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Repeatability vs Complexity: Kinematic comparison between a dressage simulator and real horses.

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Abstract

Riding simulators are designed to replicate movement of a horse for the purpose of assessment and training of horse riders, but little is known about their similarity in replicating movement of horses. This study tested the validity of a dressage simulator, by measuring cycle/stride duration, range and symmetry of displacement of the simulator and comparing displacement vectors to that of real horses trotting on a treadmill. A reflective marker was placed on the midline of the simulator at the estimated level of the 18th thoracic vertebrae (T18), and over the T18 spinous process of ten horses. The simulator displacement was recorded in trot mode, while the real horses trotted at a comfortable speed on a treadmill. Displacements in three axes of motion were measured using 10 high-speed video cameras sampling at 240Hz. Correlation tests showed high levels of statistical repeatability and symmetry of the simulator between multiple runs. Mean cycle/stride duration of the simulator was significantly faster than the group of horses by 0.17 seconds. Significant differences between the simulator and horses were shown in overall displacement in two axes, the simulator displaying 70% greater displacement in the mediolateral axis, 22% greater displacement in the craniocaudal axis, but displaying 12% less movement in the dorsoventral axis, which was not statistically significant. Displacement trajectories showed similarities in the frontal plane, displaying a butterfly-shaped sequence, but clear differences in the sagittal plane, with the horses showing an oval pattern of displacement and the simulator a clear linear displacement. Caution must therefore be taken with assumptions that riders will move in the same way on a simulator as they would on a real horse.

Keywords: equine, horse, mechanical, rider, treadmill

Conflict of interest statement

The authors have no conflict of interest to disclose.

1. Introduction

The British Horse Society (BHS) states that there are just under one million horses in the UK, with over three million people reporting to have ridden within the last year (National Equestrian Survey, 2019). Despite this, riding has received relatively little research focus compared to other sports. Studies have reported the positive effects of riding for improving sitting and standing postural control (Araujo et al., 2011), for improving balance (Shurtleff & Engsberg, 2012), increased gait speed and muscle strength (Aranda-García et al., 2015) and psychological well-being (Davis et al., 2009).

With advancing technology, a large variety of simulators are now widely used for multiple applications including learning to drive (Winter, Leeuwen, & Happee, 2012), training nurses (McCaughey & Traynor, 2010) and pilot performance testing (Müller et al., 2009). Riding simulators are currently used for learning to ride, rehabilitation of horse riders after injury and more recently for assessing the riding position or posture of professional riders (Olivier et al., 2017). The Racewood dressage simulator was used in this study as it is a widely used simulator and consists of a system of cranks and pullies, housed on a fixed steel base and covered by a fiberglass shell moulded to resemble the shape of a horse (Racewood 2020). The shell is able to move in three planes of motion and is designed to replicate the movement of a real horse and therefore to displace the rider in a similar way to that of a live horse.

There is a paucity of evidence on whether simulators replicate the movement of a real horse and allow a rider to follow the movements in the same way as they would whilst riding. It remains to be seen if riding simulators have the ability to repeatedly reproduce the same degree and pattern of displacement with every simulated motion cycle or if the movement patterns derived from the simulator are symmetrical, particularly in the mediolateral axes.

Laterality is becoming increasingly investigated in equestrianism. Symmetry of horse and rider locomotion is important to preserve physical soundness and prevent injury (Mackechnie-Guire et al., 2018), and also in competitive horses with the aim of increasing performance (Peham et al., 2001).

Few studies have incorporated the use of riding simulators, those that have done so principally used them as a tool to assist in the assessment of riders (Ille et al., 2015; Longhurst & Leśniak, 2013). Only a limited number of studies have examined the action of a riding simulator or compared their movement to that of a real horse. Walker et al. 2016 focused on the comparison of a racehorse simulator to that of a thoroughbred racehorse, making it difficult to extrapolate their findings to other riding disciplines. They reported that the racehorse simulator moved considerably differently to the racehorse however, given the differences between equestrian sports, it is difficult to transfer these findings to other simulators such as a dressage simulator. Park et al. (2014) tested a 'robo-horse' simulator used for hippotherapy and examined the validity and test-retest reliability comparing acceleration data from the simulator to seven real horses. This simulator was only able to produce movement in two dimensions, lacking lateral movement, and although it was capable of simulating walk, trot and canter, only walk gait was tested. The authors found excellent test-retest reliability of the simulator but poor correlation between acceleration data for the simulator and real horses.

Asymmetry of horses occurring due to biological systems is generally accepted and has been documented (Back, Schamhardt, & Barneveld, 1997; Murphy, Sutherland, & Arkins, 2005). This asymmetry is commonly described as the "dominance" or "handedness" of the horse. Causes of this "handedness" have been suggested to be related to the laterality of their grazing position (McGreevy & Rogers, 2005), having a tendency to repeatedly place a favored fore-limb in a more cranial position in comparison to the contralateral limb, and/or due to skeletal asymmetry (Davies & Watson, 2005).

As horses can be naturally asymmetrical, and as this asymmetry can vary between individual horses, then questions must be raised about the accuracy of any data collected regarding the true symmetry of the rider. Rider data can only be accurate and reliable if we can show that the horse and the saddle are symmetrical, which is extremely difficult under field conditions. Any asymmetry of the horse or saddle will influence the balance and stability of the rider. If simulators can be shown to be symmetrical, repeatable and allow the rider to move in the same pattern as on a real horse then this may provide the most accurate method of assessing rider's movement pattern and symmetry.

Aims and Objectives

The aims of this study were to examine the cycle duration (equivalent to stride duration of a horse), range and symmetry of movement of a dressage simulator, and to determine the validity and reliability of the simulator through comparing its displacement pattern at T18 with a group of horses trotting on a treadmill without riders. The objectives of this study were to 1) to measure the cycle duration and amplitude of displacement of a dressage simulator in the mediolateral, craniocaudal and dorsoventral axes of movement; 2) to determine the repeatability of the displacement of the simulator; 3) to measure the stride duration and amplitude of displacement of a group of horses trotting on a treadmill in the mediolateral, craniocaudal and dorsoventral axes of movement; and 4) to compare the stride duration, movement trajectories and displacement amplitudes of the simulator to that of the horses. We hypothesised that the dressage simulator and the horses will differ in stride duration, demonstrate different patterns of movement and show significant differences in the amplitudes of displacement.

2. Materials and Method

2.1 *Riding Simulator*

For this study a Racewood Dressage Simulator (Racewood Ltd, Cheshire, UK) was used (Figure 1). This simulator has five speeds, or 'gaits', each with distinct frequencies and amplitudes of displacement (slow walk, fast walk, slow trot, fast trot and canter). A 10mm reflective marker was placed on the centre point of the simulators body, immediately behind the back of the saddle which would correspond to the 18th spinous process (T18). The movement at the midline of the simulator was recorded on speed 4 (fast trot) without a rider using 10 (Bonita 10) cameras sampling at 240Hz and analysed using Vicon Nexus 2 3D motion capture system (Vicon Motion Systems Ltd, Oxford, UK). The displacement of the reflective marker was recorded over two consecutive runs each for a period of 60 seconds and then a further 10 runs for 20 seconds each. The displacement data from each of the mediolateral, craniocaudal and dorsoventral axes were collated from each run.

2.2 *Real horses*

Ten horses of mixed breed with mean age 9±2.7 years, height 16.1±3 hands high (equal to 1.65±0.08m) and weight 566±26 kg were used from a range of sporting disciplines. These horses were a convenience sample, all in regular ridden work and assumed to be sound and pain free by their owners, riders and veterinary therapists. All horses were accustomed to trotting on a treadmill. A 10mm reflective marker was placed on the midline of each horse at the level of the T18 spinous process, and on the right forelimb hoof of each horse. They were trotted on a treadmill without riders and overseen by the same experienced treadmill operator at a pace that each horse looked relaxed and comfortable with (~ 3.0 m/s). Movement was recorded using 10 Pro-reflex cameras (Qualysis AB, Goteborg, Sweden) sampling at 240Hz and data extracted and exported.

Figure 1 here

2.3 *Data Processing*

All data were exported to Microsoft Excel (Microsoft Co, Redmond, WA). Data from the 2x60 second simulator runs were cut and separated into 20 full cycles of displacement for each run using the midpoint of displacement in the x-axis as the start and finish point of each cycle. The mean displacement of all 40 cycles was calculated in the x, y and z-axes. In order to investigate symmetry of displacement in the x-axis the reference point for the mid position was taken as the point at which the simulator crosses its own displacement path. Data from the 10x20 second simulator runs were cut and separated into 10 full cycles of displacement per run. The mean and standard deviation of each of these 10 runs were calculated in all three axes.

Data from the real horses were separated into stride cycles, tracked using data from the marker on the right forelimb, using peak protraction of this limb as a reference point for the start of a new stride. Twenty strides were extracted for each horse. Deviation of the forelimb in the x-axis between each stride gave a value of left-right drift of the horse on the treadmill. For each horse the 10 strides with least drift were used for analysis of the T18 marker. The mean displacement of the T18 marker in the x, y and z-axes for 10 strides for all 10 horses were used to obtain mean values for the real horse group. Positive displacements are dorsal, caudal and right with negative being ventral, cranial and left. Cycle duration for the simulator was calculated by using the mean cycle duration for 10 individual full cycles of motion of the simulator over each of the 10x20 second runs of the simulator totalling 100 full cycles. The stride duration for the horse group was calculated using the mean of the 10 strides of each of the 10 horses giving 100 strides in total.

2.4 *Data Analysis*

Mean (± SD) displacement and maximum deviation of the T18 marker in three axes of motion, calculated from ten stride cycles of the horse simulator and ten stride cycles from each of the ten real horses, is presented to identify the general movement pattern of each scenario. Statistical analysis was conducted in SPSS Statistics v24 (IBM Co, Armonk, NY) and all data were assessed for normality and homogeneity of variance using the Shapiro-Wilk test. Displacement data from the two 60 s runs (producing 40 stride cycles) of the horse simulator were used to test for repeatability of the simulator to produce consistent movement data. Similarities between the 40 cycles was assessed using a Pearson's Product Moment Correlation and an Intraclass Correlation Coefficient were calculated to identify the consistency of the simulator data. Inter-horse movement variation between the ten real horses was examined using a one-way Analysis of Variance (ANOVA).

Displacement data from the ten 20 s runs of the horse simulator and from the ten strides with the least drift from each of the ten real horses were used to examine if differences exist between the simulator and real horses. Independent t-tests were conducted to calculate if significant differences existed in mean displacement between the two groups for each axis direction. Statistical significance was set *a priori* as $p \leq 0.05$ and used in all statistical analyses.

3. Results

3.1 Riding Simulator

Correlations were used to assess the statistical repeatability of the movement of the simulator between the 2x60 second runs. There was a strong positive correlation between repeated measurements in all three axes, with Pearson's product-moment correlation, $r(467) = 1.000$, $p < 0.001$ for mediolateral displacement, $r(467) = 0.999$, $p < 0.001$ for craniocaudal displacement and $r(467) = 1.000$, $p < 0.001$ for dorsoventral displacement, and an overall Intraclass Correlation (ICC) = 1.000 (95% CI, 1.000 to 1.000), $p < 0.001$. Further analysis of symmetry of movement in the mediolateral direction also showed a strong positive correlation of $r(70) = 0.976$, $p < 0.001$ with max. deviation left and right equal at 25.6mm (total displacement 51.2mm). These results indicate that the simulator was highly consistent in its movements and shows a high degree of symmetry.

3.2 Horse group

Using the means of displacement amplitude, a one-way ANOVA was used to compare inter-horse variations of displacement in all three axes of movement. Due to the assumption of homogeneity of variance being violated in the mediolateral and craniocaudal axes, assessed by Levene's test for equality of variances ($p = 0.019$ & $p < 0.001$ respectively), results from the Welch's post-hoc tests were used. In the mediolateral axis Welch's $F(9, 36.363) = 10.137$, $p < 0.001$, in the craniocaudal axis Welch's $F(9, 36.336) = 16.662$, $p < 0.001$ and in the dorsoventral axis ANOVA $F(9, 90) = 58.752$, $p < 0.001$. Testing demonstrated that there was a significant difference between magnitude of displacement between some horses. Mean (S.D) and ranges of displacement can be seen in Table 1.

Table 1 here

3.3 Simulator vs Horses

Comparison of the total displacement of the reflective markers at the level of T18 using independent t-tests showed the simulator to have significantly greater displacement in two of the three axes than the real horse group. The overall mean mediolateral displacement shown by the T18 reflective marker on the real horses was 30.1 ± 5.9 mm in comparison to 51.2 ± 0.1 mm for the marker in the corresponding position on the dressage simulator, $t(9.02) = -11.24$, $p<0.001$. Mean craniocaudal displacement of the horse group was 37.5 ± 9.1mm compared to 45.9 ± 0.4 mm for the simulator, $t(9.03) = -3.03$, $p=0.014$. However, in the dorsoventral direction the horses displayed a greater magnitude of displacement with mean of 88.3 ± 15.3 mm compared to 77.8 ± 0.3mm for the simulator but this was not significantly greater $t(9.01) = 2.17$, $p=0.59$. Variation between strides (standard deviation) was greater for the horse group in all three planes of movement. Data are displayed in Figure 2. Although there were differences in magnitude of movement between the horse group and the simulator in the frontal plane (as if looking from behind the horse), there were similarities in the pattern and phasing of the movements (Fig. 3a & 3b). There was a clear and obvious difference in the pattern of displacement in the sagittal plane (as if looking from the side of the horse). The simulator showed a precise linear oblique displacement from a caudal and ventral position to a more cranial and dorsal point (Fig. 4a), whereas the horses displayed a repeated oval-shaped pattern of movement (Fig. 4b), with one cycle of movement consisting of a downwards and forwards inclination, followed by an upwards and backwards movement. The calculations of cycle duration showed an mean time of 0.59±0.01 seconds for the simulator and 0.76±0.03 seconds for the horse group, demonstrating a statistically significant difference in mean stride duration between the simulator and the real horses with the simulator stride duration being faster than the real horses, 0.17±0.01, $t(9.55) = 17.942$, $p < 0.001$.

Figure 2 here

Figure 3 here

Figure 4 here

Discussion

This study was designed to investigate the validity and reliability of a dressage simulator through comparing the cycle/stride duration and 3-dimensional movement patterns of a marker placed over the area of T18 to that of a group of real horses trotting on a treadmill, and to examine the range and symmetry of the displacement of a dressage simulator. Displacement at the estimated level of T18 was measured to allow comparison of the degree and direction of displacement of the horses and the simulator directly caudal to the back of the saddle (cantle). However, even when only considering the movement of a horse at this location, the displacement vectors of a real horse are far more complex and diverse. The movement of a horse in the thoracic and lumbar region has more dimensions of motion compared to the simplified three planes of motion of the simulator. Detailed explanation of the functional anatomy and biomechanics of the thoracolumbar spine of the horse is well documented and available in the literature (Townsend, Leach, & Fretz, 1983; Zaneb, Peham, & Stanek, 2013). The rigid shell and basic internal mechanics of the simulator prevent the emulation of the complex combined movements of the horse's vertebral column. With this simulators inability to reproduce 'roll' and 'yaw' components as well as lateral bend, which are all demonstrated by the spine of a horse, it is unrealistic to expect the simulator to be able to reproduce the exact combination of movements found in a real horse. Roost et al. (2019) describe the development of a simulator that can move with six degrees of freedom, which has more recently been used to monitor body and brain behaviour of professional and non-professional riders (Byzova et al., 2020). Unfortunately, this device is not commercially available.

Results of the present study showed the pattern and displacement magnitude of the dressage simulator to be highly repeatable and consistent, with the greatest standard deviation in any direction analysed being less than 0.4 mm. Movement symmetry in the mediolateral axis is essential if the simulator is to be used to examine rider symmetry (which it is commonly used for at present). The midpoint of the simulator was determined by locating the crossover point of the pattern of displacement (Fig. 3a). Data showed the presence of a high degree of symmetry in the mediolateral plane suggesting that its use in analysing rider symmetry may be valid. Inter-horse variation of magnitude of displacement in this group of horses displayed significant differences between some horses, which was similar to Park et al. (2014) who used seven horses to compare acceleration data to that of their 'robo-horse' simulator. This was not an unexpected finding as the horse group were a group of mixed breed horses. This study could have used a group of horses of the same breed, but any conclusions drawn would have been isolated to that breed of horse, and not generalisable.

Comparison of displacement vectors and degree of mean deviation between real horses trotting on a treadmill and the dressage simulator displayed some important significant differences. These were seen in the overall displacement in two of the three axes of movement. The simulator displayed significantly greater displacement in the mediolateral and craniocaudal axes by 70% and 22% respectively, and 12% less displacement in the dorsoventral axis (though this latter displacement was not statistically significant). The phasing of movement in the frontal plane shows similarities in pattern of movement, however there was a clear difference in the sagittal plane with the horses showing an oval pattern of displacement, and the simulator a clear linear displacement. A previous study by Walker et al. (2016), comparing the sacral displacement of real horses galloping overground to that of a racehorse simulator, demonstrated differences in displacement magnitude in all three planes, as this study did (see Table 2).

Table 2 here

Walker et al. (2016) found that their group of thoroughbred racehorses showed significantly greater displacement in the mediolateral and dorsoventral directions, whereas in this study the horses demonstrated greater displacement only in the dorsoventral plane. The greatest difference in displacement between horses and simulator was in the racehorse study in the mediolateral direction, with the racehorses' displaying over 2.5 times greater displacement than the racing simulator. Comparison of the two simulators show marked differences in mean values for displacement, which would be expected as they are attempting to replicate different gaits. The variation between strides was extremely low for the dressage simulator compared to the racing simulator, which is surprising as the simulators were constructed by the same manufacturers and the internal mechanics of the dressage and racing simulator are very similar. One explanation of this may be that there was some instability of the base of the racing simulator due to the greater cycle speed required to replicate a gallop, and the greater craniocaudal displacement displayed, which was almost 4 times greater than the dressage simulator. Unfortunately, Walker et al. (2016) did not report cycle duration of the simulator or stride duration of the horses, neither did they report inter-horse variation of displacement which would have been informative as all of their horses were of the same breed.

Data from the sagittal plane from both studies show a similar displacement pattern of the two horse groups, with a single stride cycle producing an oval shape. The direction of displacement was the same in the racehorse group as shown by the group of horses trotting on the treadmill, with displacement in the cranioventral (downwards and forwards) direction followed by a caudodorsal (upwards and backwards) direction. Although Walker et al. (2016) report a similar oval pattern for the pelvis of the racing simulator, the direction of displacement was in the opposite direction to that of the horses. The dressage simulator displayed a very different linear oblique displacement moving from a caudal and ventral position to a more cranial and dorsal position. Both simulators showed greater deviation in the craniocaudal directions which may be present in order to create the sense of forward propulsion, which is absent with a static simulator, but obviously present while riding a real horse travelling over-ground. It is unlikely that riding simulators will ever be able to fully replicate the movement of real horses due to the restriction of the mechanics involved, the complex combined movements of the equine body, and the variation of horses' movements due to age, breed, size and training.

The benefits of using riding simulators will depend on upon its intended use. If it is to teach an individual to ride in preparation for sitting on a real horse or for rehabilitation of an injured rider then it may well be appropriate. Alternatively, if simulators are to be used by more experienced riders to perfect their skills, then the differences in movement patterns produced by real horses and dressage simulators highlighted in this study need to be considered. In order to evaluate their use as a tool to analyse or investigate the kinematics of riders, then further studies are required to determine whether the differences seen between the simulator and real horses will create differences in the kinematics of the riders.

Limitations

Although horses of similar height and weight were used in this study they included a variety of breeds, which may display a greater variation of displacement between horses compared to a sample of horses of the same breed. Horses were analysed whilst trotting on a treadmill rather than over-ground, however studies comparing these two conditions have shown that spinal kinematics are not identical but differences are minor (Gómez Álvarez et al., 2009). There were no riders on the horses or simulator during data collection which should not alter the displacement trajectory or amplitude of the simulator due to its internal mechanics. However, there is evidence to show that saddles and weight can influence spinal kinematics of the horse (De Cocq, van Weeren, & Back, 2004) and that the movement of a rider during rising trot results in a difference of spinal motion between the standing and sitting phases (Martin et al., 2016). It is therefore possible that comparison of a simulator and horses with riders on may show different results. The findings of this study are limited only to the gait of trot, further study would be needed to determine and similarities / differences for walk and canter.

Conclusion

This study shows that the dressage simulator is reliable and symmetrical in its movement with high degree of repeatability and low variation of difference between cycles. The simulator displays a faster cycle/stride speed and shows differences of displacement at the T18 spinal level to that of real horses. Real horses show greater displacement in the dorsoventral axis but less displacement in the mediolateral and craniocaudal axis. Both the horse group and the simulator showed similar displacement patterns in the frontal plane (viewed from the back), but different in the sagittal plane (viewed from the side). Simulators may appear to move like a real horse, but this study highlights the significant differences in cycle/stride speed, displacement pattern and magnitude of displacement. Therefore, although they may be useful for applications such as learning to ride, we must apply caution when analysing the movement of riders and especially in transposing any findings from riders on a simulator to that of riders on a real horse. Further studies are required to determine if these variations will cause difference in rider kinematics.

References

Aranda-García, S., Iricibar, A., Planas, A., Prat-Subirana, J. A., & Angulo-Barroso, R. M. (2015). Comparative effects of horse exercise versus traditional exercise programs on gait, muscle strength, and body balance in healthy older adults. *Journal of Aging and Physical Activity*, *23*(1), 78–89. https://doi.org/10.1123/JAPA.2012-0326

Araujo, T. B., Silva, N. A., Costa, J. N., Pereira, M. M., & Safons, M. P. (2011). Effect of equine-assisted therapy on the postural balance of the elderly. *Brazilian Journal of Physical Therapy*, *15*(5), 414–419. https://doi.org/10.1590/s1413-35552011005000027

Back, W., Schamhardt, H. C., & Barneveld, a. (1997). Kinematic comparison of the leading and trailing fore- and hindlimbs at the canter. *Equine Veterinary Journal. Supplement*, *23*(23), 80–83. https://doi.org/10.1111/j.2042-3306.1997.tb05060.x

Byzova, A., Roozbahani, H., Handroos, H., Hakansson, N., & Lankarani, H. M. (2020). Monitoring of the human body and brain behavior using optical motion capture system and EEG utilizing horseback riding simulator: an extended case study. *Journal of Physical Therapy Science*. https://doi.org/10.1589/jpts.32.85

Davies, H. M. S., & Watson, K. M. (2005). Third metacarpal bone laterality asymmetry and midshaft dimensions in Thoroughbred racehorses. *Australian Veterinary Journal*, *83*(4), 224–226. https://doi.org/10.1111/j.1751-0813.2005.tb11657.x

Davis, E., Davies, B., Wolfe, R., Raadsveld, R., Heine, B., Thomason, P., … Graham, H. K. (2009). A randomized controlled trial of the impact of therapeutic horse riding on the quality of life, health, and function of children with cerebral palsy. *Developmental Medicine and Child Neurology*, *51*(2), 111–119. https://doi.org/10.1111/j.1469-8749.2008.03245.x

de Cocq, P., van Weeren, P. R., & Back, W. (2004). Effects of girth, saddle and weight on movements of the horse. *Equine Veterinary Journal*, *36*(8), 758–763. https://doi.org/10.2746/0425164044848000

Gómez Álvarez, C. B., Rhodin, M., Byström, A., Back, W., & van Weeren, P. R. (2009). Back kinematics of healthy trotting horses during treadmill versus over ground locomotion. *Equine Veterinary Journal*. https://doi.org/10.2746/042516409X397370

Ille, N., von Lewinski, M., Aurich, C., Erber, R., Wulf, M., Palme, R., … Aurich, J. (2015). Riding Simulator Training Induces a Lower Sympathetic Response in Riders Than Training With Horses. *Journal of Equine Veterinary Science*, *35*(8), 668–672. https://doi.org/10.1016/j.jevs.2015.06.018

Longhurst, K., & Leśniak, K. (2013). Postural asymmetry of the rider whilst static and in sitting trot. *Journal of Veterinary Behavior: Clinical Applications and Research*, *8*(2), e15. https://doi.org/10.1016/j.jveb.2012.12.034

Mackechnie-Guire, R., Mackechnie-Guire, E., Fisher, M., Mathie, H., Bush, R., Pfau, T., & Weller, R. (2018). Relationship Between Saddle and Rider Kinematics, Horse Locomotion, and Thoracolumbar Pressures in Sound Horses. *Journal of Equine Veterinary Science*. https://doi.org/10.1016/j.jevs.2018.06.003

Martin, P., Cheze, L., Pourcelot, P., Desquilbet, L., Duray, L., & Chateau, H. (2016). Effect of the rider position during rising trot on the horse's biomechanics (back and trunk kinematics and pressure under the saddle). *Journal of Biomechanics*. https://doi.org/10.1016/j.jbiomech.2016.02.016

McCaughey, C. S., & Traynor, M. K. (2010). The role of simulation in nurse education. *Nurse Education Today*, *30*(8), 827–832. https://doi.org/10.1016/j.nedt.2010.03.005

McGreevy, P. D., & Rogers, L. J. (2005). Motor and sensory laterality in thoroughbred horses. *Applied Animal Behaviour Science*, *92*(4), 337–352. https://doi.org/10.1016/j.applanim.2004.11.012

Müller, M. P., Hänsel, M., Fichtner, A., Hardt, F., Weber, S., Kirschbaum, C., … Eich, C. (2009). Excellence in performance and stress reduction during two different full scale simulator training courses: A pilot study. *Resuscitation*. https://doi.org/10.1016/j.resuscitation.2009.04.027

Murphy, J., Sutherland, A., & Arkins, S. (2005). Idiosyncratic motor laterality in the horse. *Applied Animal Behaviour Science*, *91*(3–4), 297–310. https://doi.org/10.1016/j.applanim.2004.11.001

Olivier, A., Faugloire, E., Lejeune, L., Biau, S., & Isableu, B. (2017). Head Stability and Head-Trunk Coordination in Horseback Riders: The Contribution of Visual Information According to Expertise. *Frontiers in Human Neuroscience*, *11*(11), 1–16. https://doi.org/10.3389/fnhum.2017.00011

Peham, C., Licka, T., Kapaun, M., & Scheidl, M. (2001). A new method to quantify harmony of the horse-rider system in dressage. *Sports Engineering*, *4*(2), 95–101. https://doi.org/10.1046/j.1460-2687.2001.00077.x

Roost, L., Ellis, A. D., Morris, C., Bondi, A., Gandy, E. A., Harris, P., … Yin, S. (2019). Novel horseback riding simulator based on 6-DOF motion measurement, a motion base, and interactive control of gaits. *Journal of Equine Veterinary Science*, *14*(3), 1–7. https://doi.org/10.1080/01691864.2013.824134

Shurtleff, T., & Engsberg, J. (2012). Long-term effects of hippotherapy on one child with cerebral palsy: A research case study. *British Journal of Occupational Therapy*, *75*(8), 359–366. https://doi.org/10.4276/030802212X13433105374279

Townsend, H. G., Leach, D. H., & Fretz, P. B. (1983). Kinematics of the equine thoracolumbar spine. *Equine Veterinary Journal*. https://doi.org/10.1111/j.2042-3306.1983.tb01732.x

Winter, J. C. F. De, Leeuwen, P. M. Van, & Happee, R. (2012). Advantages and Disadvantages of Driving Simulators : A Discussion. *Proceedings of Measuring Behavior 2012*, 47–50.

Zaneb, H., Peham, C., & Stanek, C. (2013). Functional anatomy and biomechanics of the equine thoracolumbar spine: A review. *Turkish Journal of Veterinary and Animal Sciences*, Vol. 37. https://doi.org/10.3906/vet-1205-45