Equine Rehabilitation: A Review of Trunk and Hind Limb Muscle Activity and Exercise Selection

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Abstract

Exercise therapy is a key component in rehabilitation in both human and equine physiotherapy, however in relation to the equine athlete only limited evidence is available for the use of exercises in rehabilitation. The aim of this review is to analyse studies that have evaluated trunk and hindlimb muscle activation and therefore provide an evidence base for the selection of exercises. Isolating activity to specific muscle groups or positioning to preferentially activate specific muscles is challenging for physiotherapists in horses, however surface electromyography (EMG) data of muscular activity during locomotion could be applied to support selection of rehabilitation exercises employed for this goal. The literature consistently reports the positive effect of increasing speed and slope on activity of longissimus dorsi, gluteus medius, tensor fascia latae, biceps femoris, vastus lateralis and the abdominal muscles. However, there is still a lack of investigation into muscular activity during movements used for rehabilitation, despite exercises using training aids, poles and stretches being reported as therapeutic and strengthening. The use of EMG within the current studies does suggest relative patterns of muscle activity may be useful in comparing activity of one exercise to another and are worthy of further investigation in relation to rehabilitation exercise.

Keywords: horse, exercise, physiotherapy, rehabilitation, muscle, electromyography

1.0 Introduction

Exercise therapy is a key component in rehabilitation in both human and equine physiotherapy, however in relation to the equine athlete only limited evidence is available for the use of exercises in rehabilitation. Commonly, musculoskeletal pathologies in the horse, for instance those in the hindquarters or the thoracolumbar spine, are managed post medical or surgical intervention with a protocol that is based on clinical experience of the physiotherapist implementing the exercises. Anecdotally certain pathologies in the horse have clinical signs of local muscle wastage reported, for instance atrophy of the thoracolumbar epaxial muscles has been noted in the presence of overriding dorsal spinous processes (DSP), 'kissing spines' [1] and in the presences of thoracolumbar pain [2]. The presence of muscle pathology supports physiotherapist involvement in equine rehabilitation regimes. Sacro-iliac joint (SIJ) region pain is another example of a condition that contributes to poor performance and/or lameness in horses [3]. Atrophy of the gluteus medius muscle (GM) overlying the lumbar region and the ilial wing is referred to as a clinical sign of SIJ region pain [4] and muscle bulk changes are thought to be asymmetric due to the presence of asymmetric pathology. Clinical examination of 296 horses with sacroiliac region pain, found 28% had concurrent poor thoracolumbar musculature, which was reported to occur quickly within a few weeks of initial injury [4]. Back pain has also been reported to alter spinal kinematics [5] which is also likely due to a functional change in muscle activation which will require treatment to promote normal function.

Reduced strength and poor muscle endurance has been linked to a higher incidence of lower back pain and to lower extremity injuries in humans [6], yet this relationship has not been investigated in horses to date. As muscle activity reduces there will be an associated reduction in muscle size, which will have an effect on strength and muscle activation, negatively influencing performance. One of the goals of rehabilitation following injuries such as these, is to restore normal muscle activation and therefore restore function to ultimately increase performance of both the local musculoskeletal region and the horse as a whole.

Electromyographic (EMG) studies with human subjects give physiotherapists strong supporting evidence for exercise prescription, for instance EMG activity of core trunk, hip and thigh muscles during nine specific exercises has been reported [6]. In relation to a pre-tested maximum voluntary isometric contraction (MVIC), data are presented to suggest which exercise can be used to target specific muscles. A clear example is the side-bridge exercise, which activated the GM greater than 45% MVIC, and lunge exercises which produced vastus medialus obliquus activation in the same range. These data are included in a systematic review where MVIC for GM and gluteus maximus are collated for 19 and 20 different exercises respectively [7]. The MVIC levels required to effectively stimulate muscle strength gains have been investigated, concluding that 40 to 60% maximal neuromuscular activation is required to generate improvement [8].

MVIC cannot be measured in horses [9] therefore a measured EMG amplitude cannot be compared with maximal contraction to derive suggested levels of activation to result in strength gains, however EMG amplitude of one exercise compared with another, or the application of the MVC within an exercise can be used to contrast activity levels [10]. Anecdotally strength in horses is often subjectively determined by the ability to perform a required task and observed by looking at muscle size and left-right muscle symmetry. Isolating activity to specific muscle groups or positioning to preferentially activate specific muscles is challenging for physiotherapists in horses, however EMG data of muscular activity during locomotion could be applied to support selection of rehabilitation exercises employed for this goal [11].

Given the paucity of evidence which underpins equine physical therapy and rehabilitation exercise regimes, the aim of this review is to examine the evidence supporting selection of exercises for horses based on anatomical and biomechanical data as well as muscle recruitment patterns from surface electromyography studies.

To facilitate this a literature search was performed in Science Direct, Wiley Online databases and Google Scholar using the following keywords in various combinations: ‘equine’, ‘horse’, ‘rehabilitation’, ‘electromyography/EMG’, ‘muscle’, ‘longissimus dorsi’, gluteal/gluteus medius’, ‘hamstrings’, ‘biceps femoris’, ‘semitendinosus’, ‘semimembranosus’, ‘quadriceps’, ‘vastus lateralis’ and in date range 1990 - 2016. The titles and abstracts of the retrieved studies were analysed and those not relevant were discarded (i.e. those relating to quantitative EMG/nerve conduction, involving species other than the horse or involving only muscles not in the trunk and hindlimbs). The reference lists of the selected articles were searched for additional references, resulting in sixteen papers being included in the final analysis.

2.0 Recruitment of trunk and hind limb muscles based on EMG data

EMG data for the main trunk and hindquarter muscles is presented including general function of the muscle, function during different gaits, as well as function during different speeds and slopes. Where known, each section contains the effects of training on the muscle described.

2.1.1 Longissimus Dorsi

The longissimus dorsi (LD), the largest of the epaxial muscles, contracts bilaterally during thoracolumbar extension and ipsilaterally during lateral flexion, and therefore is considered the most important extensor of the back [12]. Surface electromyography has been used to investigate activity of LD during gait [13,14,15]. In walk each LD has one peak of maximum activity per stride which occurred during the stance phase of the ipsilateral hind limb [15] whereas in trot there were two maxima, the first related to the push-off of the ipsilateral hind limb and a second at push-off of the contralateral hind limb [14]. LD activity peaks between early or mid-swing phase and the end of the swing phase of the leading hind limb in canter [16] and the exact timing of LD activity varies along the length of the muscle [17].

LD activity increases linearly with speed and the reduction in flexion-extension range of movement [18], therefore in can be inferred that LD activity is required to stabilise the vertebral column against increased dynamic forces. LD activity can be also related to the kinematics of the stride, whereby in trot the suspension phase to the stride cycle will require increased muscular activity compared to the alternating periods of bipedal and tripedal support in walk [19]. LD activity during the stride effectively stiffens the spine, working eccentrically during thoracolumbar flexion and concentrically during thoracolumbar extension, onset and offset timing co-ordinated with abdominal muscle activity to oppose inertial forces of the visceral mass which increase with speed [13,18]. The activity of LD is also influenced by the horse walking and trotting on a slope, with later onset and offset, increased duration and intensity of activity noted on a slope of 6% compare with 0% [18]. This activity is suggested to be due to increased propulsion and energetic cost of travelling uphill. Extension of the intervertebral joints approximate the DSP [20] which is undesirable considering the frequent occurrence of impingement and overriding of the DSP in the horse [21]

The type of movement being performed will also affect LD recruitment. In horses walking a small circle EMG intensity of the inside LD was shown to be two to three times greater than the outer LD on a 15m diameter circle [22]. As circle diameter reduces it appears LD activity levels increase, with horses walking on a circle approximately 6m diameter recording inside LD activity five times greater than in the outside [23], therefore confirming the role of LD in lateral flexion.

In walk and trot, the unridden horse on a treadmill uses LD activity for stability rather than active back movement and it is postulated that the addition of the rider will increase extension [24], which may have an effect on the position of the DSPs [20]. The activity of LD in the ridden horse has not been reported although it could be suggested that the increase load in the thoracolumbar spine may have to be countered by increased activity of the muscles that flex the spine, such as the abdominals. However it could be hypothesised that if antagonist muscle activity was not effective at flexing the spine potentially approximation of the DSPs could have a deleterious effect on the thoracolumbar spine, increasing the risk of overriding DSP pathology.

LD activity with and without training aids has been investigated with EMG and the use of both side reins and pessoa training aid resulted in a lower level of LD activation, potentially due to the reduced stride length at walk and trot in the training aids compared to a free walk which had a longer stride length [22]. To date activity of the abdominals in a horse working with training aids has not been measured.

2.1.2 Abdominal Muscles

The abdominal muscles of the horse lie on the ventral aspect of the trunk and are arranged in four layers with the external abdominal oblique (EAO) and rectus abdominis (RA) most superficial. RA and EAO activity has been measured at walk and trot on a treadmill, using surface EMG [25]. Significant differences between the mean left and mean right muscle activities over the motion cycle at walk were seen in the six horses tested and in four of the six horses at trot. Between walk and trot muscle activity significant differences were found for EAO activity in all horses and for RA in 5 of the 6 horses. The authors presumed that the activity pattern of EAO and RA would be correlated to the gait of the horse although it appears that the activity of EAO can also be linked to the recruitment of the muscle associated with expiration [25]. Studies at canter, where breathing and motion cycles are coupled, would help further to investigate the recruitment of the EAO during gait. In walk and trot, RA was active on both sides simultaneously indicating that RA counteracts ventral spinal extension during the phase of the stride when the foot is in contact with the ground. An earlier study showed that overall RA percentage activity increased with speed as well as demonstrating a linear relationship between RA EMG activity and exercise on an increased slope from 0 to 6% [18]. Alongside LD, RA may be acting to provide greater spinal stiffness with increasing speeds which also may account for the increased EMG activity found [13,18] therefore to progressively recruit EAO and RA working the horse at trot and on an inline would facilitate more activity compared to walk and work on a level surface.

2.1.3 Gluteus Medius

The gluteal muscles of the horse, gluteus superficialis (GSP) and GM function to extend and abduct the hip joint. In trot GM is active during the second part of the swing phase [26], presumably to decelerate the limb in preparation for stance and during the first part of stance phase, retracting and stabilising the hind limb and during the second part of stance it contributes to propulsion [13]. In a study of seven mixed breed horses investigating pelvic limb anatomy, GM was the heaviest muscle in the gluteal region and estimated to be able to generate the highest force (therefore propulsion) based on its physiological cross section area (PCSA) [27]. In both Quarter horses and Arabs, GM was also found to have the largest mass and the greatest potential for isometric force production compared with other muscles in the hind limb although an interesting point to note was that GM in the Quarter Horse had greater muscle mass and PCSA than in Arabs of similar height and body mass. These features, which would increase the potential for acceleration of the horse's body mass, may be a result of both training and genetic predisposition [28]. Due to the size of GM and its potential for force production in the un-injured horse, any atrophy of this muscle would therefore have consequences to strength and function in relation to hip extension and to a lesser extent the secondary function of the muscle to abduct the hip. As GM overlies the ilium and the lumbar spine, altered activity would potentially reduce the performance of the horse if normal function of these regions is compromised.

Gradient and speed have been shown to influence gluteal muscle recruitment and activity [26,29]. A study investigating hind limb muscle activity concluded that an increase in treadmill speed and gradient increased the mean intensity of GM activity when measured by EMG in six adult welsh mountain ponies [29]. GM EMG intensity increased when walking on a 10% incline compared to horizontal locomotion. Trot also increased GM EMG activity; horses trotting on a horizontal treadmill at 2.6 to 3.0 m/s resulted in greater intensity of EMG signal compared with walking at 1.4 to 3.0 m/s. Therefore to progressively recruit GM, based on these findings, sequentially increasing from a walk to trot on the horizontal and then walking up a gradient progressing to trotting up the same gradient, will have the effect of increasing muscle activity in the horse. GM activity has been reported to increase linearly with speed (3.5 – 6m/s) and with increases 3% and 6% compared to horizontal for four riding school horses [26]. However walking on a 10% decline reduced GM EMG intensity even in relation to horizontal locomotion [29], therefore downhill slopes as part of a rehabilitation programme would not be advised to recruit GM. It should also be noted that with increasing speed of canter, there is increased flexion – extension at the lumbosacral joint [30]. This may require an alteration to GM activity although direct comparison, using EMG, of trot and canter, has not been made. With increasing speed, the flexion-extension movement of the back are reduced to increase spinal stiffness and it could be postulated that there would be greater activity of GM. However how speed effects the muscles overlying the lumbosacral region is an area for further study

2.1.4 Biceps Femoris

Biceps femoris (BF) is the most lateral of the three muscles that are part of the hamstring muscle group, with a mass second in size to GM [27,28]. The function of the BF is multifaceted. During stance the BF extends and abducts the hip and during the swing phase of the stride it acts to flex the stifle and extend the hock. The estimated force created by BF, based on calculation of PCSA, is approximately 75% that of GM [27,28], however when the data for the three portions of the hamstrings are combined the total force is 140% of GM [27]. Given BF main function as a hip extensor, this would suggest it is capable of creating a large amount of propulsive force that accelerates the body forwards.

Activity of BF when measured by EMG demonstrated increased mean intensity with velocity increasing from 1.4 to 3.0m/s and has also been shown to increase at walk and trot on a treadmill with 10% incline. In contrast GM and BF activity decreased when walking on a 10% decline with GM activity also reduced on the decline in trot when compared to horizontal which is suggested to be due to the passive nature of hip retraction on a downhill slope [29]. The BF reduction at trot was not significant and this may be due to the muscular activity required to eccentrically slow the rate of descent. BF activity measured on native ponies [29] has been repeated in thoroughbreds walking (1.6m/s) and trotting (3.5m/s) on a treadmill with five gradients (-6%, -3%, 0%, +3%, +6%) with similar increases in activity associated with increased incline and speed, and reduced GM and BF activity on the declined treadmill [31]. The recorded activity of BF is however dependant on the location of the EMG electrodes, due to the anatomy of the muscle and the activity of different portions of the muscle throughout the entire stride cycle [16]. To support selection of exercises to preferentially recruit BF more data are needed on the differences between activity in the different portions of the muscle. Consideration must also be given to the anatomical location of both GM and BF in the hindquarters which potentially could lead them to contribute to abduction of the hindlimb. Therefore an understanding of role of these muscles in turning and on circles would further assist in prescription of rehabilitation exercises.

2.1.5 Tensor Fascia Lata

The tensor fascia lata (TFL) flexes the hip and extend the stifle, with a small muscle volume relative to the proximal hind limb muscles due to substantial elastic portions, although the aponeurosis is estimated as being relatively stiff [27]. Activity of TFL begins in the middle of the stance phase and ceases in the early portion of the swing phase during walk and trot [16,26] to stabilise the stifle joint by tightening up the fascia lata around the joint. The functional role of TFL is highlighted when speed increases as mean activity and the duration of the activity during the stride increases and although activity increases with slope, TFL is less influence by the slope than GM [26].

2.1.6 Quadriceps muscle group

The quadriceps group of muscles comprises the rectus femoris, vastus medius, vastus intermedius and vastus lateralis (VL). The VL portion, which acts with an antigravity function [29] as a stifle extensor in combination vastus medius and intermedius, has been investigated in more detail via EMG due to its lateral position in the hindlimb. Volume and PSCA of VL is smaller than GM and BF [27,28] with its estimated force less than the more distal gastrocnemius, however it is only one portion of the quadriceps muscles which, in combination, create higher force [27]. VL activity, when measured with increased velocity on a slope, showed increase EMG intensity on inclined and declined treadmill (+10% and -10%) but not on the horizontal, however this is suggested to be due to force being produced by muscles other than VL at this point [29]. A subsequent study did not show any significant difference of VL activity on a 6% incline or decline compare with horizontal [31] which may show the level of slope is more significant than previously thought, suggesting that to activate VL during rehabilitation a slope of at least 10% would be desirable.

2.2 Muscle fibre type considerations

The prescription of exercises may also be based on the muscle fibre type (MFT) of the skeletal muscle undergoing rehabilitation and the muscle fibre profile of the individual horse. LD, GM, PM and BF are mainly MFT II suggesting a locomotory role compared to the deeper epaxial muscles that have a higher type I proportion and therefore a suggested primary postural stabilising role important in core spinal stability [32]. GM has a heterogeneous sample of muscle fibre types with superficial parts expressing type IIX compared with deeper portions with more type I which may reflect a preferential dynamic role superficially with a postural function more proximally [33]. Knowledge of MFT as well as and understanding the physiological demand of the exercise in relation to aerobic or anaerobic energy pathways could aid the exercise selected and the amount, speed and resistance of the exercises used. However more work needs to be undertaken on normal horses before being able to use these principles to underpin exercise selection for rehabilitative purposes.

2.3 Limitations of EMG

Intrinsic electrical interference from adjacent muscles may be present in the EMG signal and should be avoided [34,35]. The interference, known as cross-talk, occurs due to overlapping action potentials from multiple muscles or motor units, falling within an electrode's pickup zone [36]. Good experimental design should help to eliminate interference.

Surface electrodes provide a less invasive method and automatically record longer duration motor unit action potentials due to their increased surface area compared to indwelling electrodes, but by their nature will not record activity beyond the superficial layers of muscle [37,38]. In the horse it appears that fibres in the superficial compartment of skeletal muscles are organised to facilitate short duration, rapid propulsive force production supported by a predominance of type IIA and IIX fibres, whilst the deeper compartment contains fibres which support longer duration, lower intensity activities such as postural support and constitute mainly type I fibres [32,39]. Therefore the use of surface EMG sensors could potentially create a bias for data to represent superficial fast twitch fibre activity rather than characterise total muscle activity, which should be considered in their interpretation.

2.4 Selection of exercises

The main aim of rehabilitation is to return the horse to its previous level of performance [40] and exercises are used to progressively improve proprioception, neuromuscular control and to load and strengthen musculoskeletal tissues. For muscular hypertrophy to occur exercise sessions must lead to fatigue and mild cellular damage, resulting in a short term adaptive response. This increased level of stress needs to continue throughout a training programme by increasing the loading - the 'overload principle', which when appropriately managed should lead to performance improvement [41]. However based on the amount of information available for exercises in horses, the level of exercise and therefore required loading on the muscular tissues is anecdotal at best.

The literature consistently reports the positive effect of increasing speed and slope on activity of LD, GM, TFL, BF, VL and the abdominal muscles [13-18,25,29,31] and this information can be taken forward when selecting exercises to recruit specific muscles. However caution should be exercised when attempting to compare muscle activity measured via EMG trials, as the data were obtained from different breeds of horse, laboratories and using different EMG equipment. Despite this the evidence base does support the following general principles. Overall LD activity is increased with increased speed [12,15,29,18], LD activity increases on an increasing slope [18,31] as well as ipsilaterally on a decreasing circle size [22,23] and GM activity also increases with speed and on an incline [18,29,31]. BF activity is increases with increasing slope [29,31] and VL activity increased on a 10% slope [29] but not on a 6% slope [31].

Initially exercises in straight lines and on a horizontal plane are often indicated in equine rehabilitation regimes, the exercise prescription will then often progress to include lunging on a circle. Currently, there is no information on how GM, BF, TFL or VL activate when the horse in on a circle. Asymmetric recruitment can be presumed due to the asymmetry of the gait when turning [42] however whether the muscles on the inside are active for longer during the stride cycle or have a higher mean activity compared with the outside has not been investigated. During rehabilitation circular locomotion is suggested to be beneficial [22] as well as the use of training aids [43] yet as the precise effect of circular exercise on the locomotory muscles is unknown, the choice of circle size, gait and speed has to be pragmatic based on type and severity of injury as well as the goal of rehabilitation.

To progressively recruit musculature there is evidence supporting use of inclines and increased speed. It should be noted that on the incline peak forces are greater in the hindlimb compared with on the level and a shift of weight distribution is seen from a forelimb/hindlimb ratio of 57%/43% to 52%/48% [44]. Therefore consideration must be taken when prescribing exercise to increasing speed as there will be an increased ground reaction force which may require limitation if the rehabilitation is being conducted in the presence of a pathology, such as a tendon or bone injury that may be aggravated by this factor. No studies have evaluated the effect of a slope greater than 10%, therefore it should not be assumed that any benefits of a low slope correlate with the effects of increased gradient.

It is worthy to note that all the EMG data reported have been collected on un-injured horses, free from back pain and therefore further consideration must be given to muscle recruitment in horses that present with pain or unilateral injury. Neuromuscular control may be altered due to a primary muscle pathology, such as a muscle strain, or as a compensatory effect secondary to a distal injury. This consequence been demonstrated when comparing muscle activity of lame and nonlame horses where activity of GM and BF was increased during the ipsilateral stance phase in the nonlame limb in walk [45], to unload the lame limb. If this altered activity persists during rehabilitation of a horse with lameness this may result in increased incidence of muscle pain due to overuse. To prevent this undesired outcome of exercising lame horses this area requires more investigation to fully support implementation of further activities such as circles, slopes and specific gaits in rehabilitation protocols.

Whilst the kinematics of exercises often prescribed in rehabilitation have been studied, such as the use of ground poles [46,47], circles [42], the Pessoa lunge aid [22,43], baited stretches [48,49], tactile facilitation and weights added to the hindlimbs [50,51] and also the effect on muscle cross sectional area [52-4] there is still a lack of investigation into muscular activity during these movements. This is despite these types of activities being reported as therapeutic and strengthening exercises [54,55]. Inverse dynamic analysis has been used as an indirect method of assessing changes in activity of specific groups of muscles. Tactile facilitation of the pastern and coronet in the hindlimb increased net energy generation at the tarsal joint and therefore work by the tarsal flexor musculature and the addition of weights to the hindlimb pasterns increased energy generation at the hip by the hip flexors [51]. Inverse dynamic analysis does not indicate the exact muscles that are involved however the requirement for an increase in activity of the tarsal and hip flexors may promote selection of these exercises for rehabilitation. A summary of these activities and the evidence for their inclusion in equine therapeutic and rehabilitation regimes is presented in the supplementary material.

Treadmills have also been suggested to be beneficial during rehabilitation due to the control of variables such as speed, direction and incline as well as water depth in water treadmills, effecting biomechanical and physiological parameters [56,57]. However their use in general rehabilitation is limited due to cost and availability thereby strengthening the likelihood that the majority of rehabilitation would occur during exercise both in hand and ridden. In all exercise paradigms, treadmill or non-treadmill, the outcome of rehabilitation needs to be measured to evidence the use of the selected technique.

3.0 Conclusion

The aim of this review was to analyse studies that have evaluated trunk and hindlimb muscle activation and therefore provide an evidence base for the selection of exercises. This information can be adapted when implementing a rehabilitation programme which should complement that adapted from human literature. Despite obvious difficulties with comparing activity levels to MVIC or MVC the use of EMG does suggest relative patterns of muscle activity may be useful in comparing activity of one exercise to another. Further data would support the practitioner in exercise selection to rehabilitate horses post injury or supporting training programmes in horses with an underlying pathology. This would be a step forward in supporting evidence based practice within rehabilitation.

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