance bands. The right RA muscle showed a similar pattern, with a 27.2% increase in the mean ARV signal in the group with resistance bands compared to without (p = 0.619), however this did not reach statistical significance for this group. For the left and right LD muscles, the use of the resistance bands resulted in a non-significant reduction in the mean ARV value of 21.4% (p = 0.170) and 14.9% (p = 0.200) respectively compared to the group without resistance bands. Similarly, the maximum amplitude in the group with resistance bands showed a non-significant reduction in the peak low pass signal by 20.5% (p = 0.167) and 29.8% (p = 0.264) in the left and right LD muscles respectively, compared to the group without resistance bands.

Table 1: The normalized mean, standard deviation (SD), p-value, and partial eta squared (η_p^2) value of sEMG average rectified values (ARV) and maximum low pass signals in 6 horses across 15 strides at a walk, with and without ground poles and resistance bands. (LD = longissimus dorsi, RA = rectus abdominus).

	No Poles		**Poles**		**Poles Vs. No Poles**	**Resistance bands Vs. No Resistance bands**
	No Resistance Bands	**Resistance Bands**	**No Resistance Bands**	**Resistance Bands**		
ARV	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**p-vales effect size (η_p^2)**	**p-vales effect size (η_p^2)**
Left LD	0.074 (0.029)	0.066 (0.024)	0.084 (0.031)	0.072 (0.031)	p = 0.087 (0.474)	p = 0.138 (0.384)
Right LD *	0.048 (0.022)	0.042 (0.019)	0.061 (0.024)	0.050 (0.020)	p = 0.008 (0.785)	p = 0.058 (0.545)
Left RA *	0.012 (0.009)	0.015 (0.009)	0.024 (0.009)	0.025 (0.010)	p = 0.004 (0.838)	p = 0.336 (0.184)
Right RA *	0.017 (0.009)	0.019 (0.009)	0.029 (0.010)	0.030 (0.012)	p = 0.001 (0.911)	p = 0.576 (0.067)
Maximum Low pass	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**p-vales effect size (η_p^2)**	**p-vales effect size (η_p^2)**
Left LD *	0.150 (0.072)	0.132 (0.047)	0.227 (0.151)	0.153 (0.067)	p = 0.045 (0.587)	p = 0.212 (0.291)
Right LD *	0.071 (0.027)	0.061 (0.027)	0.098 (0.036)	0.086 (0.036)	p = 0.005 (0.820)	p = 0.060 (0.542)
Left RA *	0.091 (0.080)	0.134 (0.100)	0.201 (0.094)	0.222 (0.102)	p = 0.019 (0.698)	p = 0.103 (0.442)
Right RA *	0.072 (0.042)	0.090 (0.051)	0.178 (0.081)	0.185 (0.112)	p = 0.015 (0.723)	p = 0.541 (0.079)

Significant difference between poles vs. no poles (*).

Table 2: Post-Hoc pairwise comparison of of sEMG average rectified values (ARV) and maximum low pass signals of 6 horses at a walk with poles vs. no poles. (LD = longissimus dorsi, RA = rectus abdominus).

	Mean Difference (SE)	**p-value**	**95% CI Interval for the mean difference**
ARV			
Left LD	0.008 (0.004)	0.087	-0.002 to 0.018
Right LD *	0.011 (0.002)	0.008	0.004 to 0.017
Left RA *	0.011 (0.002)	0.004	0.006 to 0.017

Right RA *	0.011 (0.002)	0.001	0.007 to 0.016
Maximum Low pass			
Left LD *	0.049 (0.018)	0.045	0.002 to 0.096
Right LD *	0.026 (0.005)	0.005	0.012 to 0.040
Left RA *	0.099 (0.029)	0.019	0.024 to 0.174
Right RA *	0.100 (0.028)	0.015	0.029 to 0.172

Significant at $p < 0.05$ (*).

Table 3: Post-Hoc pairwise comparison of of sEMG average rectified values (ARV) and maximum low pass signals of 6 horses at a walk with resistance bands vs. no resistance bands. (LD = longissimus dorsi, RA = rectus abdominus).

	Mean Difference (SE)	**p-value**	**95% CI Interval for the mean difference**
ARV			
Left LD	-0.010 (0.006)	0.138	-0.025 to 0.005
Right LD	-0.009 (0.003)	0.058	-0.018 to 0.000
Left RA	0.003 (0.002)	0.336	-0.004 to 0.009
Right RA	0.001 (0.002)	0.576	-0.005 to 0.007
Maximum Low pass			
Left LD	-0.046 (0.032)	0.212	-0.128 to 0.036
Right LD	-0.011 (0.005)	0.059	-0.023 to 0.001
Left RA	0.032 (0.016)	0.103	-0.009 to 0.072
Right RA	0.013 (0.019)	0.541	-0.037 to 0.062

Table 4: The normalized mean, standard deviation (SD), p-value, and partial eta squared (η_p^2) value of sEMG average rectified values (ARV) and maximum low pass signals in 6 horses across 15 strides at a trot, with and without ground poles and resistance bands. (LD = longissimus dorsi, RA = rectus abdominus).

	No Poles		**Poles**		**Poles Vs. No Poles**	**Resistance bands Vs. No Resistance bands**
	No Resistance Bands	**Resistance Bands**	**No Resistance Bands**	**Resistance Bands**		
ARV	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**p-vales effect size (η_p^2)**	**p-vales effect size (η_p^2)**
Left LD	0.070 (0.028)	0.055 (0.033)	0.084 (0.051)	0.064 (0.042)	p = 0.142 (0.377)	p = 0.170 (0.339)
Right LD	0.047 (0.023)	0.040 (0.024)	0.061 (0.032)	0.059 (0.028)	p = 0.094 (0.460)	p = 0.200 (0.304)
Left RA †	0.037 (0.016)	0.047 (0.013)	0.059 (0.018)	0.065 (0.024)	p = 0.60 (0.538)	p = 0.022 (0.681)
Right RA	0.033 (0.011)	0.042 (0.010)	0.057 (0.021)	0.053 (0.014)	p = 0.72 (0.507)	p = 0.619 (0.053)
Maximum Low pass	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**p-vales effect size (η_p^2)**	**p-vales effect size (η_p^2)**
Left LD	0.297 (0.096)	0.236 (0.134)	0.312 (0.203)	0.233 (0.154)	p = 0.853 (0.008)	p = 0.167 (0.343)
Right LD	0.275 (0.197)	0.193 (0.159)	0.241 (0.193)	0.227 (0.154)	p = 0.997 (0.000)	p = 0.264 (0.240)
Left RA *	0.210 (0.113)	0.241 (0.069)	0.317 (0.111)	0.343 (0.089)	p = 0.013 (0.742)	p = 0.114 (0.423)
Right RA *	0.195 (0.078)	0.256 (0.063)	0.312 (0.124)	0.296 (0.083)	p = 0.013 (0.741)	p = 0.238 (0.264)

Significant difference between poles vs. no poles (*). Significant difference between resistance bands and no resistance bands (†).

Table 5: Post-Hoc pairwise comparison of of sEMG average rectified values (ARV) and maximum low pass signals of 6 horses at a trot with poles vs. no poles. (LD = longissimus dorsi, RA = rectus abdominus).

	Mean Difference (SE)	**p-value**	**95% CI Interval for the mean difference**
ARV			
Left LD	0.012 (0.007)	0.142	-0.006 to 0.029
Right LD	0.016 (0.008)	0.094	-0.004 to 0.037
Left RA	0.020 (0.008)	0.060	-0.001 to 0.041
Right RA	0.018 (0.008)	0.072	-0.002 to 0.038
Maximum Low pass			
Left LD	0.006 (0.032)	0.853	-0.075 to 0.088
Right LD	0.000 (0.039)	0.997	-0.100 to 0.100
Left RA *	0.105 (0.028)	0.013	0.034 to 0.176
Right RA *	0.079 (0.021)	0.013	0.025 to 0.132

Significant at $p < 0.05$ (*).

Table 6: Post-Hoc pairwise comparison of of sEMG average rectified values (ARV) and maximum low pass signals of 6 horses at a trot with resistance bands vs. no resistance bands.

	Mean Difference (SE)	**p-value**	**95% CI Interval for the mean difference**
ARV			
Left LD	-0.018 (0.011)	0.170	-0.046 to 0.011
Right LD	-0.005 (0.003)	0.200	-0.013 to 0.004
Left RA †	0.008 (0.0032)	0.022	0.002 to 0.015
Right RA	0.002 (0.004)	0.619	-0.009 to 0.014
Maximum Low pass			
Left LD	-0.070 (0.043)	0.167	-0.182 to 0.042
Right LD	-0.048 (0.038)	0.264	-0.146 to 0.050
Left RA	0.029 (0.015)	0.114	-0.010 to 0.068
Right RA	0.022 (0.017)	0.238	-0.021 to 0.065

Significant at $p < 0.05$ (†).

4. Discussion

sEMG is a useful technique for investigating function of the neuromuscular system in horses [27-28,31-32]. To characterize changes in the neuromuscular response with therapeutic interventions, this study reported two variables across filtered sEMG data including the average rectified value (ARV) and the maximum value from the low pass signal. The ARV is a measure suggesting average "work done" over a specified time interval and was calculated as the mean value of the full wave rectified sEMG signal over one complete gait cycle [27-30]. The maximum low pass value represents peak activity, which was also examined as some therapeutic interventions may result in brief contractions with a high peak of activity, versus longer sustained contractions with a low peak of activity [34]. To document which changes are occurring with the use of ground poles or resistance bands, both values were reported for the muscles investigated. To facilitate comparative analysis of muscle activity using sEMG, a maximal reference voluntary contraction (RVC) is employed for normalization. In humans, a maximum voluntary contraction (MVC) is used as a 100% effort measure, which can be compared to subsequent muscle activations across conditions or activities for that individual. However, it is recommended to use a RVC as a pseudoreference state for comparative analysis in cases when a MVCs is difficult or impossible to obtain, such as in animals or in humans with pain or neurologic disorders [27-28].

In this study, the LD muscle was examined given its role as one of the major spinal stabilizing muscles in horses with reported functions of spinal extension and providing lateral stability [6,13-17]. When walking over ground poles compared to without, there was a significant increase in the maximum low pass value in both left and right LD muscles correlating to larger peaks of activation. These increased peaks of LD activity may be correlated with stabilization of the axial skeleton in response to perturbations of the horse's balance as the swing limbs are raised over the ground pole obstacles [10]. With no change in withers or croup height identified with ground poles, the LD muscle is not needed for an increased suspension phase as seen with jumping, but instead may be stabilizing the axial skeleton given the increased flexions of forelimbs and hindlimbs and resulting rotation of the trunk [5,25-26]. This increase in maximum low pass value was not seen with ground poles at a trot. Previous reports have documented a linear increase in LD activity with speed, to oppose inertial forces of the visceral mass which increase with speed [13]. Therefore, it is possible that the absence of a significant increase in peak low pass sEMG activity of the LD at a trot over poles may have been related to the relative increase in baseline peak sEMG activity at a trot without poles.

There was additionally an increase in the ARV of both the left and right LD muscles by 13.5% and 27% respectively when walking over poles compared to without poles, suggesting a greater average work done across each stride, however this was only statistically significant in the right LD muscle. Previous sEMG studies have documented bilateral contraction of the longissimus dorsi muscle during thoracolumbar extension when traveling in a straight line, and with increased sEMG intensity of the inside LD muscle when traveling in a circle or lateral bending [13-16]. Lateral biases have been documented in the LD during static flexion and extension, which may be due to multiple factors including individual horse's laterality preference or handedness [13,15]. While training factors have also been postulated to be a factor for differences in muscle activation on either side of the body, this is less likely the case in the included population of untrained pasture-rested horses [13]. At a trot there was also an increase in the mean ARV in both the left and right LD muscles by 20.0% and 29.8% respectively with ground poles compared to without poles, however this did not reach statistical significance in either muscle. Further research combining surface electromyographic activity with motion capture or inertial measurement unit (IMU) sensors throughout data collection would enable characterization of the timing of induced changes in muscle activation with poles relative to phases in the gait cycle. For example, with an increase in the sEMG activity with ground poles, it could be further documented if this increase in muscle activation is occurring during forelimb and hindlimb protraction to offset axial rotation of the spine, or possibly during late swing phase for spinal stabilization during hindlimb retraction.

The core abdominal musculature is also important for providing spinal stiffness, maintaining balance and posture, and for controlling the body's angular momentum when maneuvering over obstacles [9-10,13,37]. Increased maximal activation of the rectus abdominus has been previously reported in three of six horses trotting over ground and raised poles compared to working on the flat, while mean workload was reportedly unchanged [11]. In this study both the left and right RA muscles had a significant increase in maximum low pass value of the sEMG signal with the presence of ground poles in both the trot and walk. This suggests that at both gaits, the RA bilaterally is having larger peaks of electrical activity, corresponding with a greater core abdominal muscular response with the presence of ground poles. Additionally, at a walk, the right and left RA had a significant increase in the ARV with the presence of ground poles, which suggests greater average work done across each stride. However, an increase in the ARV was not seen at a trot over ground poles, which fits with previously reported data where no change in mean workload was found [11].

The use of elastic resistance bands as a proprioceptive training tool were also of interest in this study. They are used as a training aid to improve horse posture and core strength for injury prevention and for improving performance of sport horses [1,3,6,38]. Engagement of hindquarter and abdominal musculature is thought to improve dynamic stability of the back and pelvis through core postural muscle development [22,26,33]. After a 4-week training program using an elastic resistance band system, several significant kinematic effects were found. This included a reduction in withers roll, withers pitch, and a reduction in thoracolumbar mediolateral movement, consistent with improved dynamic stability of the vertebral column [3]. To further investigate the kinematic changes induced by the elastic resistance bands, this study aimed to characterize baseline sEMG activity of selected epaxial and abdominal muscles. At a trot, both the left and right RA muscles demonstrated a respective 27% and 27.2% increase in the mean ARV signal in the group with resistance bands compared to without, however this only reached statistical significance in the left RA. This indicates a significant increase in the average work done by the left RA across each stride at a trot with the presence of the elastic resistance bands. At a walk with elastic resistance bands, the observed increase in the ARV signal and maximum low pass values of both the left and right RA muscles compared to without elastic resistance bands did not reach statistical significance. It is possible that with a larger sample size, a significant change in RA activity may have been obtained in the right RA at a trot. As discussed with the LD muscle over ground poles, lateral biases have been identified in certain paired muscle groups and can be due to factors such as training, acquired pathologies, handedness or laterality preference, or due to specific muscle function [27].

The other observation with the use of elastic resistance bands was a reduction in the mean ARV of the left and right LD muscles at a walk and trot, as well as a reduction in the maximum low pass value of the left and right LD muscles at a walk. Further research is needed to document the possible statistical significance of this reduced LD activation with elastic resistance bands. The activity of the LD muscles have been investigated with the use of side reins and the Pessoa system, which are other training aids used in horses that aim to develop the epaxial muscles and increase stabilization of the back [6,38]. The sEMG intensity of the LD muscles were not increased by the training aids but were the greatest for the control conditions at the walk and trot [6]. Theories for altered LD activity with the use of training aids include a reduction in spinal extension, increased spinal stability with the presence of the training aid, or increased eccentric versus concentric activity of the LD [25,27]. Further investigation is needed to better characterize these observed changes in LD activity.

One of the limitations of this study was that the electromyographic activity could not be directly or objectively correlated to distinct phases of the gait cycle, given the absence of objectively defined gait events. The use of a 3D motion capture system in this study was limited to checking the firing sequences of the observed muscles with known gait events to provide a confirmation of the phasic activation patterns across the gait cycle. This validation of the activation pattern of the LD and RA muscles within the gait cycle increased confidence in the subjective stride selection technique based on toe-off events from video capture and the subsequent marking of muscle onsets and offsets within the isolated strides. Motion capture was not available for use during data collection with application of elastic resistance bands and over poles. While sEMG activity was able to be compared across activations within a consistent number of strides, the absence of motion capture or inertial measurement unit sensors (IMUs) throughout the data collection limited more detailed analysis regarding the timing of muscle activations during the gait cycle.

Another limitation for the current investigation was the small population of available horses. Available horses were also of different breeds and signalments, leading to a small diverse sample population. While two horses used in this study were crossed with gaited horse breeds (Tennessee Walking Horse, Saddlebred), both individuals performed a diagonal two-beat trot for data collection, and any strides of irregular gaiting identified live or on video capture were excluded from the analysis. Utilizing horses of different breeds and body types may increase intersubject variance due to factors such as differences in muscle fiber, skin thickness, depth of subcutaneous fat, or distribution of sweat glands and sweat production [27]. Additionally, this study involved a healthy population of horses, and these findings cannot be extrapolated to horses with pathology, such as back pain or lameness. While horses were screened for lameness at the onset of the study, all sample subjects were administered a low-dose non-steroidal anti-inflammatory drug (phenylbutazone, 2.2mg/kg, once daily) throughout the data collection period to prevent exercise-induced muscle soreness, given that subjects were not maintained in routine exercise. Fitness, level of training, and fatigue are important variables to consider as they can influence adaptations in muscle tissue (fiber hypertrophy, remodeling of fiber type, improvements in timing or firing synchronization, etc.) which can influence the resulting sEMG signal [27]. All subjects were of a similar baseline level of fitness, as they were all housed in pasture with no forced or routine exercise.

For consistency of data collection, exercise protocols were completed in the same order, and with an hour break between conditions without resistance bands and with resistance bands. Given the relatively light work at a walk and trot and the hour break half way through data collection, it is unlikely that muscle fatigue was a relevant factor during data collection for this study, and therefore randomization of the study conditions should have minimally affected the sEMG results. Additionally, it has been documented that increasing speed of gait can increase muscle recruitment in the horse [13,27]. Some studies measure and account for this with use of an accelerometer. Although we appreciate that using speed as a covariate may allow for some variability, we did not record or regulate speed, and used similar methods to other studies using the horse's preferred speed [28,39]. An additional factor involved with the analysis of the therapeutic exercise conditions was testing both elastic resistance bands and ground poles simultaneously to investigate if both training tools had an additive effect in influencing muscle activation. With use of the 2x2 repeated measures ANOVA, we tested for interactions between ground poles and elastic resistance bands. However, no significant interactions were identified, therefore it can be concluded that the effects of one therapeutic strategy did not influence the effects of the other in this study.

For future study, repeating sEMG measurements over ground poles and with elastic resistance bands with a motion capture system would enable investigation of the timing of the muscle activation relative to known gait events within the gait cycle, in addition to better characterizing changes in muscle recruitment patterns, or types of activity such as concentric versus eccentric types of muscle contractions. Additionally, the combined use of a motion capture system would also allow for evaluation of kinematic changes occurring with various therapeutic conditions applied, such as changes in stride length, posture, or joint characteristics. Some other considerations include the amount of tension applied to the elastic resistance bands, as the physiological influence may change according to alterations in tension, or stored and released energy in the elastic resistance bands. While 25% stretch was used in this study, earlier research investigated elastic resistance bands under 30% stretch, and up to 50% stretch is recommended by manufacturers of an elastic resistance band system (Equicore Concepts LLC, East Lansing, Michigan, USA) [3]. Another consideration is the incorporation of a training period as the horse's posture, spinal stability, muscle activation patterns, and possible "learned" neuromuscular responses may alter with training. Clinically, it would be interesting to evaluate horses with the elastic resistance bands applied with different amounts of tension, and to watch for kinematic and electromyographic changes across a several week training period. Additionally, looking at horses of similar breed, discipline, or training level would lead to a more uniform sample population. After further documentation of the effects of certain therapeutic strategies in normal horses, this information could be applied to horses with lameness or certain pathologies, such as back pain, lumbosacral or sacroiliac restriction, or disuse atrophy.

In conclusion, the use of ground poles resulted in a significant increase in sEMG activity in the RA muscles bilaterally at a walk and trot. Additionally, a significant increase in the sEMG activity of the LD muscles bilaterally was seen with ground poles at the walk. This shows that the incorporation of ground poles in a rehabilitation program is expected to increase core abdominal activation and epaxial muscle recruitment. The use of elastic resistance bands at 25% stretch demonstrated a significant increase in sEMG activity in the left RA muscle at the trot. Results from this study require further investigation to better understand the effects of elastic resistance bands on muscle activation, particularly with reference to the type of muscle activation, the stages of the gait cycle, at different degrees of stretch, and the effect of a training period.

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Author Contributions

Karen Shaw: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project Administration, Resources, Software, Validation, Writing Original Draft, Review, Editing. ***Tena Ursini:*** Conceptualization, Data curation, Investigation, Methodology, Project Administration, Validation, Review, Editing. ***David Levine:*** Conceptualization, Formal Analysis, Methodology, Resources, Review, Editing. ***Jim Richards:*** Conceptualization, Formal Analysis, Methodology, Software, Validation, Visualization, Review, Editing. ***Steve Adair:*** Conceptualization, Investigation, Resources, Visualization, Methodology, Review, Editing.

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