THESIS

A PRELIMINARY INVESTIGATION INTO LATERAL ASYMMETRIES IN RIDER KINEMATICS AND THEIR EFFECT ON EQUINE WELFARE DURING A SHORT RIDING SESSION

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 2025

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ABSTRACT

A PRELIMINARY INVESTIGATION INTO LATERAL ASYMMETRIES IN RIDER KINEMATICS AND THEIR EFFECT ON EQUINE WELFARE DURING A SHORT RIDING SESSION

While it is understood that horse-back riders have asymmetrical riding mechanics, there is a need for further investigation on the possible effects, this has on equine welfare. The current study aimed to provide preliminary insight into the impact of rider asymmetry on acute markers of equine welfare by evaluating the horses using the ridden horse pain ethogram (RHpE) and the change in the horses' neutrophil lymphocyte ratio (NLR). Horses ($n = 6$) and riders ($n = 3$) were randomly paired (HRP, $n = 11$) and rode a short pattern at the walk, trot, and canter on the right and left rein over two data collection days. Each rider was evaluated for trunk asymmetry in the frontal plane (tilt) while riding in a straight line. Behavioral markers of equine pain were evaluated using the RHpE, with ≥8/24 behaviors indicating likely presence of musculoskeletal pain. Physiological stress was measured through evaluation of the change in (NLR) in whole blood from samples taken before and after the session. When averaged across all HRP, rider tilt was in the direction opposite to the direction of travel for all gaits and directions (absolute value 1.88°±1.86° to 4.48°±1.48°). There was no significant effect of rider tilt on NLR ($P > 0.05$). The mean RHpE score was three out of 24 behaviors. Rider tilt was present across all gaits and directions. No association was found between rider tilt and physiological and behavioral markers of acute equine stress during a short, moderate intensity riding session.

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Chapter One: Background Information

History of horses and humans

Humans have been riding horses for thousands of years [1]. Over time, the function of horse-back riding changed, as did the equipment. It is believed that the Assyrian cavalry was the first to sit with a fixed pad and cloth between themselves and their horse in 700 BC. Prior to this, riders used a simple piece of cloth or animal skin or rode bareback. Roughly 500 years later, a rudimentary saddle tree was first created to help better distribute the riders' weight over the horses back and take pressure off of the spine [2]. This had benefits for the horse and rider. It could be considered an early manifestation of equine welfare as it improved the horses' comfort and prolonged their working life [2]. The first leather saddles were developed several centuries later by the Samaritans. They are also thought to be the first saddles to include stirrups which helped the rider's balance and safety [2]. Since then, saddles have evolved but still largely resemble those used during the medieval period. Modern saddles evolved to best match their intended use. Western saddles have a wide comfortable seat and horn, perfect for riding all day in rough country and creating an anchor point when roping livestock. Dressage saddles have a deep seat and long straight leg flap, allowing the rider to sit tall on the horses back. Jumping saddles have a shallower seat and forward positioned leg flaps so the rider can move easily in and out of the saddle over fences [2].

Saddle fit is important

Saddles translate the weight of the rider to the horses back and thus must be properly fit to the horse and rider. Poor saddle fit can lead to back pain, a common problem in horses and riders [3,4]. While a properly fitting saddle is vital, it can be difficult to find a saddle that is proportionally correct for both athletes. For example, the saddle must have a long enough seat for the rider to be able to sit comfortably but it also cannot extend past the horse's 18th thoracic vertebrae (the last rib) [5]. In horse-rider pairs where the rider requires a large seat but the horse has a short back, this can prove challenging. On top of finding a proportionally correct saddle, the shape of the saddle must fit the horse's back. The height of the withers, width of the back, and shape of the back vary widely between horses. Different saddle brands and models encompass this variety, but individual fitting is still necessary to ensure a proper fit. An experienced saddle fitter has the knowledge to recommend a saddle of the proper shape, and to adjust the tree or panels to customize the fit to the specific horse statically and dynamically. While consistent saddle fit is the gold standard, access to saddle fitters can be limited by proximity or cost. Additionally, horse's backs are constantly changing and a multitude of factors affect saddle fit, so even horses who have their saddles checked consistently can have improperly fitted saddles. In fact, one study found that more than 30% of horses who had their saddle fit at least once per year had an ill-fitting saddle [4]. However, it was not determined if these saddles were fit by a member of the Society of Master Saddlers, the most prominent membership body for saddle fitters and makers [6].

Training and welfare throughout history

As equipment has evolved throughout history, so has equine welfare. It is likely that horseman have always argued about equine welfare, with rulers as early as 1434 commenting on poor horsemanship [2]. Early riding and training methods were often harsh but as the responsiveness of the military horse was emphasized, training methods shifted. The education of clear training cues was prioritized to improve communication between horse and rider, and with this the use of the seat and body position as communication aids emerged. In comparison to the previously used reins and spurs, these new aids required more tact and understanding of equine mechanics. This new style of riding developed the idea that riding was an art, and to create this art required a slow process without violence. During this time, a sign above the renowned training facility, the Great Stables of Versailles, read “Where art ends, violence starts.” It is however important to note that while this philosophy was widespread, not all instructors applied it [7].

Horses have four gaits

Equine locomotion in English disciplines generally occurs in 4 separate gaits. A gait is a complex and strictly coordinated rhythmic and automatic movement of the limbs and entire body of the animal which results in the production of progressive movement [8]. Gaits are defined based on the pattern of limb and body movement, and the number of auditory hoof impacts heard throughout a stride cycle. A stride can be defined as a full cycle of limb motion, i.e. From the time a foot contacts the ground to the next time the same foot contacts the ground [8]. The horse’s gait is cyclical, so any limb can be used to define a stride. Each stride can be further broken down into individual phases relative to the individual limbs. The stance phase is when the limb is on the ground, a swing phase when the individual foot is in the air, and a suspension phase when all limbs are off the ground and the horse’s body is in suspension [8]. The four common gaits of equine locomotion in English riding, walk, trot, canter, and gallop, all have stance and swing phases. The trot, canter, and gallop also have a suspension phase. At the walk the horse is always making contact with the ground, leading to the lack of a suspension phase [8]. At the trot and canter, two limbs contact the ground at the same time, this is referred to as the diagonal stance phase. As the name implies, diagonal legs (LF and RH, or RF and LH) contact the ground at the same time [8]. Gaits can also be defined as symmetrical (walk, trot) or asymmetrical (canter, gallop) based on the symmetry of the limb movements. Additionally, movement in each gait can be further classified based on variation in speed, however intra-gait variation will not be discussed.

Movement is not just forward

During locomotion, the horse's body moves in multiple planes and axes in addition to forward motion [9]. The horse's trunk translates and rotates in longitudinal, transverse, and vertical axes. Segments translate up and down (dorsal to ventral) as well as twist right or left (yaw) in the vertical axis. The horse moves forward and backward (craniocaudally in the horse) in the longitudinal axis, as well as leaning from side to side (tilt). Finally, the horse and rider translate from left to right in the transverse axis, and rock forward and backward (pitch, nose up/down) in this same axis [9]. Haussler et. al found that this motion begins in the spine. They attached pins and transducers to multiple dorsal spinous processes in the thoracic, lumbar, and sacral aspects of the spine to determine rotational motion in three dimensions. They found that lateral bending occurs throughout all measured aspects of the spine, with greater degrees of bending occurring as you move from cranial-caudal aspects of spine. The timing of lateral bending was also out of phase throughout the spine, with max lateral bend occurring first in the more cranial vertebrae and later (and of a greater magnitude) in more caudal vertebrae [10]. How this translation and rotation occurs varies from gait to gait.

Movement of the horse: Walk

At the walk, the limbs move in a lateral sequence with four independent beats. The horse's hind leg contacts the ground, followed by the front leg of the same side, then the diagonal hind, then the final front leg (i.e. LH, LF, RH, RF). The horse's head raises and lowers twice per stride cycle. The horse's head is at its highest during the stance phase of the forelimb before lowering during contact of the diagonal hind before raising again when the opposite front leg contacts the ground [9]. The horse's spine also undergoes two cycles of flexion and extension during the walk which begins earlier in the caudal spine and moves cranially [10]. Finally, a single cycle of lateral bending and axial rotation occurs per stride cycle at the walk along the thoracolumbar spine. The horse's spine rotates away from the planted front leg, with the greatest rotation occurring during the time that the leg contacts the ground. Lateral bending of the back occurs on the ipsilateral side to the side of hind hoof contact, with the maximal bending occurring at the time of hind foot placement [10].

Movement of the: Trot

At the trot, the diagonal pairs move in unison, with a suspension phase occurring between each diagonal phase [8]. The stability of the diagonal stance phases decreases the horse's rotation front and back and side to side [11]. The horse's body rises and falls with each diagonal pair's stance, with the maximum height reached in or just before the suspension phase, and the minimum height occurring about halfway through each stance phase [9]. This is also reflected in the flexion and extension of the horse's spine, with their spine flexing at the end of the stance phase shortly before suspension and extending at the beginning of the next stance phase. This movement is controlled by the muscles surrounding the spine [12]. Lateral bending of the spine occurs separately in the cranial and lumbosacral joint, and side-to side rotation of the trunk is greatest when the ipsilateral front limb contacts the ground [10]. There is little vertical movement of the head and neck at the trot [9].

Movement of the horse: Canter

The canter has three beats, with limbs on one side of the body extending further forward than the limbs on the contralateral side. The limbs which extend further are referred to as the ‘leading limbs’ and the opposite limbs named the ‘trailing limbs.’ The stride cycle begins with contact of the trailing hind leg, followed by the leading hind and trailing forelimb as a diagonal pair, and then finally the leading forelimb. After the leading front lifts off the ground the horse undergoes a phase of suspension. Due to the pattern of the canter, the horse performs a rocking motion, with the horse tilting up (nose up) during the suspension and hind leg stance phases, before moving through horizontal and then tilting down (nose down) during the stance phases of the front limbs [9]. The horse’s spine undergoes one cycle of flexion and extension, with maximum lumbosacral extension occurring around the time of diagonal pair contact and maximum flexion during midstance of the leading forelimb [9].

Horse & rider move in harmony

Connection and harmony between horse and rider is highly emphasized in horseback riding with the movement of the pair largely dictated by the horse due to the size difference between species, and the horse making contact with the ground [3,13]. To follow the movement of the horse, the rider also moves three-dimensionally through the body and limbs [9]. The direct contact of the rider’s pelvis with the saddle, and by extension the horse’s back, makes it particularly important to the ability and quality of the rider. The primary movement of the pelvis during riding is to rotate forwards and backways during locomotion but the pelvis also tilts side to side and twists left and right [9]. The rider’s movements are coordinated and follow the lead of the horse [3,13].

Horse-rider movement: Walk

At the walk, the movement of the saddle and rider follows the movement of the horse’s trunk, switching directions each time a hind hoof contacts the ground. As a hind limb makes contact with the ground, the horse’s croup is low, and their trunk is pitched up (withers higher than pelvis). Throughout the first half of the hindlimb stance, the croup rises causing the trunk to pitch down before reversing in the second half of the stance phase. As the croup rises, the rider sinks into the saddle. The pitch of the rider's pelvis moves opposite to the pitch of the horse's back, pitching posteriorly from hind limb contact to forelimb contact before pitching anteriorly from forelimb contact to the contact of the opposite hind [14]. There is variation in reported range of motion of rider pitch between studies, with one study reporting 9.7±2.0° in professional riders [14], while a separate study reported 8.1±4.1° in beginner riders and 11.1±3.6° in professionals [15]. Münz et al. (2014) also reported that the professionals maintained a greater posterior pitch throughout the stride. Pitching of the rider's trunk does not appear to follow a clear pattern [9]. The tilt of the horse's trunk and the rider's pelvis are synchronized. As the hind limb leaves the ground, the horse and rider tilt towards that limb (away from the weight-bearing limb) which reverses as the opposite hind leaves the ground [14]. The range of motion of the horse's pelvis has been reported as 5.6±0.6° [14] and 5.3±1.2° in experienced riders [15]. The rider's pelvis also undergoes a cycle of yaw, twisting towards the planted hind limb with a range of motion of 8.2±1.9° in the pelvis. The rider's trunk rotates in the opposite direction of the horse's trunk, with a range of motion of 5.0±1.3° [14]. The correlation between horse and rider at the walk is lower than that of other gaits, suggesting less synchronization between the pair [16].

Horse-rider movement: Sitting Trot

The trot is commonly ridden in two ways: sitting trot and rising (or posting) trot. During the sitting trot, the rider is seated throughout the stride. The rider's vertical translation follows that of the horse's back with a small lag time. The horse's back is at its highest at the start of suspension but the rider continues upward during the suspension phase before reversing and reaching its lowest point just after the middle of the diagonal stance phase [11]. The pitching motion of the rider’s pelvis is opposite to the pitch of the horse’s back but the pitch of the rider’s trunk is in the same direction as the horse’s trunk. The rider’s pelvis pitches anteriorly and their trunk posteriorly in the first half of the stance phase before switching in the second half of stance, causing the pelvis to pitch posteriorly and the trunk anteriorly [17]. The pelvic roll of the rider is often out of sync with the horse’s trunk and the saddle. The movement of the saddle corresponds with the rotation of the horse’s 10th thoracic vertebrae, rolling towards the weight bearing hind limb throughout its stance phase and then reversing direction just before the hoof leaves the ground [17,18]. The rider’s pelvis shows maximum rotation towards the planted hind limb on contact and then rolls away from this limb during its stance phase and subsequent suspension [17]. Previous literature has found variation in the direction and speed of pelvis roll in the second half of the stance phase at the trot, as well as asymmetry when comparing the left and right sides [17]. This may be an indicator of asymmetrical push off from the horse’s hind limbs. A separate study found that the rider’s trunk and pelvis roll in opposite directions [15].

Horse-rider movement: Posting Trot

The rising trot is the only gait in which the rider’s pelvis pitches in the same direction as the horse’s trunk. The rising trot is also abnormal as the movement of the horse is symmetrical but the movement of the rider is not. In the rising trot, the rider posts, spending half of the stride seated in the saddle and the other half ‘floating’ with their seat out of the saddle. This is driven by the vertical motion of the horse pushing the rider out of the saddle and leads to the rider sitting during the stance phase of one diagonal pair and out of the saddle during the stance phase of the other diagonal pair. This asymmetrical movement is reflected in the tilt of the rider’s pelvis. One study found that the rider’s pelvis tilted away from the loaded hind leg during stance, but the magnitude of tilt is decreased during the sitting diagonal stance compared to the non-sitting diagonal [18]. This study also found that the pelvis stiffens during the sitting stance, suggesting this may account for the decrease in tilt. From contact to midstance of each diagonal pair, the saddle and rider's pelvis rotated away from the planted hindlimb in yaw [17]. Evaluation of lateral motion of the rider has found that there was greater lateral motion of the rider during the rising trot than sitting trot, however the difference was not significant [19]. There were however differences in saddle forces between sitting and rising trot. Peak forces in the saddle are higher in sitting trot than rising trot [19]. When comparing forces during the rising trot, peak force was lower on the rising diagonal but both peaks were lower than during the sitting trot. A third way to ride the trot, 2-point position, is when the rider consistently hovers above the saddle. This position resulted in lower overall force than the sitting and posting trot [19].

Horse-rider movement: Canter

At the canter, the pitch of the rider's trunk is larger than that of walk or trot, and out of sync with the horse's trunk pitch. The rider's pelvis tilts in the opposite direction to the horse's trunk, tilting away from the side of the trailing limb during stance before reversing direction and tilting towards the side of the leading limbs throughout the diagonal stance phase and finally reversing back the other direction around leading forelimb contact [15]. This occurs through a range of motion of 5.9 ±1.5 degrees [15]. The yaw rotation of the rider's trunk is larger than reported in the walk and trot [13].

Asymmetry occurs in riders

Asymmetry is common in riding and non-riding populations. A 2005 review study evaluating pelvic-limb radiographs in non-riding populations found that 90% of the studied population had some level of asymmetry in anatomic leg-length [20]. The mean leg-length inequality (LLI) was 5.21±4.1mm, with the shorter leg being the right more often. However, not all leg length inequality is clinically significant. For LLI to be considered significant, it must be associated with back pain, injury, muscle strength asymmetry, or other physiological changes [20]. These symptoms are related to the ability of the spine and pelvis to compensate for LLI and as this will vary between individuals. However, Knutson (2005) determined that most individuals are able to compensate for LLI up to 20mm [20]. A study evaluating lateral displacement of the center of mass in the frontal plane during movement from seated to standing in healthy adults found significant interindividual and intraindividual differences in weight bearing and center of mass [21]. Some individuals consistently preferred one leg over the other and others had no preference. However, all individuals saw lateral displacement of center of mass and unequal leg pressure at the beginning and/or end of a sit-to-stand event. Based on this information, it is reasonable to assume that most individuals display some level of lateral asymmetry while performing this type of motion, but the type of asymmetry is not always consistent across trials with an individual.

Normal asymmetry: Asymmetrical gaits, Asymmetrical aids

Asymmetry is not inherently abnormal. Asymmetry naturally occurs in gaits, riding mechanics, and rider aids. Some equine gaits, such as the walk and trot, are symmetrical, and as such the forces transmitted to the rider should also be symmetrical and mirror images of each other in the two halves of the stride [9]. However, asymmetrical gaits, like the canter and gallop, the period of time between footfalls in a stride is not equal and thus the forces transmitted to the rider are asymmetrical and require adaptive movement by the rider to stay in harmony with the horse [9]. Additionally, riders monopolize on equine biomechanics to communicate with their horse. Effective riders use their body, legs, and arms to methodically encourage and discourage movement in different aspects of the horse’s body to produce complex movement without interfering with their horse. These aids are often unilateral or require independent movement from each side of the body, leading to inherent laterality in horse and rider. Unfortunately, no research has been performed to date on this aspect of the horse-rider interaction. Additionally, some aspects of rider movement are also inherently asymmetrical. The trot is a symmetrical gait but a common rider position, the posting trot, is not. During the stance phase of one diagonal pair, the rider is on the down diagonal and is sitting in the saddle. When the opposite pair are in their stance phase, the rider is on the up diagonal and is out of the saddle. This leads to asymmetric forces on the horse’s back, with the force on the saddle higher and minimum position of the horse’s pelvis lower during the sitting diagonal. The rider’s pelvis is also stiffer while seated, leading to less lateral tilt of the rider's pelvis during the seated diagonal [18]. The maximum height of the horse’s pelvis is also lower during the stance phase while the rider is rising, likely due to downward momentum created during the rising movement of the rider counteracting the horse’s hindlimb push off [22]. Research in this area is limited but is widely understood by riders, and lead to establishment of the ‘correct diagonal.’ While traveling straight, the timing of the diagonals does not matter. However, while turning or on a circle the horses minimum pelvic height differs, with the minimum pelvic height higher during the stance phase of the inner hind limb. Posting so that the rider sits during the stance phase of the outside forelimb and inner hindlimb counteracts the natural asymmetry of the horse’s pelvis making the minimum height during both stance phases more symmetrical, making the horse more comfortable to ride and likely leading to the establishment of a ‘correct diagonal’ [22].

Individual asymmetry: Horses

In addition to inherent symmetry in horse-back riding, the horse and rider can also show individual asymmetry. Horses often have a dominant side, just like humans have a dominant hand/foot. Meij & Meij (1980) evaluated 30 horses (26 geldings, 4 mares) for sidedness during ridden work and found that 25 of the included horses were preferential to tracking left or counterclockwise. This was evaluated based on a 0-4 scale of the following markers: degree of resistance of the jaw/stiffness of the neck muscles relative to each side, inability to move in a straight line, difficulty obtaining the correct curvature of the body during a turn, irregularity of paces, and resistance when performing lateral movements [23]. A more recent study of 40 horses (20 geldings, 20 mares) by Murphy et al., 2005 found that the geldings had more left lateralized responses while mares had more right lateralized responses when investigating sidedness by evaluating the leg used to initiate movement, the direction taken to avoid an obstacle while unmounted and while ridden, and direction chosen at initiation of rolling [24]. This result was seen in all procedures; however not all findings are statistically significant. This study did not determine a cause of laterality but suggested that it may be genetically predetermined and/or influenced my environmental factors.

Mechanical asymmetry/lameness: McIII length in horses

A study evaluating length differences between left and right third metacarpal bone (McIII) length in racing Thoroughbreds appears to agree with the left-sided preference reported by Meij & Meij (1980) [25]. They found that most included horses (76%) had a longer right McIII than left. They suggest that a longer right McIII may explain why horses are generally stiffer to the left, softer to the right, and harder to train (potentially weaker) to the right as noted in Meij & Meij (1980). Interestingly, they also found a difference based on the origin of the horses. This study included horses from 2 yards: one in Victoria, Australia and the other in South Australia. The Victorian horses had a significantly larger mean difference (5.1±0.7mm vs. 1.5±0.6mm) between right and left McIII than the South Australian horses. They suggest this may have been unknowingly selected for or against based on the direction the horses raced. Horses at the Victorian yard exclusively raced counterclockwise, putting the longer right McIII on the outside of the turn giving the horse an advantage. However, horses at the South Australian yard raced both directions and were selected from stock that had similar success both directions meaning that there was no overall advantage to having one McIII longer than the other [25]. Unfortunately, this study did not report the sex of the included horses so their findings cannot be compared to the sex-associated sidedness found by Murphy et al., 2005. The findings of this study suggest that sidedness in horses may be unknowingly selected for due to its connection to performance, however this needs to be further evaluated in non-racing populations.

Mechanical asymmetry/lameness: Forelimb conformation asymmetry, Horses

Asymmetry in horses can also be due to left-right forelimb confirmation asymmetry. One study used reflective markers around the hoof and distal limb and tracking markers over the dorsolateral aspect of the first phalanx to compare locomotor asymmetries in horses with functional differences in dorsal hoof wall angles compared to horses with even feet (<1.5º between forefeet) [26]. All included horses were graded as sound based on the AAEP lameness scale [27]. They found that there was a significant difference in functional kinematic parameters between the front feet of uneven horses, while there was no significant difference between any parameters in horses with even feet. None of the functional parameters varied between foot categories (flat, medium, upright). Based on these results, they determined that variation between feet was more important to loading dynamics than the specific conformation of the feet. They suggest that the differences between feet could imply asymmetrical loading between limbs which may or may not be pathological. A separate study found that elite jumping horses with uneven feet were almost twice as likely to retire early compared to horses with even feet [28].

Cause of lameness, horses

Lameness in horses can be the result of several factors. Confirmational asymmetry can lead to apparent asymmetry on lameness evaluation without pain, commonly referred to as a 'mechanical lameness' [29]. Differences in cannon bone length and some cases of hoof asymmetry as described above can be considered mechanical lameness. However, lameness can also arise due to improper balancing of the hoof, orthopedic disease secondary to poor confirmation, injury, or a host of other factors. Lameness is generally the result of pain and leads to changes to the horse's stance or gait [29]. In cases of pain-related lameness, regional or local analgesia is often used to help diagnose the location of lameness and temporarily relieve pain [29]. This is commonly done with use of a 'nerve block,' a local anesthetic or analgesic injected into the area of suspected lameness [29]. When evaluating pain-related lameness, one study determined that horses who were evaluated to have mild-moderate lameness had abnormal saddle pressure measurements which were resolved when the horse was given diagnostic analgesia [30]. Abnormalities in saddle pressure patterns corresponded to clinicians' evaluation of lameness. Following diagnostic analgesic, each horse's lameness was reduced based on clinician evaluation and comments from the professional rider. Asymmetry in pressure distribution was also reduced.

Individual asymmetry: Riders

In addition to asymmetry in horses, riders can also display individual abnormalities in position. Some changes in rider position are related to rider experience level.

Previous research has found that experienced riders have a more vertical trunk than novice riders [31]. The experienced rider is able to sit deeper into the saddle and better absorb the vertical forces of the horse [31]. Due to this, the experienced rider is better able to adapt to the movements of the horse allowing them to maintain a more consistent position with more timing synchronization between horse and rider [31–33]. Asymmetry may also be increased in riders with more years riding and competition level. One study evaluated skeletal asymmetry in riders while seated in a dressage saddle, via measurement of pelvic and trunk measures as the rider was seated normally, laterally bending right and left, and rotating right and left [11]. They found that riders with more years riding, and a higher competition level had more functional asymmetry to the right. They also found that riders with less years of experience sat with their left iliac crest higher than the right while riders with more years of experience sat with the right iliac crest higher. Additionally, they reported that riders with postural defects had a trend of increased prevalence of pain in riders at a higher competition level. These findings are in agreement with a previous study which found that asymmetry in lateral bending was associated with diagnosis of low back pain [34].

Cause of rider asymmetry

Rider asymmetry can occur for several reasons, however variation in reported asymmetry can make determining the cause difficult [4]. Previous research has reported shifts in pressure distribution to the left while riding or sitting on a flat surface [35,36], while others have reported higher weight on the right in riders sitting on a flat surface and riding [37]. Another study reported a roughly even split of left and right asymmetries in stirrup weight distribution during simulated riding with a saddle on a wooden horse [38], while another study reported upper trunk asymmetry in novice riders but no asymmetry in experienced riders [39]. A study evaluating stirrup pressure distribution with riders on a wooden model found that most riders distributed asymmetrical forces to each stirrup with the direction of asymmetry changing throughout the testing session [38].

Improving rider asymmetry: Unmounted workouts

In some cases, rider asymmetry can be improved through utilization of unmounted training programs. Previous research has found that riders had more left-right postural stability on a flat pressure mat and increased symmetry in the side-to-side distribution of their vertical force when seated on a plastic saddle horse following manual physiotherapy of the muscles connecting to the pelvis [40]. A separate study in which riders performed a sport-specific 20-minute core fitness program three times per week for eight weeks found that following the fitness program, riders showed significantly less left-right mean pressure differential, and that the horses mean stride length increased by 8.4% [41]

Added weight causes extension of horses back

Adding a rider also affects the horse's kinematics, with previous studies showing extension of the thoracolumbar spine (often referred to as 'hollowing') during standing and locomotion when weight is added to the horse's back (a rider or dead weight). At the walk and trot, hollowing was only seen when substantial weight was added to a saddled horse [42]. At the canter, the saddle alone caused thoracolumbar extension. This study didn't see changes to the horse's range of motion due to the hollowing of the back, suggesting that riders of average weight do not restrict the mobility, or by extension athletic ability, of the horse. However, thoracolumbar extension does have a slight effect on the confirmation of the spine, bringing the spinous processes of the thoracolumbar vertebrae closer together and altering the forces on the spine and connected structures. This minor change can predispose the horse to future conditions, such as Kissing Spines [42]. A separate study evaluated stride variables, plasma lactate changes, and heart rate during a working session on a treadmill in unmounted horses, horses carrying 90kg of deadweight, and horses carrying a 90kg rider [43]. This study found no difference in stride duration in horses who did and did not carry additional weight at the walk, trot, or canter. However, the horses who carried additional weight did have a longer relative stance duration at the trot and canter in comparison to horses who did not carry additional weight. Horses who carried additional weight also had larger forelimb fetlock extension at the walk and trot, and a larger maximum fetlock range of motion at all gaits. When evaluating the hindlimb, increases in maximum range of motion and fetlock extension were seen in horses with additional weight at all gaits. However, this was only significant at the trot. The addition of a rider impacts the kinematics and locomotion of the horse, but it is generally assumed that the movement of the horse-rider pair are driven by the horse [9].

Rider influenced equine lameness

Lameness in horses can be induced or diminished by the rider. Changing the diagonal during the trot can influence pre-existing asymmetries in the horse. Without a rider, a horse with a hindlimb lameness will often have decreased push off of the lame leg [22]. A rider rising out of the saddle (up diagonal) creates downward momentum which counteracts the push off of the hind limb, decreasing the pelvic rise and mimicking a push off lameness in the leg [22]. Conversely, the appearance of a hindlimb lameness can be reduced if the rider is on the up diagonal during the push off phase of the non-lame limb, as it makes the hind limb push off more even. This result can also be seen while on a circle. Without a rider, there is less downward movement of the pelvis during the stance phase of the inside hind leg. Riders posting on the correct diagonal (rising as the outside front/inside hind leave the ground) while circling increases symmetry in the horse's pelvis when compared to unmounted horses on a lunge line. Additionally, posting on the incorrect diagonal induced the highest amount of asymmetry seen while traveling straight or on a circle [22,44].

Induced asymmetry affects horses

Addition of an asymmetric rider leads to additional changes in spine and limb movement and loading patterns. One study which artificially induced rider asymmetry at the trot by shortening one stirrup 5cm found that when the shortened stirrup was on the outside, there was a significant increase in forelimb and hindlimb fetlock extension, and hind limb protraction in the inside limbs when compared to horses ridden with symmetric stirrups [45]. They also found an increase in lateral bending (bending around the dorsoventral axis) in the thoracic spine, lumbar spine, and pelvis, as well as increased mediolateral displacement of the horses thoracic and lumbar spine. When the shortened stirrup was on the inside, there was an increase in flexion-extension (rotation around transverse axis), axial rotation (rotation around longitudinal axis), and lateral bending in the thoracic spine, lumbar spine, and pelvis. They also found a decrease in carpal flexion in the inside limb. Changes to the horses' loading and movement are likely due to asymmetry in the rider's pressure distribution. It has been documented that upper body tilt led to increased force on the same side as tilt, while collapsing the hip led to increased pressure on the contralateral side [36]. The shortening of a stirrup resulted in the rider's tilting their trunk towards the shortened stirrup, which is assumed to increase pressure under the saddle on the side of the shorter stirrup [45]. The authors of this study suspect the rider's asymmetry creates asymmetric loading between the horse's right and left sides leading to the changes in equine locomotion.

Equine asymmetry can translate to rider

Asymmetry in pressure distribution of the rider can also be the result of lameness in the horse. A study involving horses with poor hindlimb engagement and mild to moderate lameness when ridden found asymmetry in the pressure distribution under the four quadrants of the saddle which corresponded to a lameness evaluation performed by a clinician [30]. The included horses were given diagnostic analgesia, after which their lameness was determined to be reduced by the clinician and rider. There was also a reduction in the asymmetry in the saddle pressure distribution and an increase in the pressure fluctuation during the stride cycle, which indicates increased intra-stride accelerations. This corresponds to improvement in hindlimb propulsion noted by the clinician and rider [30].

Asymmetries influence on injury

It is anecdotally believed that rider position has implications in equine soundness and thus welfare [3]. Subjectively, is it easy to understand that the changes to pressure distribution induced by the addition of a rider could overly stress aspects of the horse's musculoskeletal system, leading to injury and shortening the horse's working life. However, there is little research investigating the interaction between rider asymmetry and equine pathology. Regardless, it is known that musculoskeletal disease is a major problem in sport horses. A large study of over 1,800 Dutch Warmbloods found that 55% of deaths in this population were the result of musculoskeletal diseases, namely joint diseases (44%) [46]. Other common musculoskeletal causes of death included undetermined lameness (14%) and diseases of the back, sacroiliac joint, and tendons (13%). While horses were included in this study based on participation of the Swedish Riding Horse Quality Test which is often performed by horses in competition homes, the etiology of these musculoskeletal diseases is unknown and thus it cannot be assumed that this is due to asymmetries in rider position.

Equine welfare is complex

Part of the difficulty evaluating the impact of rider asymmetry on riding horses is the complexity of equine welfare. There is no widespread agreement on a definition of welfare across scholars, and many involved with horses perceive good welfare differently [47]. The Animal Welfare Act aimed to define a minimum level of care that all animals are entitled to, which defined five aspects of welfare, the five freedoms [48]. These freedoms include freedom from hunger and thirst, freedom from discomfort, freedom from pain, injury and disease, freedom from fear and distress, and freedom to behave normally. While this bill has had a positive effect on welfare, equine and otherwise, it also has its faults. It defines ideal states and operates under the assumption that any negative effects are inherently bad [49]. However, negative experiences or states are imperative for survival; hunger drives the animal to seek out food, and pain leads to escape or avoidance behavior. Without this feedback, animals would not survive.

Stress

This is deeply connected with stress. Stress is a relationship between an organism and external or internal factors that act to disrupt homeostasis [50]. Acute stress, more specifically, is the process of constant flow moving around a homeostatic point. During a stress response, the body shifts from control of the parasympathetic nervous system to control of the sympathetic nervous system. There are three phases to a stress response. Phase one is the ‘alarm stage’ where there is an increased release of catecholamines, corticotropin-releasing hormone, prolactin, growth hormone, and glucagon, as well as a decrease in the release of hypothalamic gonadotropin-releasing hormone (GnRH). This activates the cardiovascular, respiratory, and locomotory systems and leads to the consumption of a large amount of energy [50]. This stage activates the fight or flight response as a survival mechanism. If the stress event is not resolved during the first phase, the body enters the second wave, the 'resistance phase.' At this time there is an increase in glucocorticoids to support the effects of the alarm stage. The third wave is the 'recovery phase' where the body moves back under the control of the parasympathetic nervous system [50]. The stress response activates neural and hormonal networks which leads to changes in the metabolic, cardiovascular, musculoskeletal, and immunological systems of the body [50].

Stress is not always negative

As welfare is often evaluated based on stress, and any stress is presumed to indicate a negative state, it is often presumed that good welfare is defined by the absence of stress. However, stress is more complicated than this assumption implies. What a horse regards as stressful is highly individual and determined by the combination of genetic, environmental, and developmental factors [50]. As such, their stress response is also individual and rooted in their perception of the situation [50]. Even when a stress response does occur, not all stress is bad. There are several types of stress. Distress is stress of severe intensity which cannot be resolved by adaptation of the animal. It is associated with a negative state and is the type of stress commonly referred to. In contrast, eustress is physiological and leads to long-term positive biological adaptation [50]. An example of eustress is physical training which increases the horses muscle mass and soft tissue strength. Determining if stress will have a positive, neutral, or negative outcome is often not black and white but is instead related to the horse's perceived central nervous system control of the situation [50].

A more inclusive model

Equine welfare is a high priority among equestrians, but their perception of welfare is often focused on human actions dedicated to preventing negative experiences and fails to consider the horse's mental state. These beliefs align with the Five Freedoms outlined above [47]. While important, physical welfare is only half of the equation. A newer model, the Five Domains, aims to encompass the other part of the equation: the horse's mental state [51]. This model includes: (1) nutrition, (2) physical environment, (3) health, (4) behavioral interactions, (5) mental state. The first three domains are focused on the physical state of the horse. The fourth domain focuses on evidence of the horse consciously seeking specific goals during behavioral interactions with the environment, non-human animals, and humans [51]. Domains 1-4 lead to negative or positive subjective experiences which contribute to horse's mental state as evaluated in the fifth domain [51]. This design emphasizes the primary determinate of welfare, the horse's mental state, and considers that the animals mental state is influenced by their physical and behavioral state [51].

Perception of equine welfare is anthropocentric

Rider's perception of good and bad welfare is often rooted in personal perception [47]. Equestrians often determine welfare based off tangible items. They commonly use welfare and horse care interchangeably and assume that their horses are happy if their physical needs are met without any direct evaluation of their mental state [47]. This is particularly common in ridden horses as physical health is closely related to athletic performance, but equine tolerance of human intervention leaves them susceptible to subpar welfare [47]. This is exacerbated as riders commonly have poor understanding of horse behavior. This is particularly common with conflict behaviors which are viewed as problematic instead of a welfare problem. Due to rider perception of these behaviors, horses may be punished for expressing them. These horses are often labeled as ‘hot’ or difficult [47].

Stigma around equine welfare

Many equestrians believe that there is stigma around discussing welfare and as such are hesitant to speak up about welfare issues in the industry which can lead to discrepancies between rider’s personal opinions on welfare and the views they share publicly [47]. This may be rooted in conflict between the demands of competition and the horse’s needs [52]. It may also be related to individuals' fear that they provide inadequate welfare to their horses. This concern is understandable as there is no validated tool for assessing ridden horse welfare [52,53]. In the absence of a comprehensive tool, evaluation of ridden horse welfare relies on measurement of physiological and behavioral indicators of stress [50].

Physiological acute stress response

During an acute stress response, the body first perceives a stressor through the sensory system [50]. The brain then interprets the signal as a threat and triggers a nonspecific and specific stress response. The catecholaminergic neurons in the locus coeruleus (LC-NA system) are responsible for activation of the sympathetic-adrenal medullary (SAM) axis, and the hypothalamus is responsible for activation of the hypothalamus-pituitary-adrenal (HPA) axis. These axes are the primary pathways responsible for activation of a stress responses which is then fine-tuned by several other brain circuits and body systems. Within seconds of LC-NA system activation, there is activation of the SAM axis, and the distant release of norepinephrine (NA), epinephrine (E), and dopamine. Due to this, some have suggested that this process should be referred to as the LC-NA-sympathetic system, not the SAM axis [50].

Catecholamine (NE, E) release during an acute stress response leads to a significant increase in equine cardiac function which can be measured as an increased heart rate, stroke volume, cardiac output, and blood pressure. These changes are short lived (5-60sec) but result in a 7-8 fold increase in cardiac function. Heart rate can increase from 30-40bpm at rest to 240bpm. As cardiac output increases, the body's demand for oxygen does as well. This leads to an increase in respiratory rate from 12-20 breaths per min to 180 breaths per minute, and an increase in tidal volume from 4-7L to 10L during intense stress exercise. There is also enhancement of different immune functions due to the binding of catecholamines to β-2 adrenergic receptors on immune cells (primarily on the NK cells), and through blood mobilization and sympathetic innervation of lymphoid organs [50].The effect of catecholamines on to β-2 adrenergic receptors also leads to significant lipolysis, inhibition of insulin secretion, increase in glucagon and glucose concentration, release of ACTH, cortisol, and renin. Additionally, catecholamines change the distribution of energy in the body, directing more blood towards the CNS, cardiovascular, and respiratory systems and less blood towards the digestive and reproductive tracts to increase the body's ability to cope with and evade stressful situations [50]. Exercise can increase levels of catecholamines, however significant increases in plasma epinephrine were only seen during strenuous exercise particularly when coupled with psychogenic stress [50].

The resistance stage of the acute stress response relates to strong activation of the HPA axis and renin-angiotensin system (RAS) [50]. The exact timing and duration of the resistance phase is dependent on the stress factor as the main goal of this phase is to provide additional energy for the system. In general, HPA activation is slightly slower than that of the SAM axis. Immediately following onset of a stressor there is a rise in corticotropin-releasing factor (CRF) followed by peak secretion of pituitary ACTH 5-15sec later, and finally a peak of cortisol 15-60min later. Cortisol has over 100 functions in the body, promoting energy mobilization and distribution [50]. Cortisol and other glucocorticoids also work to support and enhance the effects of catecholamines. It enhances sensitivity of the cardiovascular system and prolongs actions in neuromuscular junctions [50].

In the absence of stress, there is a pulsatile secretion of CRF, VP, ACTH, and glucocorticoids (one per hr) with greater amplitudes in the morning than at night. Peak cortisol values occur shortly after waking in the morning and are at their lowest between 6:00-9:00pm [50]. This cycle is disrupted during exercise and stressful conditions [54]. During stress events, cortisol levels increase but the level of increase is dependent on the stress factors, duration, frequency, and individual variability. Cortisol levels are also influenced by exercise induced stress [50]. A significant increase in cortisol is attributed to exercise duration but not intensity and is dependent on the horse's demeanor and previous experiences. In chronically stressed horses there is a depletion of cortisol stores and concentrations can vary greatly. During transportation related acute stress responses, peak cortisol levels were reached 10-20min after the onset of the stress event [55]. Plasma cortisol levels range from 12 to 68 ng/mL (total cortisol) [50]. Cortisol is often used for analysis of acute stress. When doing so it is best to collect blood samples before and after the potential stressor due to the large variability in basal values due to time of day and individuality between horses [56].

Evaluating acute stress: NLR

The evaluation of neutrophil lymphocyte ratios is an emerging physiological marker of acute stress. The NLR is determined by calculating the ratio of the total number of neutrophils to the total number of lymphocytes [57]. During a stress event, a significant increase has been found in NLR in humans, horses, and mice [55,58,59]. Neutrophils and lymphocytes are white blood cells impacted by HPA and SAM axis influence which leads to leukocytosis [60]. The exact mechanism of action of stress on NLR is unknown. What is known is that this response begins with an increase in lymphocyte numbers followed by increased neutrophil numbers. A study evaluating the NLR in rats during an acute stress response found that after six minutes of restraint, both neutrophil and lymphocyte numbers increased [58]. Neutrophil numbers increased until the two-hour mark while lymphocyte numbers reportedly dropped to baseline in between 15 minutes [58] and one hour [8]. Lymphocyte numbers continued to decrease below baseline until approximately the two-hour mark [58]. The use of NLR in behavioral studies is complicated as exercise has been shown to increase NLR in horses and humans [61,62]. However, studies in humans have found that individuals performing consistent exercise showed a decrease in NLR due to an increase in lymphocyte numbers [61]. In these populations, a significant change in NLR was only found during significant stress events [63]. A separate study in humans found that a significant difference in NLR was only found during high-intensity exercise [64]. While these findings have not yet been evaluated in horses, NLR use in behavior studies is growing due to the simplicity. Other physiological stress markers are also affected by exercise, so regardless of the evaluated marker, results need to be evaluated in relation to other variables [65]. Normal basal NLR values are approximately 60:40, however there is a high level of variability between individuals and as such evaluation of NLR in the context of acute stress is most accurate if evaluated before and after a potential stress event [58].

Evaluating acute stress: Non-hematological measures

Outside of hematological changes associated with stress, physiological stress in the horse has also been evaluated via eye and body temperature, heart rate (HR) and heart rate variability (HRV), and muscle tension [50,56,66]. As described above, horses increase their blood volume, cardiac output, and respiratory rate during a stress response. A study evaluating HR and HRV in horses compared horses while moving forwards (control) to horses moving backwards (acute stressor) for three minutes [67]. They found significant increases in HR and HRV during the backwards walking treatment compared to forwards walking, which agreed with evaluated conflict behaviors. Based on these results, they concluded that HR and HRV were suitable methods to evaluate horse's stress response during low exercise training [67]. As HR is also impacted by exercise, in the context of ridden horse welfare it is important to determine viability of HR as a stress indicator during exercise. One study evaluated horse's HR response to a novel object (umbrella) while trotting on a lunge line. They used a mathematical model to differentiate between the physical and behavioral components of HR, and found that there was an increase in the behavioral component of HR during exposure to the novel object [68].

The surface temperature of the skin is also influenced by increased blood circulation associated with a stress response [60]. This increase in temperature can be measured with the use of infra-red thermography cameras [60]. Temperature changes of the face have also been used to measure stress in multiple mammals. In the horse, these evaluations generally use the hairless periorbital region adjacent to the medial canthus of the eye [60]. It is important to consider that exercise will also increase body temperature, however a previous study evaluating eye and body temperatures during an exercise session found a significant difference associated with stress [69]. Horses were lunged for 15 minutes on two separate days. On one day they were lunged with a Pessoa training aid and the other day they were lunged without. They found a significant difference in eye temperature across the two treatments but no significant difference in neck or ear temperature. This study also evaluated core body temperature using a rectal thermometer and found a significant difference between treatments [69].

Muscle tension has also been used in recent years to evaluate acute stress in horses [66]. One study placed electrodes on muscles of the cheek, neck, and back which were used to evaluate muscle tension during three treatments (novel object, sham clipping, social isolation) compared to control (box stall) [66]. They did find significant changes to muscular tension between treatment and control, however the direction of change varied across muscles and treatments. It is also important to note that while these treatments were assumed to induce acute stress, they did not find any significant effect on plasma cortisol levels between any treatment and control. The use of muscle tension in ridden horse behavior studies is limited as locomotion also induces muscle activation which may be misinterpreted as muscle tension [66].

As physiological parameters are highly susceptible to error, particularly during exercise, behavioral parameters may provide a more accurate assessment of ridden horse welfare [56]. In addition to physiological changes, activation of the autonomic nervous system also leads to behavioral responses. These responses can either be active (fight or flight) or passive (freezing, hiding, exhibiting abnormal behaviors or stereotypies) [70]. Assessment of behavior is generally performed using an ethogram to assess the frequency or duration of conflict or pain related behaviors [56]. Due to the greater technical effort required to assess duration, frequency of behavior is more commonly assessed [56]. This is most commonly performed using video analysis but there has been success performing analysis during a riding session [71,72]. Historically, development of an ethogram for studies has been based on two source texts containing a thorough 143 behavior list and illustrations based on observations of natural horse behavior from a managed semi-feral herd, respectively [73,74]. In more recent years, qualitative behavioral assessment, horse grimace scale, and ridden horse pain ethogram have been developed [75–77]. The qualitative behavioral assessment focuses on assessing and quantifying the expressive quality of an animal's dynamic interaction with the environment and is based on the premise that human observers are able to integrate details of what an animal is doing and how they are doing it [76]. It involves an observer creating a list of terms to describe the horse's expressions, creating scoring sheets with the observer's terms in random order, and then having the observer score video clips with the scoring sheets. This method showed significant consensus between observers however there was no outside analysis of the horses' demeanor or behaviors and so more robust objective evidence is required to confirm accuracy [72]. Other ethograms commonly include evaluation of facial expression, the FEReq and Horse Grimace Scale (HGS) [77,78]. The FEReq contains 14 facial expressions developed from photographs of lame and nonlame horses during riding sessions. It was then utilized by veterinary professionals and horse owners to evaluate lateral photographs of training heads. They found that the ethogram could be reliably utilized to describe facial features, but they could not determine if lame horses could be differentiated from nonlame horses [77]. The HGS was developed based on the facial expressions of horses following surgical castration compared to horses who underwent nonpainful surgical procedures [78]. There is also an ethogram designed to evaluate pain in the face and body of ridden horses [71].

The ridden horse pain ethogram is a published ethogram comprised of 24 individual behaviors, developed to evaluate horses for musculoskeletal pain during riding [71]. The presence of ≥8/24 behaviors is likely to indicate the horse is in pain. This ethogram was designed to simplify evaluation of low-grade lameness by veterinarians. To develop this ethogram, Dyson et al. began with a with an ethogram developed to evaluate ridden horse behavior by a veterinary surgeon in equine orthopedics (Royal College of Veterinary Surgeons) and British horse society instructor, and a Diplomate of the American College of Veterinary Behavior and American College of Veterinary welfare based on previously published description of behaviors in ridden horses (conflict and pain related behaviors) [71]. To do so, video recordings of lame and non-lame horses were evaluated. A total of 117 behavioral markers were placed into three categories: facial markers, body markers (head and tail posture and movement), and gait markers (speed and regularity of rhythm, responsiveness, bucking, rearing, and sudden stops). Using this ethogram, a intrabserver repeatability study was performed using one observer and video recordings of 9 horses (3 non-lame, 6 lame). The average video times were 5±2.8 minutes. The observer was an equine veterinarian who had previously undergone one year of postgraduate equine training, and training in equine behavior [77]. A binary (yes or no) result for each behavioral marker was recorded twice in random order by the observer separately in the trot and canter on each rein and while moving in a straight line and while circling. This resulted in at least 4 analyses per horse which were analyzed to determine a binary occurrence score, a total sum of occurrence score, and mean occurrence score. The two observations were compared for consistency. The binary occurrence score for each horse from assessment one was compared to the score from assessment two, and the percentage agreement per horse and behavior was calculated. A Spearman's rank correlation between the mean occurrence from each assessment for all behavioral markers was performed to assess the consistency of behavioral markers. Additionally, the consistency of individual markers was further evaluated by calculating the average deviation of assessment one. When individual marker occurrence was evaluated, 6 markers had low agreement (56%) and 17 had slightly higher (78%) agreement. Markers with low agreement were omitted, although the authors do not specify if this was markers with 56% agreement and those with 78% agreement, or just the 6 markers in the first group. Additionally, behavioral markers which denoted similar features or movements which had identical results between markers, and high consistently between assessment one and two were combined to a single marker [75].

The second ethogram was used to evaluate recordings of lame (n = 13) and non-lame horses (n = 24) by the same observer as ethogram one at the trot and canter on the right and left rein, trot circles both directions, and transitions between gaits. The cohort of non-lame horses were all evaluated by an experienced lameness clinician on hard ground, after flexion tests, on the lunge on hard and soft surfaces, and while ridden. Any horse with a stiff-stilted gait in canter or a quadrupedally shortened cranial phase of the step were not included. All horses included were Warmbloods used for dressage (n = 11) or show jumping (n = 2), and ranged in age from 3-13 years. While the presence of conflict behaviors are a good indicator of stress but the absence of these behaviors does not definitively mean that the horse is not experiencing stress [56]. As such, it is best to measure physiological and behavioral parameters when evaluating stress in horses [79].

Chapter Two: Investigating Lateral Asymmetries & Equine Welfare

1. Introduction

Recent studies have shown frequent asymmetries in rider center of mass and pressure distribution during horse-back riding sessions. Despite anecdotal information that rider asymmetry increases the difficulty of training and may increase the risk of injury for the horse and rider, there has been little investigation into its effect on equine welfare [3,13]. Horseback riding is a highly dynamic sport that requires two athletes of different species to move as one. This synchrony is largely driven by the horse, with the rider expected to follow the horse's movement [9]. This skill improves with riding experience but requires consistent attention, even for advanced riders. Riders also affect equine locomotion during riding sessions [9]. The complexity of horse-rider interactions makes determining the causes and effects of asymmetric kinematics difficult to predict. In addition, horses and riders commonly show varying levels of individual lateral bias and many aids given by the rider during riding sessions are unilateral, such as using the left rein to turn left or vice versa [38,40].

While there is substantial evidence that asymmetries in rider kinematics are common, the effects of these imbalances on equine welfare are largely unknown [80]. Horse and human laterality can be due to conformation, injury, or coached discrepancies [40,80]. Human asymmetry has been documented while riding and on the ground [81]. Engell et.al (2019) evaluated lateral kinematics during riding sessions compared to while rocking side-to side on a balance chair [81]. This study found lateral asymmetries during both treatments, with the degrees of pelvis or head roll increasing during riding when compared to rocking the balance chair. This reported laterality, or at least the ability of the rider to move laterally, may not be a negative, however. A study that evaluated the relationship between riders' ability to independently move the pelvis while on an exercise ball with riding performance and equine ridden stress indicators found that rider's ability to roll the pelvis side-to-side is a strong indicator of riding performance and leads to the expression of fewer conflict behaviors, or less resistance, and more harmony with the horse. They suggest this is due to the rider moving their pelvis to maintain contact with the saddle. The results of this study suggest that some degree of lateral movement in the rider does not increase physiological stress in the horse and may be beneficial to the horse-rider interaction.

The objective of the current study was to investigate if lateral asymmetries in rider trunk kinematics are related to signs of equine pain or markers of stress during a short riding session. It was hypothesized that on average riders would display lateral asymmetry (tilt) while riding, and that increases in lateral trunk asymmetries would result in increases in markers of equine physiological and behavioral stress.

2. *Materials & Methods*

2.1 Ethical Approval

This study was approved by the Institutional Animal Care and Use Committee of Colorado State University (IACUC; protocol 6139). All applicable national, international, and/or institutional guidelines for the care and use of animals and their welfare were followed.

2.2 Horses

Six warmblood horses (4 geldings, 2 mares) with ages ranging from 8-17 years old were used for this study. Each of these horses are owned by Colorado State University and housed at the Equine Teaching and Research Center (ETRC) in Fort Collins, CO. All horses were experienced English riding horses and used for university riding classes prior to and during this study. On data collections days, horses were not ridden or worked outside of the present study. All horses were housed at Colorado State University's Equine Teaching and Research Center (ETRC) in group turnout on dry lot or pasture. All horses had access to shelter, free choice salt and water, hay through a slow feeder, and were fed a vitamin mineral supplement. Horses were fed to meet the requirements of moderate working horses [82]. Prior to the start of the study, all horses were assessed as sound by the instructor overseeing their care. During their use in university riding classes, horses were ridden five times per week for 45-60 minutes, at the walk and trot, with some canter. Twice a week they had a jumping session.

2.3 Riders

Experienced student riders were offered to participate in this study based on enrollment in a riding class at CSU using the participating horses. Three riders were able to participate in the study. Based on results from a self-reported survey, two of the riders had been riding for more than 10 years. The third rider had been riding for 2-5 years. All riders were right-handed and described their riding history as instructor-taught. Each rider had ridden at least one of the six horses prior to the study during riding lessons. Participants were not evaluated by the riding instructor when performing the riding pattern.

2.4 Study Design

Data collection for this study occurred at Colorado State University's Temple Grandin Equine Center (TGEC) arena in Fort Collins, Colorado during November and December of 2024. Two of the six horses had been ridden in the filming arena previously. The remaining horses had never been in the arena. Horse rider pairs (HRP) were assigned randomly using an internet-based random number generator [83]. No horse rider pairs were filmed more than once. Horses were ridden in their usual English tack and jumping saddles during data collection. During the riding session, each HRP rode for a total of 10-20 minutes. Riders were instructed to warm up for 5-10 minutes prior to performing a filmed riding pattern. The riding pattern consisted of two laps around the arena at the walk, two at the rising trot, and two at the canter in both directions. During the warm-up and riding pattern each rider wore a fitted riding shirt to allow for analysis of the rider's upper body tilt. Tilt was analyzed during the riding pattern as the HRP moved down one long-side of the arena in a straight line. Video recordings of the entire arena were utilized to evaluate the horse for pain related behaviors during the riding pattern using an ethogram. Each horse's physiological stress was evaluated by calculating the change in their neutrophil lymphocyte ratio from blood collected immediately prior to saddling and 5-10 minutes after the riding pattern ended and the rider dismounted.

Data from 11 HRP was available for analysis. Six HRP were included in data collection day one (*n= 6 horses, 3 riders*). Five HRP (*n= 5 horses, 2 riders*) were included in data collection day two. All horses and riders from collection day two were included in collection day one. One horse from collection day one was excluded from day two due to a mild acute injury. One rider from collection day one was unavailable during collection day two. Each horse was only ridden once per session. Riders rode 1-3 horses per session.

2.5 Fitted Riding Shirts

To allow for analysis of the rider's upper body placement, each rider wore a specialized long sleeved fitted riding shirt (The Refined Rider, The Equestrian "Straight Rider") during the riding sessions (Figure 1). Riders were given the option to wear the riding shirt on its own or on top of another fitted riding shirt. As shown in Fig. 1, the shirts have several horizontal and vertical lines to allow for upper body analysis, including a vertical line along the rider's midline on the anterior and posterior aspect of the shirt.

Figure 1. The fitted riding shirt with horizontal and vertical lines (The Equestrian "Straight Rider") from The Refined Rider worn by riders in the study to allow for upper body analysis.

2.6 Video Analysis

Continuous surveillance cameras (Reolink CH02 RLC-823A 16X) had been previously installed in the four corners of the TGEC arena 11 feet from the ground. Each riding session was continuously recorded. Three of the cameras (northwest, southwest, and southeast) were positioned to cover the opposing side of the arena from where the camera was mounted. To allow for head/tail visibility for lateral asymmetry analysis described later in this paper, the northeast camera was positioned to look south down the eastern long side of the arena. Due to the positioning of the northeast camera, a small area in the southwest and northwest corners of the arena was blind to all cameras. See Fig. 2 for the specific coverage of each camera.

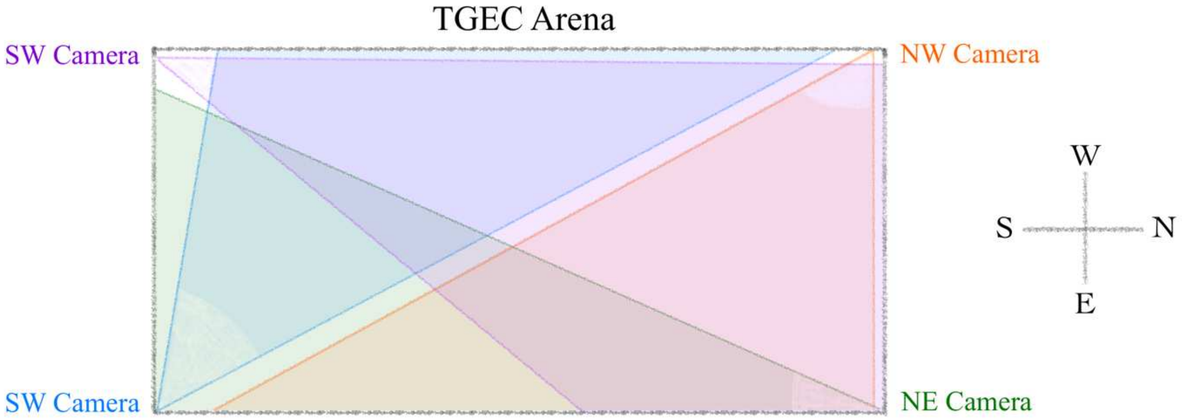

Fig. 2. Diagram showing the visible coverage of each camera in the TGEC arena.

2.7 Lateral Rider Asymmetry

To measure lateral trunk asymmetry (tilt), the camera in the northeast corner of the TGEC Arena was positioned with the field of view down the long side of the arena as described in section 2.6. This allowed for visualization of the vertical lines on the midline of the riding shirts which could then be measured as an angle compared to vertical (zero degrees) using Kinovea, a motion analysis software (2023.1.2). Virtual markers were placed on the top and bottom of the shirt's midline, near the top of the pelvis and top of the thoracic spine (when traveling right/away from the camera) or center of the riders' sternum (when traveling left/towards the camera) and a straight line was drawn between the two markers and compared to vertical (zero degrees) using the angle-to-vertical tool. This was then repeated for each frame as the HRP moved down the long side of the arena, with the pass beginning when the HRP exited the corner of the arena and began traveling along a straight line (defined as the front and hind feet grossly following the same track). Analysis for each pass was ceased at the end of the last stride where the HRP were traveling straight (when tracking right/away from the camera) or when the last visible stride ended while tracking towards the camera. A stride is defined as the time when the inside front leg (left front) first contacted the ground to the next time the same foot contacts the ground while the HRP traveled towards the camera, or from the first contact of the outside hind leg (right hind) to the next time the foot struck the ground when the HRP were traveling away from the camera. During some passes, the HRP entered or exited the camera view without riding the entirety of the long side of the arena. These passes were included if the pair rode a straight line for at least three strides. Only the strides where the HRP were riding a straight line were included. Tilt values were recorded at the walk, rising trot, and canter while tracking left and right, leading to six pass types: left walk, right walk, left trot, right trot, left canter, right canter. Canter passes where the HRP were not traveling on the correct lead (left lead traveling left, right lead traveling right) were not included.

Data from each frame, and the stride in which it occurred, was tabulated in Microsoft Excel (Version 16.95.4) to generate an average tilt and total range of motion (ROM) per HRP pass. Individual HRP tilt and ROM were also averaged together to get a total study value for each direction and gait combination (pass type). Average tilt and ROM for each direction were also calculated for individual horses and riders. The individual tilt values were averaged across HRP for each pass type. Missing passes present in our dataset were either the result of missing data, failure to maintain gait, incorrect lead, or inability to measure tilt due to lack of visibility of shirt lines. All passes that were excluded due to lack of visualization were the result of the horse's head and/or neck blocking the camera's view of the vertical shirt lines. Video frames where a tilt angle was not able to be measured were excluded from the data points of the pass. In instances where >50% of video frames for the pass were obstructed, the pass was excluded from tilt analysis. A total of eight passes from all horses measured were excluded due to lack of visualization.

The second stride for each pass type was graphed to allow for gross comparison of rider tilt throughout a stride with previously reported information (Fig. 3). As the number of video frames per stride varied between HRP, the time when each HRP began and ended their second stride was recorded and averaged by pass type across all HRP. This created an average time when the group started and ended their second stride. These time points were then used as the beginning and end points for the single stride graphs for each pass type.

2.8 Ridden Horse Pain Ethogram

Following the ridden sessions, pain and stress-related behaviors were assessed through video observations using the Ridden Horse Pain Ethogram (RHpE) [71]. The RHpE is a published ethogram comprised of 24 behaviors, developed by comparing behavioral markers in cohorts of lame (n = 24, lameness scores 1-4, median 3) horses and non-lame (n = 13) horses. Twenty-four behaviors were selected based on a high correlation with lameness and high intra-observer reliability. The most frequent behavioral markers are at least 10 times more likely to be seen in lame horses compared to non-lame horses. Lame horses had a mean score of 9/24, and a maximum score of 14/24 behavioral markers, while the non-lame horses had a mean score of 2±1.4 and a maximum score of 6±2 behaviors present during evaluation. It was determined that the presence of ≥8 of 24 behavioral markers is indicative of musculoskeletal pain [75]. This ethogram was further validated in a small cohort (n = 10) of horses with bilateral hind limb proximal suspensory desmopathy and sacroiliac joint region pain with lameness scores of 1-2/8. Following lameness abolition via diagnostic analgesics, scores were reduced on average 6.2 times per horse. [84].

In alignment with this ethogram, the horse rider pairs (HRP) in this study were given a short period (5-10min) to warm-up prior to observation, followed by a 5-10min session where the horse was evaluated for presence of any of the 24 behaviors at the walk, trot, and canter while traveling both directions. The number of behaviors present was totaled, and horses with a total score of eight or more behaviors were considered to have a positive ethogram for that session.

2.9 Blood collection

2.9.1 Neutrophil-Lymphocyte Ratios

Jugular blood samples were collected from each horse five minutes prior to the beginning of the warmup and five minutes after cessation of the riding session for analysis of changes to their neutrophil lymphocyte ratio (NLR) throughout the session. The number and distribution of neutrophils and lymphocytes in the body changes in response to cortisol and epinephrine [85,86]. Comparing NLR before and after a potential stress event can provide insight into the body's physiological response and has been used as a marker of acute stress in horses and other mammals 15,16]. The collected samples were placed in a vacutainer tube containing EDTA (BD Vacutainer, Franklin Lakes, NJ). Tubes were immediately inverted to ensure proper mixing with the anti-coagulant and placed on ice before being transported to the laboratory. A complete blood count (CBC) with 5-way differential was completed at the Colorado State University's Veterinary Diagnostic Laboratory using the Siemans Advia 120 Hematology System Analyzer. The NLR before and after the session was calculated using the following equation:

$$NLR = \frac{total\ \#\ Neutrophils}{total\ \#\ Lymphocytes}$$

The change in NLR before and after the session was found using the following equation:

$$\Delta\ NLR = pre\ session\ NLR - post\ session\ NLR$$

2.9.2 Cortisol Circadian Rhythm

Twelve days after the last data collection day, blood samples were collected from each horse for analysis of cortisol circadian rhythm to test for a chronic physiological stress response.

Blood collection was performed on a day when the horses were not exercised. Six milliliters of blood were drawn from each horse at 8am and 4pm via jugular venipuncture with a 20-gauge needle and a sodium heparin vacuum tube (BD Vacutainer, Franklin Lakes, NJ). Each tube was immediately placed on ice before being centrifuged at 3500rpm (1534 g-force) for 10 minutes. Immediately following centrifuging, plasma was removed from the blood tube and placed in a polypropylene microcentrifuge tube and subsequently frozen. Samples were later sent on dry ice to Cornell University's Animal Health Diagnostic Center for immunoassay cortisol analysis (IMMULITE 2000 Veterinary Cortisol, Llanberis, Gwynedd United Kingdom). Each horse's CCR percent change was found using the following equation:

$$CCR\ \% = \frac{pm\ cortisol\left(\frac{ug}{mL}\right)}{am\ cortisol\left(\frac{ug}{mL}\right)} x\ 100$$

2.10 Statistical Analysis

A Pearson's correlation coefficient was run to test for any significant correlation between tilt values for each pass type (LW, LT, LC, RW, RT, RC). A two-way ANOVA was conducted to analyze the association between NLR difference (response variable) and individual riders (fixed effect) or NLR difference (response variable) and individual horses (fixed effect). A separate two-way ANOVA was also run to analyze the association between tilt value (response variable) and rider direction interaction (fixed effect). Pre- and post- session neutrophil lymphocyte ratios were analyzed for normality using a Shapiro-Wilk Normality test before a paired t-test was run to determine if there was a significant difference between the time-points. Association between rider tilt and change in NLR was analyzed using Spearman's rank correlation coefficient the rider tilt data was not normally distributed Analyses were conducted using R software (version 4.3.2) with significance declared at *P* = 0.05 and trends declared at *P* = 0.10. All results are presented as means and SD.

3. Results

3.1 Lateral Rider Asymmetry

The total number of HRP passes included varied across pass types from 13 to 21. The group mean tilt and range of motion means and standard deviation for each pass type are listed in Table 1. The number of strides per pass ranged from 3-15. The results for left passes at all gaits showed a right rider tilt. The opposite was seen when the riders tracked right, with tilt averages at the walk, trot, and canter showing a left rider tilt. The mean for the absolute tilt for each direction-gait combination ranged from 1.88 to 4.48 degrees (Table 1). Variation between individual horses and riders can be seen in Tables 2 and 3. Most individual passes also had an average tilt in the direction opposite to the direction of movement. In only 8 (1 left walk, 1 left trot, 2 left canter, 4 right canter) of 105 total passes the rider had an average tilt in the same direction as the direction of movement. A positive correlation was found between all gaits when tracking left, and between the right walk and right canter, and right trot and right canter (Table 4). There was a trend for a positive correlation between the right walk and trot, (P = 0.058) (Table 4). There was no significant difference in tilt values for riders when comparing directions (F = 3.065, P = 0.084 but a trend was present. Figure 3 shows the single stride graphs for each pass type. Across all pass types, rider tilt varied in a waveform pattern throughout the stride.

Table 1. Tilt and range of motion (ROM) mean±sd for each pass type. Degrees of tilt are reported relative to the camera. A positive tilt value indicates the rider tilted in the direction opposite to the direction of travel of the HRP.

Pass Type	**Tilt** (°; mean±sd)	**ROM** (°; mean±sd)
Left Walk	3.10±1.96	8.45±3.38
Right Walk	4.48±1.48	9.88±4.54
Left Trot	1.88±1.86	7.47±4.63
Right Trot	3.43±2.48	8.59±3.02

Left Canter	2.10±2.85	11.37±5.01
Right Canter	2.23±3.72	12.98±4.43

Table 2. Tilt and range of motion (ROM) mean±sd for each rider by direction. Degrees of tilt are reported relative to the camera. A positive tilt value indicates the rider tilted in the direction opposite to the direction of travel of the HRP.

Rider	**Direction**	**n**	**Tilt** (°; mean±sd)	**ROM** (°; mean±sd)
I	Left	25	2.239±2.138	9.551±4.879
	Right	28	2.324±3.400	11.776±4.622
II	Left	11	0.712±0.739	6.186±3.571
	Right	12	3.423±1.534	8.810±2.979
III	Left	14	3.759±2.243	9.508±4.216
	Right	15	5.026±1.581	9.404±4.146

Table 3. Rider tilt and range of motion (ROM) mean±sd for each horse by direction. Degrees of tilt are reported relative to the camera. A positive tilt value indicates the rider tilted in the direction opposite to the direction of travel of the HRP.

Horse	**Direction**	**n**	**Tilt** (°; mean±sd)	**ROM** (°; mean±sd)
A	Left	9	3.251±2.259	7.697±3.869
	Right	10	3.506±1.440	9.475±6.088
B	Left	9	0.080±1.230	9.193±5.596
	Right	11	1.276±2.755	9.603±4.348
C	Left	5	2.682±0.930	9.454±3.634
	Right	6	3.319±1.809	11.596±2.774
D	Left	9	1.120±0.741	5.959±3.276
	Right	11	2.945±1.765	10.797±3.821
E	Left	7	2.121±1.590	11.195±5.583
	Right	7	1.531±3.509	12.016±5.117
F	Left	11	4.080±2.463	9.878±4.361
	Right	10	6.941±1.740	10.367±3.417

Table 4: Pearson's Correlation Analysis results comparing tilt values for different pass types. Bolded values indicate significance. Italicized values indicate a trend.

Pass Type 1	**Pass Type 2**	***r***	***P*-value**
Left Walk	**Left Trot**	0.90	**<0.001**
Left Walk	**Left Canter**	0.69	**0.038**
Left Trot	**Left Canter**	0.69	**0.009**
Right Walk	*Right Trot*	*0.50*	*0.058*
Right Walk	**Right Canter**	0.72	**0.003**
Right Trot	**Right Canter**	0.61	**0.005**
Left Walk	Right Trot	0.39	0.146

Left Walk	Right Canter	-0.56	0.850
Left Trot	Right Canter	0.28	0.239
Right Walk	Left Walk	-0.08	0.807
Right Walk	Left Trot	-0.02	0.938
Right Walk	Left Canter	0.37	0.262
Right Trot	Left Trot	0.20	0.384
Right Trot	Left Canter	0.48	0.094
Right Canter	Left Canter	0.41	0.186

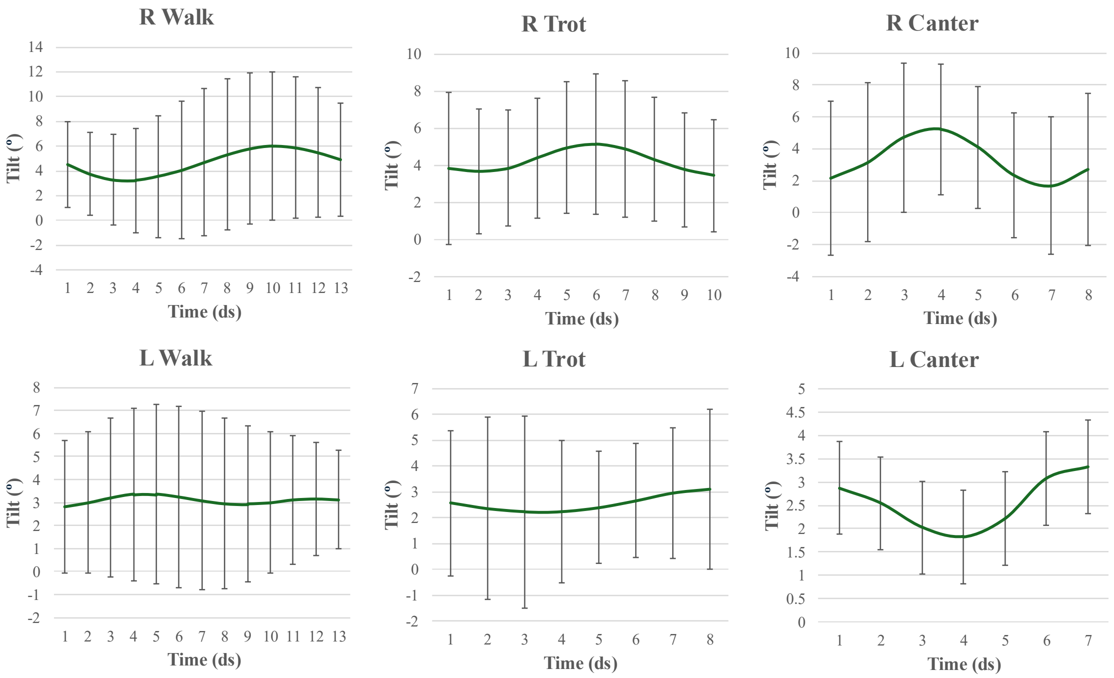

Figure 3. Mean and SD of rider tilt values during the second stride of the tilt analysis across horse rider pairs for each gait direction combination (pass type).

3.2 Ridden Horse Pain Ethogram

The mean Ridden Horse Pain Ethogram score was 3/24. The behavioral markers displayed during this study and the number of HRP who displayed them are listed in Table 5. None of the horses in the present study had scores of ≥8/24, with the range of scores between 1 and 5 out of 24 behaviors (Table 6).

Table 5. Behavioral markers from the Ridden Horse Pain Ethogram expressed during the riding sessions, as well as the number of pairs who displayed them.

Behavioral Marker	**# of HRP**
Repeated changes of head position (up/down), not in rhythm with the trot	3

Head in front of vertical >10º for >10sec	10
Head position changes regularly, tossed or twisted from side to side, corrected constantly	3
Ears rotated back behind vertical or flat >5sec, repeatedly lie flat	3
Tail clamped tightly to middle or held to one side	1
Tail swishing large movements, repeatedly up and down/side to side/circular, repeated during transitions	4
A rushed gait (frequency of trot steps >40/15s), irregular rhythm of trot/canter; repeated changes of speed in trot/canter	1
Hindlimbs do not follow tracks of forelimbs but repeatedly deviated to left or right on three tracks in trot or canter	1
Spontaneous changes of gait	3
Sudden change of direction, against rider's cues; spooking	3
Reluctance to move forwards	3

3.3 Cortisol Circadian Rhythm

All horses' cortisol levels were higher during the 8 am blood draw than during the 4 pm blood draw (Table 6). The CCR percentage for each horse varied from 24.24% to 52.04%. 4/6 horses had a CCR percent change >30%.

Table 6. The a.m. cortisol value (ug/mL), p.m. cortisol value (ug/mL), and CCR percent for each horse in the study.

Horse	**a.m. cortisol (ug/mL)**	**p.m. cortisol (ug/mL)**	**CCR (%)**
A	5.18	1.28	24.71
B	4.54	1.74	38.33
C	5.61	1.36	24.24
D	3.67	1.91	52.04
E	5.46	1.89	34.62
F	5.84	1.89	32.36

3.4 NLR

The effect of the riding session on Neutrophil Lymphocyte ratio varied across HRP. NLR increased in five HRP, decreased in five HRP, and stayed the same for one HRP. A Shapiro-Wilk Normality Test was run which found no evidence of non-normality. A paired t-test did not find a significant difference in values between the pre-session NLR (0.89±0.024) and post-session NLR (0.72±0.08); T(10) = 0.73, *P* = 0.48 (Table 7).

Table 7. Pre- and post- session NLR for each HRP, Δ NLR per HRP and RHpE scores for each HRP.

HRP	Horse	Rider	Pre NLR	Post NLR	Δ NLR	RHpE
1	A	I	-0.2	0.3	-0.5	2
2	B	II	1.5	0.4	1.1	3
3	C	I	0.4	0.2	0.2	4
4	D	II	0.5	0.5	0.0	1
5	E	III	1.6	2.0	-0.4	4
6	F	I	0.5	-0.4	0.9	2
7	B	I	1.4	1.6	-0.2	4
8	E	I	0.7	1.4	-0.7	2
9	D	I	1.6	-0.2	1.8	2
10	F	III	1.1	0.9	0.2	4
11	A	III	0.7	1.2	-0.5	5

3.5 NLR – Tilt type, Horses, Riders

None of the pass types revealed a significant effect between rider tilt and NLR difference (*P* ≥ 0.05). The right walk tilt showed a very weak trend (*P* = 0.10) (Table 8). Neither ANOVA with horse (F = 0.050, P = 0.952) or rider as main treatments (*F* = 0.612, *P* = 0.706) had an effect on NLR.

Table 8. Spearman's rank correlation comparing rider tilt and the change in neutrophil lymphocyte ratio.

Pass Type	*r*	***P*-value**
Left Walk	-0.411	0.751
Right Walk	0.065	0.100
Left Trot	-0.20	0.836
Right Trot	-0.1	0.288
Left Canter	0.243	0.569
Right Canter	0.171	0.878

The Spearman's rank correlation found no significant association between tilt value and change to NLR for any direction-gait combination (Table 8).

4. Discussion

The cortisol circadian rhythm results from the study horses showed that 4 of 6 horses had a CCR >30% (Table 6). This is the reference value used by the laboratory which analyzed the samples and has been used in previous literature as the determinate for a normal CCR [87].

These results indicate that the two horses with CCR <30% may have been experiencing chronic stress during this study. However, other research has found values as low as 20% in horses with no known pain, stress, or metabolic changes [88]. Additionally, research reports that cortisol levels are at their highest between 6-9am [88,89]. Samples in this study were drawn at 8 am which may have been after the peak values for these horses, potentially leading to an artificially lowered CCR. These two horses were also related, and a genetic component may have been present.

Evaluation of the rider tilt values measured in this study showed that all riders had some level of lateral asymmetry, and that on average they tilted in the direction opposite to the direction of travel at all measured gaits and directions (Table 1). Only 7.6% of the total passes differed, tilting in the direction of the HRP's direction of movement. One rider's asymmetry was balanced as shown by similar tilt values in both directions (rider I; left: 2.239°, right: 2.324°) (Table 2). Others had greater variation when comparing the two directions (rider II; left: 0.712°, right: 3.423°). Variation was also seen when comparing rider tilt on different horses (Table 3). While interesting, this data is biased as not all possible horse and rider combinations were evaluated during this study. There was a strong positive correlation between most tilt values when comparing different gaits while traveling the same direction (Table 4). However, there was not any significant correlation when comparing tilt values in the opposite direction at the same or different gaits. These results are biased by the fact that HRP had an unequal number of replications for each pass type. Due to the small sample size in this study, rider and horse-specific tilt for each pass type was not evaluated. However, the variation in tilt values by direction (Table 2) may provide some insight into why there was a positive correlation across gaits while traveling the same direction but no correlation when compared to the same or different gaits while traveling in the opposite direction. Based on this information, future investigation into this relationship is warranted.

The acute stress responses from the horses as shown in the NLR, were not influenced by riders. Since there was a lot of individual horse variation. No significant difference was found in neutrophil lymphocyte ratios before and after the riding session in the present study. When comparing rider tilt to changes in neutrophil lymphocyte ratio, we did not find a significant effect for any pass type (Table 8). This suggests that trunk tilt alone does not cause a physiological acute stress response as measured in NLR in the horse after a short, moderate intensity riding session. These results agreed with our behavioral assessment. Evaluation of the RHpE did not find any horses exhibiting greater than five of the 24 pain related markers (Table 5, Table 6). Scores <8/24 is considered nonsignificant and are not indicative of musculoskeletal pain [71]. These results did not support our second hypothesis, that a significant increase in NLR and RHpE would be seen during passes with increased rider tilt.

Previous studies have reported conflicting information on the direction of lateral asymmetry, with some studies reporting higher weight on the right during riding and while sitting on a flat surface [37] and others reporting higher weight on the left in riders sitting on a flat surface [35] and while riding [35,36]. The study which found higher weight on the left while riding evaluated the riders while at stance and on a straight line at the sitting trot to the right and left [35,36]. Another study reported an even split of left and right asymmetries in stirrup weight distribution during simulated riding with a saddle on a wooden horse [38]. The directionality of tilt reported in the present study has not been previously documented, and the cause of the deviation from reported literature is unknown. However, given the discrepancy across previous literature, further studies are warranted. It is worth mentioning that this study was performed in an indoor arena.

The arena type utilized in asymmetry studies is not always reported and may be an unexplored factor affecting rider tilt. Additionally, several studies measuring rider asymmetry have been performed on a treadmill [14,17] or riding simulator [38,39] which may also have an impact on results. Whil the direction of tilt was unexpected, the fact that tilt commonly occurred agreed with previous research and our first hypothesis. It is well documented that the majority of riders, regardless of skill level, sit with asymmetrical force in the saddle and while unmounted [11,13,18]. These findings are also reflected in non-riding individuals [34,90].

The current study's results with the data analyzed appear to disagree with the anecdotal belief that rider asymmetries decrease equine welfare[3,13]. However, the present study was performed on a small sample size and does not account for potential long-term implications of rider asymmetries or biases in the measured variables. RHpE behavioral markers are all scored equally, despite evidence that some markers are more indicative of musculoskeletal pain than others [91]. Several studies have shown that lateral trunk tilt while riding increases forces under the saddle on the ipsilateral side while traveling in a straight line [36,80], which could lead to unequal loading of the horse's limbs or imbalances in muscle growth to compensate for the rider [41]. Additionally, to better understand equine welfare as it relates to rider kinematics, we must also consider that some degree of rider laterality may be a result of asymmetry, and potentially disfunction, in the horse's body. One study explored this idea, collecting saddle pressure mat data on a small subset of horses with decreased performance while being ridden by a professional rider [30]. The results of the pressure data showed asymmetries that corresponded with a clinician's assessment of the horse. Diagnostic local analgesics were administered, and pressure mat data was again collected which showed marked improvement in pressure distribution and increased range of fluctuations during the stride cycle, indicating a decrease in gait abnormalities and increase in hind-end impulsion. These results agreed with clinician assessment and rider comments.

Even in the absence of underlying pathology, the equine back is not static and moves in multiple planes and axes during locomotion [9]. As the present study only evaluated lateral rotation, that will be the primary movement discussed, however it is important to note that this is only one aspect of equine movement. Rider movement documented in this study appears to follow previous literature. However, this is based on single stride graphs (Fig. 3) which were averages across HRP. Variation in time of footfall and stride duration of each horse was present. Thus, direct comparison to previous literature cannot be made.

While walking, all four limbs strike the ground at different times. The horse’s back, saddle, and the rider's pelvis undergo one cycle of lateral rotation (tilt) per stride. As the hind limb lifts off the ground, they roll to the ipsilateral side, away from the planted hind limb. This rotation then reverses as the opposite hind lifts off the ground. The total range of motion during this cycle has been reported as 5.6±0.6 degrees [14] and 5.3±1.2 degrees [15]. The results of the present study were in agreement with the cycle of lateral rider asymmetry previously documented. We did see a larger range of motion in the walk than previously reported, with an average of 8.45±3.38 degrees while tracking left, and 9.88±4.54 degrees while tracking right (Table 1). This larger range of motion may be due to differences in rider experience level, as previous research has found that professional riders keep their pelvis closer to the midline of the horse than amateur riders [15]. The populations reported on above were largely professionals, however there was group of amateur riders also had a smaller ROM (6.3±1.9 degrees) than in the present study [15].

The trot also has one cycle of tilt per stride, but previous investigations of the movement of the rider's pelvis have shown large variability between studies. The horse's trunk and saddle roll towards the weight bearing hind limb during its stance phase which then reverses just prior to the foot leaving the ground [17]. Previous research agrees that the tilt of the rider's pelvis is out of sync with the horse and saddle, rotated maximally towards the hind leg on ground contact before rolling away from the planted limb during the stance and suspension phases [15,17]. However, there is variation in reported movement of the rider's pelvis during the second half of the stance phase. Byström et al. (2009) found that rider tilt varied greatly between horse-rider pairs and for some were largely asymmetrical between diagonal pairs during the sitting trot [17]. Variation was also seen during the rising trot. During the rising trot, the rider sits during the stance phase of one diagonal pair and is out of the saddle during the stance phase of the opposite diagonal pair. One study found that the rider's pelvis tilted away from the loaded hind leg during stance but the magnitude of tilt is decreased during the sitting diagonal stance compared to the non-sitting diagonal [18]. This finding corroborates with the current study findings although analyzed in a different way. The same study also found that the pelvis stiffens during the sitting stance, suggesting this may account for the decrease in tilt. Other studies have reported that the rider's pelvis and trunk roll in opposite directions [15]. Range of motion of the riders pelvis during trot has been reported as 5.1±1.1 degrees [14] and 4.1±1.0 degrees [15]. Riders in the present study closely followed the reported movement the rider's pelvis as documented in previous studies [15,17]. The current study also saw a larger range of motion of the rider's trunk (7.47±4.62 degrees left trot, 8.59±3.02 degrees right trot) when compared to rider's pelvic range of motion reported previously (Table 1). As with walk, this is likely due to the variation in the population of riders [15]. Additionally, we may have seen different results if the riders had performed a sitting trot instead of rising trot. Previous literature documented a smaller lateral range of motion at the sitting trot when compared to the rising trot [19].

The canter is a three-beat gait with a leading and trailing side of the body. This asymmetrical pattern is used to identify which lead the horse is on, with the left lead indicating that the left legs are the leading limbs and vice versa. During a canter lead, the trailing hind strikes the ground first, followed by the leading hind and trailing front leg striking simultaneously. The leading front leg strikes last, followed by a phase of suspension. Generally, horses are ridden on the same lead as the direction of movement (left lead while tracking left) but cantering on the opposite lead (counter canter) is also possible among more experienced horse-rider pairs. While cantering, the horse's trunk rolls toward the side of the trailing hind limb while planted, then rolls towards the side of the leading limbs during the diagonal stance phase before reversing around the time of contact of the leading front leg. Previous literature has reported that the movement of the rider's pelvis and trunk has inversely mirrored the roll of the horse's trunk through a range of motion of 5.9 ± 1.5 degrees [15,92]. In the present study, however, the movement of the rider's trunk more closely followed the movement of the horse's trunk. The range of motion found at the canter in the present study was also larger than previously documented, at 11.37±5.0 degrees when tracking left and 12.98±4.43 degrees when tracking right (Table 1). The reason for this discrepancy with previous literature is unknown but may be the result of measuring the rider's trunk tilt relative to the position of their pelvis instead of comparing to a global coordinate system [92].

When graphed, cyclicity in rider tilt throughout the stride is apparent (Fig. 3). On visual examination, these cycles appeared more consistent when tracking to the right than tracking left. However, this is anecdotal, and no substantial difference was found between the two groups

(Table 1). There are a limited number of studies evaluating this movement, and by extension no determined normal values for rider motion or laterality. Given the movement of the horse's trunk and the saddle, it is to be expected that some movement will be transferred to the rider. Conversely, laterality can be exacerbated by pathologies of the horse or ill-fitting tack [4,30]. In addition, rider tilt is also influenced by rider conformation, injury, and trained movement patterns [40,80]. The multitude of factors that affect rider asymmetry complicate determining normal versus atypical tilt but also highlight the importance of doing so. Future investigations need to set standards for rider tilt to help differentiate between normal locomotion and potential abnormalities.

While lateral rider asymmetries may be indicators of underlying pathologies, they are also potentially beneficial to horseback riding. A study evaluating the correlations between riders' ability to move their pelvis through three motions on an exercise ball with riding performance and equine welfare indicators found that as riders' ability to roll their pelvis from side to side on the ball increased, so did their riding quality and harmony [37]. Additionally, horses ridden by riders who scored 'good' on the exercise ball test displayed fewer conflict behaviors during riding when compared to horses ridden by riders who scored lower on the ball test. They suggest that the ability to move the pelvis side-to-side may allow the riders' seat to stay in more consistent contact with the saddle during locomotion. Additionally, it may also improve the riders' ability to tip the pelvis anteriorly and posteriorly throughout the stride, as there should be a small amount of laterality during this motion [37]. It is important to note that horses ridden by riders in the 'good' group did have a significantly higher heart rate when compared to horses ridden by riders with a lower score, however there was not significant difference in cortisol values [37]. Eighteen of the 20 riders included in this study weighted the right side of the saddle more heavily while seated with no significant correlation between pelvic roll ability and seated weight difference. However, pelvic tilt was not analyzed during the riding session [37]. The results of this study suggest that pelvic tilt ability may improve communication and connection between the horse and rider and, potentially, that pelvic tilt is a better indicator of riding ability than lateral symmetry during a seated pressure test.

As the connection of movement in the horse-rider pair is improved with an experienced rider [31] and accurate timing of the riders pelvic and trunk motion is related to higher dressage scores [93], the results of the exercise ball study could lead one to assume that equine welfare would be decreased when ridden by a less experienced rider. However, Strunk et. al (2018) found no difference in equine behavioral assessment when comparing beginner and advanced riders [32]. Furthermore, it could be easily assumed that more experienced riders would display less asymmetry and by extension a better connection to the horse, but there are conflicting conclusions in the research on this topic. Several studies comparing novice and experienced riders have found that the experienced riders were more stable and symmetrical [33,39,80], however there are also reports that asymmetry increased with riding experience [11]. Overall, more research into the potential effects of asymmetries in rider kinematics is needed.

This study provides information on one aspect of rider asymmetry through a limited number of parameters and a small, unbalanced population of horses and riders. When evaluating the findings of this study, these limitations must be considered. Not all possible horse rider pairs were included. Horses were not formally evaluated for soundness or tack fit prior to the start of the study. While none of the horses included were determined to show acute stress or pain during the riding sessions, the presence of underlying pathologies is still possible and may have unknowingly affected results. Results may have been influenced by the low structure of the riding program and/or the unstructured warm-up (although this type of warm up is common in studies of this nature). Due to the necessary positioning of the cameras to allow for tilt analysis, there were small sections of the arena that were not visible on any camera, and as such any behaviors performed in those areas were not recorded or included in analysis. Due to the use of riding shirts with the ability to twist, there may be some discrepancies in tilt analysis due to misalignment of the shirt over the rider's midline. The shirts were visually inspected before and after each ride to limit this possibility, but minor discrepancies are possible. Future evaluation of the impact of rider asymmetries on equine welfare with consideration of populations and parameters not evaluated in the present study are warranted and necessary before any conclusions on the relationship can be drawn.

5. *Conclusions*

Evaluation of rider asymmetry is multifactorial, and future investigation is needed before any conclusions can be made on the implications of rider asymmetry on equine welfare. This study found that riders tilt in the direction opposite to the direction of movement at the walk, rising trot, and canter. The magnitude of tilt changes throughout each stride in a cyclical pattern. A short, moderate intensity riding session by an asymmetric rider did not lead to a significant change in the horses in neutrophil lymphocyte ratio, or the display of a significant number of pain related behaviors. Future investigation should evaluate a normal range of rider tilt and validate the use of specialized riding shirts in tilt evaluations. If validated, the use of these commercially available shirts and a slow-motion video-camera could provide a low-cost and accessible method of evaluating rider tilt.

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