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Review

The horse–saddle–rider interaction

Line Greve, Sue Dyson *

Centre for Equine Studies, Animal Health Trust, Lanwades Park, Kentford, Newmarket, Suffolk CB8 7UU, UK

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ABSTRACT

Common causes of poor performance in horses include factors related to the horse, the rider and/or the saddle, and their interrelationships remain challenging to determine. Horse-related factors (such as thoracolumbar region pain and/or lameness), rider-related factors (such as crookedness, inability to ride in rhythm with the horse, inability to work the horse in a correct frame to improve core strength and muscular support of the thoracolumbar spine of the horse), and saddle-related factors (such as poor fit causing focal areas of increased pressure) may all contribute to poor performance to varying degrees.

Knowledge of the horse–saddle–rider interaction is limited. Traditionally, saddle fit has been evaluated in standing horses, but it is now possible to measure the force and pressure at the interface between the saddle and the horse dynamically. The purpose of this review is critically to discuss available evidence of the interaction between the horse, the rider and the saddle, highlighting not only what is known, but also what is not known.

Introduction

Back pain and dysfunction are common causes of poor performance in horses (Zimmerman et al., 2011a,b). One recent large-scale study of British dressage horses demonstrated that 25% had a history of back-related problems (Murray et al., 2010). Reasons may include primary thoracolumbar osseous pathology (Gillen et al., 2009; Girodroux et al., 2009; Meehan et al., 2009; Zimmerman et al., 2011a,b), or back muscle soreness developed secondarily to lameness, incorrect training, a poorly skilled rider, a saddle not fitting the horse and/or a saddle not fitting the rider. However, there is a lack of scientific data relating directly to riders. Both experimentally-induced forelimb or hindlimb lameness (Gómez Alvarez et al., 2007, 2008) and back pain/stiffness have been shown to alter the biomechanics of the spine and shift the centre of gravity (Wennerstrand et al., 2004, 2009). This may predispose to rider back pain or stiffness (Lagarde et al., 2005; Symes and Ellis, 2009) and abnormal saddle movement, such as saddle slip consistently to one side (Greve and Dyson, 2012). Saddle slip may induce focal areas of increased pressure beneath the saddle (deCocq et al., 2006).

Rider pain or stiffness may induce rider crookedness and can diminish the ability of the rider to follow the movement of the horse (Lagarde et al., 2005; Symes and Ellis, 2009). In turn, this may cause exacerbation of equine thoracolumbar region pain and/or lameness. Such a vicious circle may occur in many horses, making it clinically challenging to determine whether altered biomechanical function of the spine is caused by primary thoracolumbar region pain (Wennerstrand et al., 2004, 2009), sacroiliac joint region pain (Dyson and Murray, 2003; Dyson, 2008) or primary lameness (Landman et al., 2004; Gómez Alvarez et al., 2007, 2008), because the conditions often co-exist (Zimmerman et al., 2011b). However, to date, there is little quantitative biomechanical evidence linking lameness and function of the thoracolumbar region.

The purpose of this review is to discuss critically available evidence of the interaction between the horse, the rider and the saddle, highlighting not only what we do know, but also what we do not know.

Measurement technology

A variety of pressure mats which can be placed underneath or on top of saddles to measure applied force have been used historically, including the Saddle Tech (Harman, 1997) and FSA (Jeffcott et al., 1999; deCocq et al., 2006). There are two commercially available pressure mats in current scientific use, CONFORMat (Tekscan) and Pliance (NOVEL) but there have been no objective comparisons between the two mats. Nonetheless, bench testing to determine accuracy, hysteresis, repeatability, stability, creep, rate of loading, response and mat artefacts, environmental effects, calibration stability and contoured loading performance is important to ensure validity of data from any pressure mat (Nicholson et al., 2001).

Ideally, standardised testing should insure that the total force measured is within ±10% of a known applied force (Ferguson-Pell

* Corresponding author. Tel.: +44 1638 751908.
E-mail address: sue.dyson@aht.org.uk (S. Dyson).

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et al., 2001). The CONFORMat contains more sensing elements per unit area (0.5 sensels/cm^2) than the Pliance system (0.1 sensels/cm^2) and has a significantly higher sampling rate. The CONFORMat has resistive sensing elements, whereas the Pliance has capacitive sensing elements. There are advantages and disadvantages of the two types of sensing elements, which are discussed in-depth elsewhere (Ashruf, 2002). The CONFORMat is usually used with one sensor overlying the spinous processes; the pressure applied to the spinous processes can therefore be measured. However, stretching of the mat over the back may lead to erroneous readings. Tekscan also produce a mat with two sensors on each side of the back similar to the Pliance. Whichever mat is used, for consistent results of measurement of the forces applied to a horse's back, the mat should be left in place on the horse's back throughout measurements, the position of the mat should be marked on the horse's hair coat, the rider should mount from a high mounting block or via a 'leg-up', the girth should be tightened, one hole at a time, by alternating the right and left sides and daily calibration is essential (deCocq et al., 2006, 2009a; Belock et al., 2012).

The pressure data acquired is surrounded by a lot of 'noise', with considerable variations in the pressure patterns and, unless specific scientific questions are asked, there is a risk of subjective over-interpretation of the data (Holmes and Jeffcott, 2010). Each sensing element measures the peak pressure within the sensor, so they have a tendency to overestimate the force. The mat shapes to the contour of the body and registers the force-component applied perpendicular to its surface. The forces measured that act vertically on a sloping border is an underestimation of the true vertical force. In areas where the back contour comes close to vertical, such as the wither area, the underestimation is considerable. Thus, data collected will be influenced by the shape of the horse's back and the incident angle of the transmitted forces: the total measured force recorded for a rider on a horse with a narrow, sloping back may be less than that for a horse with a broad, flat back. The pressure data cannot distinguish between the effect of the rider, the saddle and the movements of the horse (Bystrom et al., 2009, 2010a,b). The resulting multidimensional data and analysis requires consideration of force magnitude, its spatial distribution and temporal changes (Belock et al., 2012). In some studies focal areas of pressure have been assessed using either the mean pressure value over the entire measurement period or the maximum pressure value; mean values were more repeatable (deCocq et al., 2006: von Peinen et al., 2010). The area over which the measurements were acquired has varied among studies, which may account for variability in results (Meschan et al., 2007; von Peinen et al., 2010).

Currently, data have mainly been presented by normalising a number of strides into one stride, usually compiling total force divided into six areas (left, right; cranial, middle and caudal) (Bystrom et al., 2009, 2010a,b), but although there are many possible variables it is not known which method gives the most valid and useful information. Nonetheless, these mats do provide an objective way of measuring either the force applied to a horse's back via the saddle or the force applied to a saddle by a rider. They also provide an objective way of assessing the stability of the rider's position in the saddle by calculating the excursion of the centre of pressure (Peham et al., 2010). There are descriptions of correlating pressure mat data with the phase in the stride cycle (Bystrom et al., 2010b, 2011). There is the potential to extract more data, such as quantifying peak pressures in space, time and magnitude; specialised analysis tools may be required to maximise the usefulness of the acquired data.

Traditionally, the gold standard method for collecting equine back kinematic data (Faber et al., 2001, 2002), limb movement data (Keegan, 2007), and rider movement data (Bystrom et al., 2009, 2010a) has been by the use of optical motion cameras. These measurements are best accomplished by using force-measuring treadmills and therefore the technology is principally restricted to gait laboratories (Buchner et al., 1994). Optical motion systems can also be used overground, but there are two major drawbacks of these systems for the study of horse–rider interaction. Firstly, the field of view is limited. This can be solved by using more cameras, but this is expensive. Secondly, it is not possible to study movement of parts of the body that are blocked from view and an important part of the back of the horse cannot be viewed directly because of the saddle. It is, however, possible to measure the movements in front and behind the saddle and to predict the movements beneath the saddle.

Several groups around the world are working on the development of body sensor-based objective movement examination systems, with wireless transmission of data. Inertial measurement units (IMUs) have recently been validated as a reliable and repeatable method to collect objective equine movement data (Keegan, 2007; Keegan et al., 2004, 2011; Pfau et al., 2005; Warner et al., 2010; Halling-Thomsen et al., 2010). Poll and croup mounted sensors have been used to objectively quantify forelimb and hindlimb lameness (Keegan et al., 2004). However, the IMUs can be mounted on any subject and therefore not only have potential for assessment of horse and rider movement outside gait laboratories, but also for the investigation of the biomechanical relationship between equine back movement and limb movement and the changes that occur with injury. By combining the use of back pressure measurements and IMUs mounted on the saddle, the rider and the horse, the measurement technology might provide the answers which will help increase our understanding of how back movement varies in normal or diseased horses and identify the key differences.

The saddle

Saddle design

The saddle must fit both the horse, whose shape is continually changing at different gaits, and the rider, enabling them to remain in balance at a variety of paces (Dyson, 2012). Coupling these two complex dynamic forms through the medium of a saddle is extremely challenging and the study of this is complex. Traditionally saddle designs were made by rote, lore, feel and experience. It is only relatively recently that technologies have become available that permit detailed study of this complex dynamic system.

Saddle designers traditionally started from a rigid frame (the tree) which, when well-fitted, can spread load, but cannot adapt to the changing shape of the horse's back as it moves. A variety of methods have been used to mitigate this problem (flocking, padding, air bags, flexible trees and others). More recently some saddle designers have introduced designs with no tree or vestiges of the tree (pommel arch or head plate, for example), which allow flexibility to adapt to the changing shape of the horse's back, but might be expected to spread load less well. Efforts to mitigate this problem include partial trees and stiffer flexible materials. Additional pads and numnahs are often used in an attempt to improve saddle function, but although the manufacturers make sweeping claims about reduced concussion and altered force distribution, these have not been validated by scientific studies and in some instances additional pads may actually be detrimental by increasing focal pressure (Kotschwar et al., 2010a,b).

So-called treeless saddles are flexible and are suggested to fit a wider range of back shapes than a conventional treed saddle, by providing an adaptable interface between the horse and the rider (Belock et al., 2012). However there are a number of different designs, several of which are not free of rigid parts, and are therefore not truly treeless saddles. Two studies concluded that the tested treeless saddles, one of which had a head plate (Latif et al., 2010), were more likely to concentrate the force on a localised area of the horse's back, underneath the rider's seat bones (Latif et al., 2010; Belock et al., 2011). However, these conclusions do not necessarily apply to other treeless saddles. Localised force concentration has also been observed in wide-treed conventional saddles (Meschan et al., 2007), and when horses are ridden bareback (Clayton et al., 2012). The most common saddle-fitting problem with full-treed saddles is bridging, where loading on the horse's back is concentrated in the cranial and caudal thirds of the saddle and the middle third is relatively unloaded. Bridging is often associated with a narrow tree (Harman, 1997; Meschan et al., 2007).

Saddle fit

Poor saddle fit has been associated with back pain in horses (Harman, 1999; Jeffcott et al., 1999), although there are limited studies that have addressed this scientifically (Werner et al., 2002; von Peinen et al., 2010; Medjell and Aksnes, 2012). However, to our knowledge, objective data addressing the potential consequences of the saddle not fitting the rider, or not allowing the rider to sit in a position in which they can ride in balance, have not been reported. The goal of fitting the saddle to the rider is to diminish crookedness and uncontrolled rider movements that disturb the balance and synchrony of the horse. Crooked riders sit and move asymmetrically (Symes and Ellis, 2009). This may result in training misunderstandings, because the signals from the rider to the horse are likely to be imprecise and inconsistent. It may also predispose to back pain in the horse and the rider due to asymmetric back muscle activation in the rider, potentially causing spinal instability (Al-Eisa et al., 2006), and asymmetric pressure applied to the horse's back.

A poorly fitting saddle may result in focal swelling, but can also cause abnormal pressure without swelling and result in increased forces at the bone muscle interface (Daniel et al., 1981; Le et al., 1984; von Peinen et al., 2010). It has previously been suggested that mean pressure values >11 kPa are likely to be detrimental (Nyikos et al., 2005; Mönkemöller et al., 2005; Meschan et al., 2007; Bystrom et al., 2010a,b). However, this threshold value is based on a small study of 26 horses with or without back pain (Nyikos et al., 2005). Case definitions were limited, and other factors that may affect the pressure distribution pattern such as hindlimb lameness (Bystrom et al., 2011; Greve and Dyson, 2012), rider crookedness (Lagarde et al., 2005; Symes and Ellis, 2009) and poorly fitting saddles (Meschan et al., 2007; Belock et al., 2012) were not assessed. Focal pressure in the cranial saddle region was compared in normal horses and horses with focal dry spots and muscle soreness, with or without swelling, during ridden exercise at walk, trot and canter (von Peinen et al., 2010). Mean pressure in control horses ranged from 7.8 kPa (walk) to 10.9 kPa (canter), whereas mean pressures in horse with clinical signs were more than twice those in control horses.

While a poorly fitting saddle may increase the total force applied to the back (Meschan et al., 2007) and result in focal areas of increased pressure (deCocq et al., 2006; von Peinen et al., 2010), it is also possible that it may cause an increased activity of the thoracolumbar epaxial muscles and result in an increased impact of the rider (C. Peham, personal communication). This supports a previous suggestion that excessive muscular activity is aggravated by nociception (Perl, 1976) and that increasing activity of the longissimus dorsi muscle in the second phase of the stance phase (Licka et al., 2004b) coincides with increased pressure values (Fruehwirth et al., 2004). An association between a poorly fitting saddle and epaxial muscle atrophy has been suggested (Werner et al., 2002).

Rider-related factors

Rider experience and position

An understanding of the principles of training and the skill of a rider will influence how a horse moves through its back and the interaction between the horse, the saddle and the rider (Peham et al., 2001; Lagarde et al., 2005). There has been limited investigation of kinetics, kinematics and forces applied to horses' backs in rising versus sitting trot (deCocq et al., 2009b, 2010a; Roepstorff et al., 2009), in two-point seats vs. three-point seats (Pfau et al., 2009; Peham et al., 2004, 2010) and in situations with different rider positions (deCocq et al., 2009a). Riders in two-point seats were more stable than in rising or sitting trot (Peham et al., 2010) and the uncoupled movement of horse and rider in two-point seats enabled the horse to go faster (Pfau et al., 2009). The total force remained unchanged between different rider positions in a standing horse wearing a rigid, full-tree saddle, although the force distribution increased towards the direction in which the rider was leaning (deCocq et al., 2009a). During locomotion the horse moves the rider up and down and forwards and backwards, the direction and amount depending on the gait, and the rider has to adjust their movement continually to accommodate the mechanical interaction with the horse. The aim is for motion, coordination, agility and balance of both the rider and horse to be in harmony (Meyners, 2004).

Skilled riders exhibit a fluid and flexible motion, absorbing the movements of the horse, whereas less skilled riders are stiff and tense in their adjustments and unable to follow the movement of the horse (Lagarde et al., 2005). Physical or postural asymmetry of a rider results in asymmetric distribution of force via the saddle to the horse. If recognised, this can be addressed by specific exercises tailored to the nature of the asymmetry (Meyners, 2004). Persistent crookedness of a rider could potentially, by physical or behavioural influence, cause asymmetry in horse locomotion, resulting in an established asymmetric locomotor pattern and/or secondary pain.

Riding and back pain

There is anecdotal information that riders suffer a high prevalence of back pain. How and to what extent this compromises their ability to ride symmetrically, in rhythm and harmony has not been documented, but clearly there is likely to be a significant effect. It has been suggested that the shape of the saddle may influence the incidence of rider back pain, with a Western-type saddle being protective compared with a conventional general purpose saddle (Quinn and Bird, 1996). However, the study design, which was questionnaire-based, did not take into account many other variable factors which may have influenced these results, such as rider skill, general musculoskeletal fitness, types of horses and their gait characteristics and the sports disciplines (e.g., dressage, show jumping, cross-country, pleasure riding, Western performance riding, etc.) and the level at which it was performed.

There also is anecdotal information that riding may be beneficial in the management of human back pain, which is extremely prevalent, perhaps because of the tendency for increased sitting in the population (Carlson, 2009). Further investigation is merited to determine whether riding, as a 'sitting sport', could possibly be a model for good sitting posture and be promoted as therapy for back pain.

Rider skills

Little is known about how riding skills are developed from novice to expert, but examination of lame horses ridden by riders with different skill level has shown that riders can alter the degree of lameness measured by the vertical movement of the head and croup (Licka et al., 2004a). Electromyographic recording of selected core-stabilising muscles of riders indicated that experienced riders had more muscle activity and were thus more stable in their postures compared with inexperienced riders (Terada, 2000). However, musculoskeletal fitness was not taken into account.

There is evidence that good riders maintain synchronisation with the horse (Peham et al., 2001; Lagarde et al., 2005; Clayton et al., 2011) and keep the horse in balance, working truly on the bit, in a correct frame (Peham et al., 2004). Long-term correct training may improve the core strength and muscular support of the thoracolumbar spine of the horse (Licka et al., 2009) and could potentially enable horses to cope despite lameness and/or back pain. However, skilled riders may be continually making subtle adjustments with the horse, which disguise problems so that back or lameness problems are insidiously progressive, and not recognised until the rider is changed to a less skilled rider, or until a major loss of performance is apparent. In contrast, poor riding may influence the functional thoracolumbar biomechanics negatively, causing hollowness of the back, loss of core strength, and may contribute to the development of thoracolumbar region pain (Zimmerman et al., 2011b).

Rider bodyweight

The magnitude of the forces applied to a horse's back increases with the rider bodyweight (BW) and with increased velocity (Jeffcott et al., 1999; deCocq et al., 2006, 2009a). Therefore, focal concentration of forces beneath riders, induced by poorly fitting saddles (Meschan et al., 2007; Belock et al., 2011), is of greater concern with heavier riders and when ridden at high forward velocity or when landing after a fence. However, with a well-fitted saddle, a heavy rider in balance may be less detrimental than a lighter rider who is not in balance. A rider's ability to ride in rhythm with the horse not only requires practice, training and sensitivity to a horse's motion, but is also influenced by their own symmetry, balance, fitness, pain, stability and correctness of position (Symes and Ellis, 2009). The position of the rider is also influenced by the fit of saddle to the horse (Peham et al., 2004; Mönkemöller et al., 2005) and the fit of the saddle to the rider.

The BW of a rider increases the loads on all the limbs and shifts the position of the centre of mass towards the forelimbs, thus ground reaction forces are increased in both forelimbs and hindlimbs, compared with a non-ridden horse (Schamhardt et al., 1991). However, comparison between a rider and a static load of equivalent BW showed that a rider could shift part of the load towards the hindlimbs. Assessment of limb kinematics of horses in walk, trot and canter on a treadmill revealed little differences between a rider or an equivalent 'dead weight' (Sloet van Oldruitenborgh-Oosterbaan et al., 1995, 1997). The effect of a saddle and a load (75 kg) equivalent to a rider on kinematics of both the limbs and back of horses working on a treadmill indicated that at walk, trot and canter there was a small increase in extension of the back, but the range of motion was unchanged compared with an unloaded back (deCocq et al., 2004). There was increased forelimb retraction at walk and trot in the loaded horse. However, it should be noted that the position of the head and neck was not evaluated, which may alter thoracolumbar movement (Gómez Alvarez et al., 2006).

The effect of an additional 18 kg dead weight on jumping technique was assessed in a small number of horses which were unaccustomed to jumping with added load (Clayton, 1997). The horses were ridden by riders of 61 kg, without or with additional load. Added weight resulted in the leading forelimb landing closer to the fence, with increased maximal carpal and fetlock extension. In the first departure stride, the stance duration of the hindlimbs decreased and the advanced placement between them was reduced. However, it must be borne in mind that dead weight is not necessarily equivalent to live weight, and a horse accustomed to carrying more weight may adjust its balance and technique. To our knowledge, there are no studies which have addressed the maximum weight that a horse of a certain size should be expected to carry.

The rider's influence on head and neck position

The position of a horse's head and neck is influenced by the sports discipline in which it is involved and the effect of the rider. It is clear clinically, and has been demonstrated experimentally, that the position of a horse's head and neck influences movement of the thoracolumbar region. In walk and trot on a treadmill raising the head and neck resulted in extension of the thoracic region and flexion in the lumbar region and reduced sagittal range of motion in non-ridden horses (Gómez Alvarez et al., 2006). Lowering the head and neck resulted in flexion of the thoracic region and extension of the lumbar region and increased range of motion in the caudal thoracic and lumbar regions. There was no change in axial rotation of the pelvis. However, it should be noted that between horse variability exceeded between neck position variability. There was little difference in limb kinematics of Grand Prix dressage horses ridden on a treadmill with the head and neck in a variety of positions (Weishaupt et al., 2006).

High head and neck carriage affected limb timing and load distribution, whereas a low deep and round position had little effect. If a rider excessively elevates the head and neck, thoracolumbar movement may be compromised (Rhodin et al., 2005, 2009), whereas with a low head and neck position there is increased range of motion through the back (i.e., greater swing through the back). However, details about rider effects in different specific equestrian activities remain to be investigated.

Horse-related factors

Movement pattern

The reaction force of the rider equals the total force underneath the saddle and is influenced by the vertical displacement of the horse (deCocq et al., 2010a). Horses with a more bouncy stride receive higher inertial loading from the rider because of gravitational force. Several studies have implicated ground reaction force of the limbs during movement as underlying determinants of the dynamic pattern of total force underneath the saddle (Fruehwirth et al., 2004; Bystrom et al., 2009, 2010a,b). The individual pattern is influenced by the sports discipline of the horse, various riding techniques and training methods, quality of exercise programmes, type and duration of work, fitness, natural flexibility of the back, extravagance of paces, overall impulsion and balance. Available data suggest that a higher velocity causes increased force amplitude (Bogisch et al., 2008). Specific dressage movements such as shoulder-in and travers result in asymmetrical loading of the back, with differences in the maximum total saddle forces on the left and right sides (deCocq et al., 2010b).

Asymmetry of movement

A pilot study has revealed alterations in force distribution in horses with hindlimb lameness and back pain (Bystrom et al., 2011). Motion analysis has demonstrated symmetrical thoracolumbar movement in sound horses (Audigié et al., 1999; Johnston et al., 2004). However, the amplitude and symmetry of thoracolumbar motion is influenced by either experimentally-induced transient forelimb or hindlimb lameness (Buchner et al., 1996; Pourcelot et al., 1998; Gómez Alvarez et al., 2007, 2008) or experimentally-induced back pain (Wennerstrand et al., 2004, 2009). Concurrent back pain and lameness were not induced in these studies, although are commonly recognised clinically (Landman et al., 2004; Zimmerman et al., 2011b).

An on-going prospective study comparing movement of the saddle in sound and lame horses demonstrated that saddle slip consistently to one side is a good indicator of the presence of hindlimb lameness, although this could also be induced by an ill-fitting saddle, asymmetry in shape of the horse's back, or asymmetry of the rider. Saddle slip directly associated with hindlimb lameness was abolished when the lameness was eliminated by diagnostic analgesia, verifying a causal relationship. However, it is clear that horses vary in their adaptation of gait in the face of hindlimb lameness. Saddle slip was generally towards the side of the lame(r) hindlimb, but in a minority of horses the saddle slipped towards the non-lame or less lame limb. Moreover, the presence of saddle slip was not related to the degree of lameness.

There is a lot of published information on back kinematics from treadmill studies (Roepstorff et al., 1994; Johnston et al., 2004; Wennerstrand et al., 2004, 2009), but limited information on ridden horses. Several studies have shown that IMUs have potential for assessing back motion in a ridden horse (Pfau et al., 2005; Warner et al., 2010). Pressure mats may also be used for objective assessment of back mobility, evaluating left–right symmetry of total forces and the craniocaudal excursion of the centre of pressure (von Rechenberg, 2006; Bystrom et al., 2011). However, how back kinematics, saddle movement and ease of saddle fit are influenced by lameness, back stiffness/pain and the length and shape of the back still need to be established. Nonetheless, it is a common clinical observation that a horse with thoracolumbar or sacroiliac region pain will hold its back stiffly when ridden. This makes it more difficult for a rider to absorb the movement of the horse, especially in sitting trot and canter. In sitting trot the horse may brace its back and come slightly above the bit, further jarring the rider. As the horse uses its back less freely there is secondary atrophy of the epaxial muscles, potentially weakening the back, thus creating a vicious circle.

Better understanding of the changes that occur in back shape with different patterns of work and in association with pain is required. We need to know how to measure these in moving horses, which are also affected both by the saddle and by the rider's ability to adjust their movements to accommodate the mechanical interaction with the horse. This might help us to identify risk factors which render horses susceptible to thoracolumbar pain. Accurately identifying horses with back pathology and/or lameness might allow us to retrospectively determine what leads to abnormal saddle movement, and thereby prevent it. The cause and effect link between pathology and dysfunctional thoracolumbar biomechanics still needs to be established and much work will be required to do so.

Conclusions

In order to establish the interrelationship between saddle movement, back pain/stiffness and gait irregularities, we need to know more about the basics of the quantitative relationship between back movement variables and limb asymmetries under a variety of movement conditions. Combining conventional techniques for back pain assessment with back kinematics data (Warner et al., 2010), force measurements under the saddle (von Peinen et al., 2009), alongside measuring back muscle activity by using electromyography (Licka et al., 2004b; Groesel et al., 2010) and ultrasonographic evaluation of multifidus (Stubbs et al., 2006) and other epaxial muscles to assess both size and symmetry, may enable us to improve our fundamental understanding of spinal biomechanics and the changes that occur with injury. It may also allow us to develop individualised monitoring programmes and permit preventative interventions.

Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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