VARIABILITY OF SAGITTAL JOINT KINEMATICS OF FEMALE HORSE-RIDERS OVER A JUMP.

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This study aimed to improve understanding of horse-rider technique in show jumping, to support the development of training programs. Range of motion, peak flexion and extension angles were estimated for the shoulder, elbows, hips, knees, and ankles of six female riders jumping two different fence types (oxer and straight), using a full-body inertial motion unit (IMU) suit (MVN Awinda). Horse kinematics were recorded using IMU and GPS technology (Alogo Move Pro). All rider joints showed inter-participant (population standard deviation range: 5.4°(ankle) - 43.2° (elbow)) and intra-participant variability (individual SD range: 1.7°(ankle) - 57.5°(hips)). Findings suggest differences in riding strategies and/or in strategy execution, challenging the traditional, strict equestrian guidelines, and highlighting the need for greater characterisation of show jumping strategies.

KEYWORDS: Show jumping, movement strategy, inertial motion sensors, technique analysis, equine, movement patterns.

INTRODUCTION: Current show jumping training principles provide detailed guidelines as to rider technique. Riders must elevate their pelvis out of the saddle and slightly backwards, tilting their trunk forward and distributing their weight equally through their legs. Forces generated by the horse should be absorbed by the knees and ankles, the heels positioned as the lowest point of the body. Over the jump itself, riders should hinge from the hips, keeping their back flat and lowering their shoulders during take-off. Their hands should move up and forward, allowing the reins to follow the movement of horse's mouth. Upon descent and landing riders extend their hips and pitch their trunk backwards (B.H.S., 2017a, B.H.S., 2017c). Despite these detailed guidelines, variations in their application are observed. In show jumping, emphasis is on the performance outcome: clearance of an obstacle course within a given time, without falling, knocking down a fence or the horse refusing to jump. Riders' strategies to achieve this are not evaluated, allowing expression of individual technique, and potentially resulting in several successful strategies. Significant postural differences have been described at specific moments of the jump, between elite and non-elite riders (Nankervis et al., 2015). These postural differences may provide elite riders with greater stability, as their body segments can display lower peak accelerations over a jump (Patterson et al., 2010). Intra-rider variability has also been found when jumping different fence types (Nankervis et al., 2015). This movement variability may reflect the need for riders to adapt to variability in their horse's biomechanics (Becker and Lewczuk, 2022, Schambardt et al., 1993) and hence the fluctuating forces experienced when jumping. Poor technique in show jumping can result in the horse and/or rider knocking down the fence or falling, with considerable risk of injury. Understanding rider technique is crucial to support athlete training and management while ensuring their safety. This study aimed to describe rider joint kinematics when jumping, hypothesising important inter-rider variability which would contrast with current equestrian training guidelines. Given the effect of fence type on horses' jump path (Fercher, 2017), it was also theorised riders' kinematics would differ between fence types.

METHODS: This study was approved by Hartpury university's research and ethics committee. Six female riders (mean ± sd age: 21 ± 3 years, height: 1.69 ± 0.07 m, mass: 57 ± 12 kg), participated in the study riding their own horses (age: 10 ± 3 years, height: 1.63 ± 0.09 m). Participants had all competed in amateur show jumping competitions (jumping 1.0 to 1.2 m), without being eliminated (i.e. falling off or horse refusing more than twice). Riders self-certified they and their horses were free of injury and pain which would preclude them from training or competition. Rider kinematics were recorded at 60 Hz, using fifteen IMUs (MVN Awinda, Movella Technologies, Netherlands, 2022) affixed to the head, shoulders, upper and lower arms, sternum, pelvis, upper and lower legs, and feet. An additional prop sensor was affixed to the dorsal aspect of riders' saddles. Riders wore tight riding equipment, and an Xsens Lycra top (Movella Technologies, Netherlands, 2023) to which IMUs could be affixed. Rider full-body measurements were entered in MVN Analyze (Movella Technologies, Netherlands, 2023) and calibration was performed following manufacturer guidelines. Horse kinematics were recorded at 100 Hz using Alogo MovePro (Alogo Analysis SA, 2023), a single motion tracker sensor combining IMU and GPS technology. Alogo MovePro was secured on horses' girths with a purpose-built sensor holder (Alogo Analysis SA, 2023). The study took place in an equestrian arena familiar to the participants and with an appropriately maintained surface. After a 10-minute self-prescribed ridden warm-up and a standardised jumping warm-up, participants jumped two fence types: a vertical (a fence only one pole wide, height: 1.0 m) and an oxer (a fence built with two bars to give it width, height: 1.0. m, width: 0.8 m). The horse's jump being inherently asymmetrical, recordings of two successful jumps were taken in each direction, for each fence type. A successful jump was defined as the horse and rider both clearing the fence without knocking a pole down or the rider being unseated in the saddle. Starting fence type and direction were randomised. A 13.0 x 1.5 m path was delimited to standardise the approach to the fences. In MVN Analyze (Xsens Technologies, Netherlands, 2023), rider kinematics were processed using a high definition, zero-level scenario. Rider kinematic data was extracted from the end of the last approach stride (end of forelimb stance) immediately preceding take-off (A1), to the landing of the forelimbs after the jump suspension phase. Using synchronised video recordings, forelimb stance in A1 was established as the minimum vertical position of the prop sensor immediately preceding its global maxima, which correlated with take-off. Forelimb landing was identified using minimum vertical velocity after take-off, correlating with the impulse created when the horse lands and regains forward momentum. Flexion-extension angles were estimated for the shoulder (upper-arm to shoulder segment angles, or glenohumeral joint), elbow (upper to lower arms segment angle), hip (pelvis to upper leg segment angle, defined at the centre of rotation of the hip joint), knee (upper to lower leg segment angle), and ankle (lower leg to foot segment angle, defined midway between the lateral and medial malleoli). For each jump, peak flexion and extension, and range of motion (ROM) were calculated in MATLAB (version R2023b, MathWorks, USA, 2023). Variable means were estimated as an average of left and right joint kinematics. MVN Awinda estimates flexion/ extension angles with an accuracy equal or lower than ± 10 degrees compared to optical motion capture (Schepers et al., 2018). Horse speed, jump length, height and take-off angle were extracted from the Alogo software, which reports accuracy of 5.5-29.7 % compared to optical motion capture (Guyard et al., 2023). Statistical significance was set at $p=0.05$. Data exploration and statistical analysis were conducted in RStudio (Rstudio team, 2021). Data normality, the presence of outliers, homogeneity, and collinearity within the data was evaluated. No effect of jump order was found (Spearman's rank correlation); thus trials were considered as independent events. Effect of fence type on joint ROM and peak angles were assessed using a Mann-Whitney test. Inter-participant and intra-participant variability in ROM and peak angles were evaluated using a Kruskal-Wallis test and standard deviations, respectively (Sánchez et al., 2014, Preatoni et al., 2012).

RESULTS: The analysis found no significant differences in horses' jump kinematics (Table 1), rider joint ROM or peak angles (Mann-Whitney, $p>0.05$) over the different fences. Riders' mean ranks significantly differed for ROM, peak flexion, and peak extension angles for all joints (Kruskal-Wallis, all joints: $p<0.0001$, Figure 1), highlighting the presence of inter-participant variability. Inter-participant variability was highest for elbows, which displayed the greatest standard deviation of ROM across the sample population (mean ± SD = 92.0 ± 43.2°). The inter-participant variability was lowest for the ankles, which displayed the smallest standard deviation of ROM across the sample population (12.6 ± 5.4°). Intra-participant variability (as measured by individual standard deviations) differed in its magnitude between joints and participants (Figure 1). Individual standard deviation of ROM was greatest for the knees and the elbows (Figure 1).

Table 1: Descriptive statistics of horses' linear kinematics presented as mean ± standard deviation, characterising the jumps analysed. No significant differences were found between fence types for any variable (Mann-Whitney, p>0.05).

Fence type	Speed ($m.s^{-1}$)	Take-off angle (degrees)	Jump height (m)	Jump length (m)
Vertical (n=24)	4.6 ± 0.8	32.4 ± 6.8	1.4 ± 0.1	4.7 ± 0.6
Oxer (n=24)	4.2 ± 0.7	34.1 ± 7.0	1.4 ± 0.1	4.7 ± 0.6

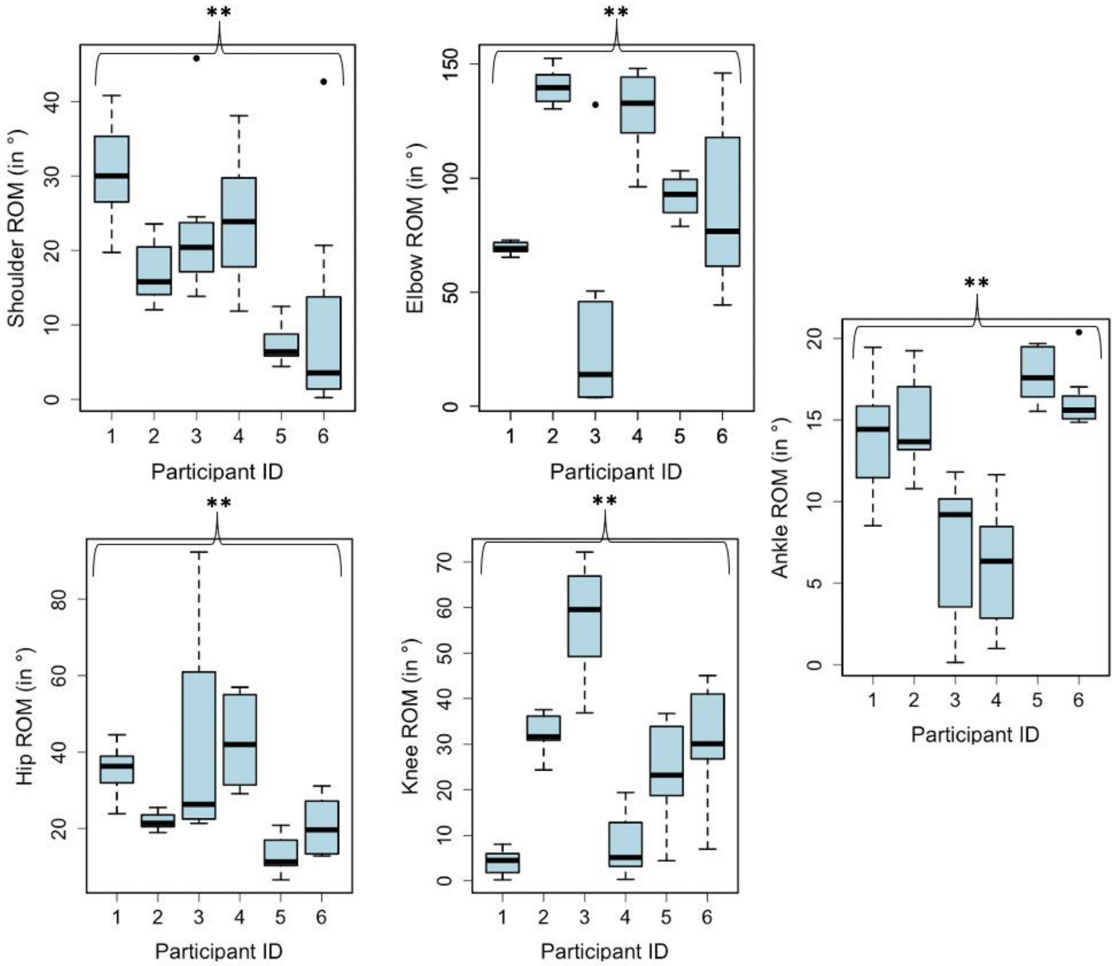

Figure 1: Boxplots of joint angles flexion/extension ROM (in degrees) for individual participants over all jumps (n=4). Significant inter-participant differences are indicated as follows: **p<0.0001 (Kruskal-Wallis test).

DISCUSSION: Variability was observed at inter and intra-participant levels, demonstrating riders can utilise different movement patterns when jumping. Given the interdependence of horse and rider biomechanics, variability in rider kinematics may reflect their ability to adapt to variations in the horse's biomechanics. The variability observed seemingly clashes with the rigidity of current training guidelines. It is unclear however, whether it was a result of riders differing in their strategies or in their execution of the same strategy. If diverging strategies were employed, variability measures may have been inflated by the comparison of different movement solutions (Cowin et al., 2022). The amateur level of the sample population may also have inflated variability measures. Elite riders can maintain more stability over a jump (Patterson et al., 2010) thus a more experienced cohort may show lower intra-participant variability, having a greater ability to adapt to the forces experienced when jumping. Overall performance was not impacted (all jumps were successful), but movement variability may have more discrete consequences which could impact performance under more challenging conditions (e.g.: jumping a whole course or higher fences). For example, variability in elbow kinematics could affect the constant and stable contact between the horse's mouth and rider's hands, advocated in equestrian training guidelines (Terada et al., 2006). This contact is essential to help the rider communicate cues to the horse and provide them with tactile information on how the horse is moving. Important variations in contact can impair the rider's ability to control and react to the horse's movement. It can also impact the amount of force the rider is placing on the bit and thus the horse's mouth. The lack of significant differences in rider and horse kinematics over the different fence types is inconsistent with published studies (Fercher, 2017, Nankervis et al., 2015). Fence dimensions in this study (1 m, 1 x 0.8 m) though required minimal elevation of the horses' center of mass and were possibly not great enough to alter the movement strategy employed by horses and their riders. For horse and rider kinematics soft tissue artefact, equipment and clothing movement, and technological accuracy should also be considered as potential sources of error.

CONCLUSION: This study provided discrete descriptive statistics on female rider joint kinematics when jumping. It demonstrated inter and intra-rider variability in joint ROM, peak flexion, and peak extension values, supporting the theory riders can utilise a range of successful jumping techniques, potentially highly individualised. Findings suggest athlete training programs may benefit from more individualisation of the typically strict equestrian training principles. Future studies should leverage continuous data to investigate the temporal patterns of individual techniques, and account for the highly dynamic nature of horse and rider movement. Greater characterisation of rider strategies would also help future technique analyses to better distinguish between strategy and execution variability.

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