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RESEARCH ARTICLE

A preliminary investigation of the use of inertial sensing technology for the measurement of hip rotation asymmetry in horse riders

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Abstract

This study investigated the use of inertial sensing technology as an indicator of asymmetry in horse riders, evidenced by discrepancies in the angle of external rotation of the hip joint. 12 horse and rider combinations were assessed with the rider wearing the Xsens^{TM} MVN inertial motion capture suit. Asymmetry (left v right) was revealed in mean hip external rotation of all riders, with values ranging from 1° to 27° and 83% showed greater external rotation of the right hip. This study represents novel use of inertial sensing equipment in its application to the measurement of rider motion patterns. The technique is non-invasive, is capable of recording rider hip rotation asymmetry whilst performing a range of movements unhindered and was found to be efficient and practical, with potential to further advance the analysis of horse and rider interactions.

Keywords: Horse rider, Back pain, Asymmetry, Hip rotation, Inertial sensor

1. Introduction

Low back pain is a common musculoskeletal complaint in the general population, with considerable variation in estimates of its prevalence between studies. Walker (2000) suggests values of up to 33% for point prevalence, 65% for one-year prevalence and 84% for lifetime prevalence. It is likely that around one-third of the UK adult population are affected by low back pain each year (National Institute for Clinical Excellence 2009). Studies have reported that some of the highest injury rates are found in equestrian sports (Quinn & Bird 1995; Pilato, Shifrin, & Bixby-Hammett 2007) and asymmetric stress has been identified as a contributory factor (Krivickas 1997).

Asymmetry is amongst the many aetiological factors requiring consideration in the management of chronic back pain in athletes (Nadler, Malanga, DePrince, Stitik, & Feinberg 2000). Both human and equine bodies are designed with a symmetrical structure, for efficient load distribution during functional activity. Genetic inheritance, limb dominance and environmental stimuli all contribute to asymmetric musculo-skeletal development (Turner 2011). The efficient execution of riding movement is reliant on maintenance of balance and posture of both rider and horse during dynamic interaction. The distribution and magnitude of mechanical stress on the body of the rider and horse is altered by anatomical asymmetry. Motor control is subject to lateral bias and conditioning that reinforces bias, increasing exposure to asymmetric stress and subsequent injury (Turner 2011).

Imperfect torsions, created by asymmetry of motion segments and muscles, can manifest as scoliosis deformities (Asher & Burton 1999). Increased unilateral torque forces have been suggested as causal factors in the higher incidence of functional scoliosis found in athletes (Omey, Micheli & Gerbino 2000). A number of studies have concluded that combining high training volume with mal-alignment is indicated as an anatomic risk factor for overuse injury (Krivickas 1997; Ahonen 2008; Fousekis, Tsepsis & Vagenas 2010). Functional scoliosis also occurs as a compensation for leg length inequality (Friberg 1983). Turner (2011) refers to the problems of quantifying the contribution of asymmetric intrinsic and extrinsic factors and emphasises the need for reliable assessment of anatomic asymmetry and consideration of the implications of sport-specific functional asymmetries, in particular addressing leg length inequality, scoliosis, pelvic tilt, hip, knee and ankle joint asymmetries.

Whilst riding, it is important that the movement of the rider's hips, pelvis and torso allow them to maintain stable phase synchrony between their own body and that of the horse. This temporal co-ordination allows greater comfort and clearer communication for both horse and rider, thus enabling a balanced and harmonious partnership. An asymmetrical posture can have a significant effect on balance and stability, impeding performance and increasing the risk of injury to both horse and rider (Nevison & Timmis 2013).

Peham, Licka, Schobesberger and Meschan, (2004) determined that as a consequence of the three interacting systems of horse, saddle, and rider, riding is a very complex movement which is difficult to characterise. Movements of horse and rider influence each other, resulting in a so-called complex coupled system. The intrinsic non-linearity of this system makes it hard to deal with mathematically. Peham, Licka, Kapaun and Scheidl (2001) compared the effects of different rider skills upon motion pattern consistency, demonstrating that a skilled rider disturbs the pattern less.

A limited number of studies have been carried out into horse and rider posture and asymmetry, with much of what has been done using video analysis (Byström, Rhodin, von Peinen, Weishaupt & Roepstorff 2009; Symes & Ellis 2009; Kang et al. 2010) or saddle pressure testing (Peham et al. 2010). All these authors suggest the need for further studies.

A key disadvantage of optical motion cameras is the limited field of view (Greve & Dyson 2012), restricting analysis to straight-line capture or very short view in the sagittal plane whilst passing the camera on a circular path. A wider field of view is possible using multiple camera systems but these are expensive and lack portability, making them difficult to utilise within a riding arena. Parallax errors are also present and need to be corrected for. Equine treadmills have been successful in observing asymmetry in the horse caused by subclinical lameness (Orito et al. 2007); however, only a limited number of studies (Byström et al. 2009; Byström, Rhodin, von Peinen, Weishaupt & Roepstorff 2010) have been carried out with ridden horses on an equine treadmill. This technique is limited by the restricted availability of such equipment, the necessity for the horse to be experienced in working on a treadmill and the high experience level required of the rider. The natural gait, speed, tempo and symmetry of movement may also be compromised (Peham et al. 2004).

Accuracy of optical motion analysis relies on correct placement of biomechanical markers (McGinley, Baker, Wolfe & Morris 2009). It is also critical that they remain reliably in position; however, keeping them attached to horse and rider during motion is difficult due to the effects of dust and sweat on adhesive attachments. Automated motion tracking via reflective markers can be problematic in environments with inconsistent light levels and cluttered backgrounds (Zhou & Hu 2008), common features of riding arenas. Another limitation is that parts of both horse and rider's bodies may be hidden from view, restricting the analysis that can be accurately performed (Greve & Dyson 2012).

Bergmann, Mayagoitia, and Smith (2009) reported that body-worn, inertial motion sensors are a practical, non-constraining alternative to optical motion analysis for the measurement of lower-extremity joint angles. Ease of setup and portability makes them suitable for use by clinicians and researchers outside the laboratory environment. Ha, Saber-Sheikh, Moore and Jones (2013) performed a protocol validation study, comparing inertial motion sensors with an electromagnetic tracking system for the measurement of spinal range of movement. Examples of use in motion tracking and clinical research include analysis of hip joint flexion and extension during human walking gait (Saber-Sheikh, Bryant, Glazzard, Hamel & Lee 2010);

measurement of joint angle of catch during fast passive muscle stretch of medial hamstrings, soleus and gastrocnemius, in the spasticity assessment of children with Cerebral Palsy (Van den Noort, Scholtes & Harlaar 2009); and measurement of lumber, hip, knee and ankle joint angles of skiers (Kondo, Doki & Hirose 2012).

The aim of this study was to investigate whether inertial sensing technology is a practical tool for the identification and measurement of asymmetries in the rider's position, using hip rotation as the marker. A common flaw in the riding posture is external rotation of the hip joint, which results in reduced mobility of the pelvis and thus inability to coordinate the rider's movements with the horse's stride. Comparison of hip rotation angles was used to identify postural asymmetry in the frontal plane.

2. Experimental

2.1 Participants

Twelve horse and rider combinations were used for this study. Participants comprised 2 advanced-level combinations (one eventer and one show jumper) and 10 amateur-level combinations (one rider rode 6 horses and 5 riders rode the same horse). The riders comprised 6 female and 1 male aged 19 to 47 years (mean 29, standard deviation = 11 years), with mean weight 62, standard deviation = 6.7kg and mean height 161.8, standard deviation = 6.75 cm.

To avoid the risk of unpredictable behaviour, horses were a minimum age of 5 years and accustomed to working in different situations. In order to maximize accuracy and quality of manoeuvres, both riders and horses were of an experience level equivalent to a minimum standard of affiliated novice level dressage and familiar with the activities that they were expected to perform.

2.2 Equipment

All horses were ridden in their own tack, which was English-style, with the show jumper using a jumping saddle and the remainder using general purpose or dressage saddles.

The riders were fitted with the Xsens^{TM} MVN (MoCap) system shown in Figure 1, comprising a full body, camera-less lycra suit with 17 embedded inertial measurement unit (IMU) sensors (http://www.xsens.com). The sensors incorporate accelerometers, gyroscopes and magnetometers, providing 3-dimensional orientation with accuracy found to be within 1° (Van den Noort, Scholtes & Harlaar 2009). The system estimates body segment orientation and position changes via the integration of the gyroscope and accelerometer signals, continuously updating a 23 segment biomechanical model of the human body with 22 joints, automatically correcting for drift and other errors. The system runs in real-time with an update rate of 120 Hz. Data is captured wirelessly (via Bluetooth^{TM}) by the MVN Studio^{TM} software package, which provides functionality to observe, record and export in 3-dimensions. A full description of the hardware, software and mathematical calculations involved is provided by Roetenberg, Luinge and Slycke (2009).

To facilitate placement of the IMUs on the riders' legs, short boots were worn, with chaps and/or spurs added if preferred.

2.3 Arena Layout

A straight runway was marked out in the centre of the riding arena to ensure that the horse and rider combination was unaffected by the proximity of any fence or boundary wall. The runway was marked out as in Figure 2, with poles 1 m apart, placed end-to-end to provide a straight distance of approximately 30 m. Additional poles and jumping blocks or wings were used to guide the horse and rider accurately into the runway. A 15 m circle was also marked out, passing through gaps in the runway poles.

The laptop and receiver used to communicate with the Xsens^{TM} system was positioned adjacent to the runway, to ensure the best possible range of capture.

2.4 Data Collection

Before commencement of data collection, the system was calibrated for each rider, using two standard calibration routines as recommended by Xsens^{TM}: The N-pose requires the participant to stand in an adapted anatomical neutral position with arms straight downwards, thumbs to the front and feet a foot-width apart. The participant was required to hold this position for 20 seconds, during which time the calibration took place. To accurately record hand motion a second calibration (the Hand-pose) is required, where the participant places both hands in front of their body, palms together and elbows in to their side. During the 20 second calibration the participant rotates and tilts the hands, keeping palms together and arms still.

Once mounted, each combination performed a brief self-selected warm-up to accustom both rider and horse to the suit and the arena layout. This warm-up included riding down the runway a number of times until the rider was satisfied that both they and the horse could execute this manoeuvre accurately at a rhythmical, balanced trot.

A 5 second data capture was taken for each combination at halt in the centre of the runway. Rising trot was then established (with the rider rising to the outside diagonal) and the combination performed a traversal of the runway, followed by a circle, on each rein before walking, resting and repeating.

Recording of straight lines was started as the turn was made onto the runway and stopped as the combination turned out at the end, remaining on the same rein. For circles, recording started as they passed through the first pair of markers and stopped as they completed the movement by passing through the same pair of markers.

2.5 Data Processing

Datasets were cropped in the MVN Studio^{TM} software, using visual inspection, to isolate the frames for 2 complete stride cycles for straight line captures and 10 complete stride cycles for trot circles. Data was then exported to XML format and Microsoft Excel^{TM} used to filter the required joint angle data values. This was saved in CSV format and used as input to a series of scripts written using the R Statistical Package (Ihaka & Gentleman 1996).

2.6 Ethical, Health and Safety Considerations

The research was carried out in compliance with relevant laws and institutional guidelines. It did not raise any significant ethical issues beyond the minimum standards set by the University of Sunderland Research Ethics Committee and was able to be self-certified by the researchers, who had completed the institution’s approved course in

Research Ethics. The participants have been protected by anonymity, were fully informed of the nature of the research and gave full, informed consent to the use of data collected.

Appropriate methods of health and safety management were adopted. The horses were wearing their usual equipment, were not purposefully harmed and were considered to be carrying out their normal activities. Riders wore British Standard (BS kite marked) riding hats at all times when mounted. Appropriate footwear and gloves were worn both when riding and when handling the horse. The Xsens^{TM} suit had previously been used within sporting contexts so was not considered a health and safety risk. Each participant signed a standard disclaimer before commencing the testing.

3. Results

3.1 External rotation of the rider hips

The external rotation of left and right hip for each rider was considered for five data capture scenarios: trot rising (left rein straight line), trot rising (right rein straight line), trot rising (left rein circle), trot rising (right rein circle) and halt. The mean and standard deviation of left and right hip external rotation angles for each combination, executing each of the movements are shown in Table I.

External rotation of the hip was measured about the longitudinal axis of the femur, as illustrated in Figure 3. A larger angle indicates a greater external rotation and differences in angle between left and right hips identifies the presence of asymmetry. Standard deviations give an indication of the range of external rotation angle as the rider moves through the rise and sit phases of the stride cycle.

Figure 4 shows the range of rotation of left and right hip for the most asymmetric rider in rising trot on each rein (travelling down the straight runway).

3.2 Asymmetry in rider hip rotations

The extent of asymmetry was determined by calculating the difference between left and right external hip rotations (Table II). The asymmetry was found to change as the rider moved through the sitting and rising phases of the trot stride cycle. The asymmetry values for all combinations, performing rising trot in a straight line on left and right reins, are shown in Figure 5 and for rising trot on left and right circles, Figure 6.

The MVN Studio^{TM} software supplied with the Xsens^{TM} suit provides a 3-dimensional representation of the data using a human anatomical model. Figure 7 shows a series of screen captures from MVN Studio^{TM}, comparing the rider with the least hip rotation asymmetry against the rider with the maximum hip rotation asymmetry, during the rise and sit phase of rising trot. The rider in the right-handed pair of images clearly shows significant postural flaws, with a greater external rotation of the right hip.

3.3 Repeatability

In order to determine the potential intra-rater repeatability of the methodology, two captures from each horse and rider combination travelling down the straight runway were compared, each for two full stride cycles.

A Pearson product-moment correlation coefficient was computed to assess the relationship between the mean hip rotation asymmetry for each combination, across the two captures. There was a strong correlation between the two means for both trot rising on the left rein, $r(10) = .981$, $p < .01$; and trot rising on the right rein, $r(10) = .961$, $p < .01$.

Using a paired T-Test, there was a small significant difference between the mean hip rotation asymmetry for trot rising on the left rein, $t(11) = 3.722$, $p = .003$; but no significant difference for trot rising on the right rein, $t(11) = -0.745$, $p = .472$.

These high correlations indicate good intra-rater repeatability of the methodology, although a full validation study, including more extensive repeatability testing would be necessary to confirm this.

4. Discussion

In walk, as the horse's hind foot contacts the ground, the horse's hip lifts and pushes the rider's hemi-pelvis forward and up. The full movement pattern of the rider's hemi-pelvis segment is forward-up-back-down, often described as a backwards pedal motion.

Gait asymmetry in the horse, which may be caused by a one-sided stiffness, can result in the horse shortening its stride on the stiff side. Most of the horse's movement transmitted to the rider is absorbed by the rider's hip joints, thus any loss of mobility at the hip will transfer the force to the riders lumbo-pelvic region, with the potential to cause injuries higher up the kinetic chain.

The pelvis should be in a neutral rotation, with common flaws being a posteriorly rotated pelvis, resulting in loss of lumbar lordosis, or an anteriorly rotated pelvis, resulting in increased lumbar lordosis. The ability to maintain a more controlled upright trunk position is dependent on the rider's level of experience (Douglas, Price & Peters 2012). Both of these flawed postures result in instability, reduced control of the torso and reduced mobility of the hip joints, all of which have the potential to increase the risk of injury to the rider.

This study has demonstrated that inertial sensing technology is a practical tool for the measurement of asymmetry in rider hip angle rotation, enabling data analysis to include movements carried out within normal riding activity, rather than just in artificially-imposed straight lines or circling past a fixed video camera. This provides the potential to capture and analyse data for specific movements, full dressage tests and show jumping courses, limited only by the wireless range of the Xsens^{TM} IMU technology.

Wireless range was found to be reliable within a 20 x 40 m area and the system was used successfully in indoor (n=10) and outdoor (n=2) arenas. Occasional problems were experienced due to loss of wireless signals between the suit and the laptop. This occurred at a consistent location in one outdoor arena, outside of the marked runway. The cause could not be identified but was believed to be due to interference, perhaps by close proximity of a radio mast. In another case, it occurred in a large indoor arena, when the combination moved beyond 40m from the receiver. To eliminate this, the laptop operator was relocated within the arena, at a safe location close to the runway. If wireless signals were lost, bringing the rider to a halt next to the receiver and waiting for the software to reconnect was sufficient to recommence recording.

The Xsens^{TM} suit allows for quick changeover between participants and the MVN Studio^{TM} software provides batch export of multiple datasets to XML format. For example, a session comprising 10 horse and rider combinations (5 different riders) with export of the 105 data files, was completed in 4 hours.

A time-consuming process is currently the manual extraction of CSV files from the XML data via Microsoft Excel^{TM} (approximately 90 seconds per dataset) but software could be written to automate this. Development of R scripts for analysis enables fast and efficient generation of plots and statistics across multiple datasets. An additional benefit is that they can be scaled upwards for larger sample sizes, by adding additional filenames to a configuration file.

Comparisons between repeated captures showed good correlation for intra-rater repeatability. There is, however, need for a validation study in order to confirm the repeatability of the technique and its reliability when compared with other methods, e.g. optical motion analysis and saddle pressure testing.

Results identified the presence of asymmetry in hip rotation angles. Of the datasets considered in this study, all horse and rider combinations showed asymmetry in external rotation of the hips. Combining the two captures for each combination, in trot down the straight runway, mean asymmetry values ranged from 1 degree to 27 degrees, with 10 of the 12 combinations (83%) showing greater external rotation of the right hip. Further investigation, using larger samples, is necessary to determine whether this is a pattern and if asymmetry is horse, rider or saddle related. In this study, the riders were not tested to determine whether they were left or right -handed or -footed but this would be a useful addition to future studies, in order to determine whether this is a factor in the bias towards greater external rotation of the right hip. Further studies are also necessary to investigate whether asymmetry is affected by skill level of horse, rider or both.

IMUs have been used successfully in equine gait analysis (Pfau, Witte & Wilson 2005; Thomsen, Jensen, Sørenson, Lindegaard & Andersen 2010; Starke, Witte, Maya & Pfau 2012). These have shown the presence of asymmetry in the horse, so it is necessary to consider whether the asymmetry shown in the rider is related to, and consistent with, asymmetry of the horse, or if they are independent. The presence of the saddle between horse and rider further complicates the interaction (Greve & Dyson 2012).

Future studies, synchronising IMUs on rider, horse and saddle, will provide a comprehensive picture of how the elements interact, enabling analysis to be carried out in more realistic riding environments.

5. Conclusions

Understanding functional asymmetry in interactions between horse, rider and saddle is important if horse and rider health, welfare and performance are to be improved. Results from this small sample of datasets provide evidence that all riders demonstrated a degree of hip rotation asymmetry. This technology can assist in meeting the needs of elite competitive riders and coaches, who require a tool for assessment within “normal” training and competitive environments.

This study demonstrates that the Xsens^{TM} motion capture suit has potential to be a useful, non-invasive technique, capable of recording rider hip rotation asymmetry whilst performing a range of movements unhindered. The technique goes beyond conventional optical motion analysis by providing the means of assessing the rider with greater accuracy. The system was found to be efficient and practical, with potential to further advance the analysis of horse and rider interactions.

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Text for Table of Contents

This article proposes the use of an inertial motion capture suit as an alternative to video analysis for identifying motion patterns in horse riders, focusing on the practical application of the technology to measure asymmetry in rider hip rotation angles.

Table I

Mean left (L) and right (R) hip external rotation angles (in degrees), whilst carrying out a range of movements

	Halt		Trot Left		Trot Right		Trot Circle Left		Trot Circle Right	
	L	R	L	R	L	R	L	R	L	R
B-R1H1	-3±1	9±0	-2±5	0±3	0±4	1±4	0±6	11±3	1±5	0±7
S-R1H1	29±2	-1±1	24±6	9±4	22±7	4±6	29±8	5±5	29±7	2±6
W-R1H1	11±0	19±0	10±5	19±4	6±4	20±5	7±5	24±4	7±4	24±6
W-R1H2	9±0	21±0	14±4	21±5	13±4	20±4	12±4	24±3	12±3	23±6
W-R1H3	8±0	19±0	11±4	21±4	8±4	19±4	7±5	24±4	8±4	21±6
W-R1H4	9±0	19±0	14±3	22±4	14±4	20±3	11±5	27±4	13±4	20±4
W-R1H5	10±0	22±0	9±3	22±3	9±3	23±3	4±3	27±2	13±3	21±5
W-R1H6	5±0	18±0	11±3	21±4	11±3	21±3	9±3	28±3	10±3	23±5
W-R2H6	13±0	13±0	17±4	22±4	14±3	25±5	15±4	28±6	14±4	28±8
W-R3H6	13±0	13±0	18±5	20±6	18±5	19±7	16±5	25±5	14±4	20±9
W-R4H6	-2±0	26±0	3±6	30±3	1±4	23±5	-2±5	25±3	-5±5	25±4
W-R5H6	15±0	10±0	16±4	12±6	16±4	12±7	13±6	13±6	14±3	14±8

Table II

Mean asymmetry values (in degrees) for hip external rotation, calculated by taking the difference between left and right hip rotation angles (right hip – left hip)

	Halt	Trot Left	Trot Right	Trot Circle Left	Trot Circle Right
B-R1H1	11±2	2±5	1±6	11±7	0±9
S-R1H1	-30±2	-15±7	-18±10	-24±9	-27±9
W-R1H1	7±0	9±7	14±6	17±7	16±9
W-R1H2	12±0	7±7	8±6	12±6	11±8
W-R1H3	10±0	9±6	11±5	17±6	13±7
W-R1H4	10±0	8±5	6±5	16±8	8±6
W-R1H5	12±0	12±5	14±4	23±4	7±6
W-R1H6	12±1	10±6	10±5	20±4	13±6
W-R2H6	0±0	5±4	11±6	13±6	14±10
W-R3H6	1±0	1±4	1±7	9±5	7±7
W-R4H6	28±0	27±8	22±5	27±5	30±6
W-R5H6	-5±0	-3±6	-4±8	0±8	0±9

Figure 1.
Xsens^{TM} suit. Shows a rider wearing the Xsens^{TM} motion capture suit.

Figure 2.
Arena setup. Shows the layout of guide poles to provide a 30 m runway and 15 m circle, together with placement of the laptop used to receive the wireless signals from the Xsens^{TM} suit.

Figure 3.
Axis of hip rotation. Shows a line along the longitudinal axis of the femur, about which hip rotation is measured.

Figure 4.
Hip rotation asymmetry. Shows range of external rotation angles for the left and right hips of an asymmetric rider, comparing rising trot on left and right reins.

Figure 5.
Summary of hip rotation asymmetry (straight lines). Shows the variations in external hip rotation asymmetry across all riders in rising trot on a straight line, comparing left rein with right rein.

Figure 6.
Summary of hip rotation asymmetry (trot circles). Shows the variations in external hip rotation asymmetry across all riders in rising trot, comparing left rein circles with right rein circles.

Figure 7.
Rider posture during the rise and sit phases of rising trot. Sample screen captures from MVN Studio^{TM}, comparing the rise and sit phases of rising trot for the rider with the least asymmetry in hip rotation against the rider with the greatest asymmetry in hip rotation.