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ORIGINAL ARTICLE

2D versus 3D in the kinematic analysis of the horse at the trot

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Abstract The handled trot of three Lusitano Purebred stallions was analyzed by using 2D and 3D kinematical analysis methods. Using the same capture and analysis system, 2D and 3D data of some linear (stride length, maximal height of the hoof trajectories) and angular (angular range of motion, inclination of bone segments) variables were obtained. A paired Student T-test was performed in order to detect statistically significant differences between data resulting from the two methodologies With respect to the angular variables, there were significant differences in scapula inclination, shoulder angle, cannon inclination and protraction-retraction angle in the forelimb variables, but none of them were statistically different in the hind limb. Differences between the two methods were found in most of the linear variables analyzed.

Keywords Horse · Kinematics · Motion analysis · Locomotion

Introduction

At the present time, the biomechanical study of the horse's locomotion is carried out by using different techniques, such as stereophotogrammetry, videography, and accelerometry. In this field of research, clinical and performance evaluations demand accurate techniques and reliable results, but they are usually associated with complexity. To perform studies under field conditions, it is necessary to design less complex methodologies.

Much has been written about equine kinematics studies by using computer-aided videography, pointing out the influence of different factors such as speed (Galisteo et al. 1998), gait quality (Morales et al. 1998), breed (Cano et al. 2001), or genetics (Molina et al. 2008).

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According to Clayton and Schamhardt (2001), in two-dimensional studies the angular data are usually reported as flexion and extension in the sagital plane. This could be a reasonable simplification because the horse's joints have evolved to swing primarily in this plane as an energy-saving mechanism. Recent studies have analyzed the accuracy of the measurements obtained by using 3D motion capture systems compared to those using photographic methods, and the former have shown a good reliability compared to other commercial systems (Garrido-Castro et al. 2006). Another point worth considering is that the 2D method involves simpler equipment (one camera, one plane to calibrate, no DTL transformations, etc.), and is apparently cheaper and easier to use under field conditions.

Weller et al. (2006) highlighted the high accuracy and precision of the 3D computerized motion analysis system in the assessment of conformational measurements on standing horses based on anatomical references. According to these authors, the identification of anatomical landmarks was found to cause the greatest variation in the measurements for proximal conformation parameters, with the inter-operator variation being larger than the intra-operator one. Markers placed over easily identifiable anatomical landmarks have also been usually employed for videographic motion analysis (Morales et al. 1998; Cano et al. 2001). However, we were unable to find in the literature whether, in the case of the horses moving and with a single operator determining the position of markers, there would be any significant differences between 2D and 3D results.

In order to be able to choose one of the methodologies for a concrete experimental design, it seems to be of great importance to verify the real differences under the same recording conditions. Using the same motion capture and analysis system, 2D and 3D data of linear and angular variables were compared in the present paper.

Material and methods

Three Lusitano Purebred stallions from the Monte da Ravasqueira Stud Farm (Portugal) were used in this study. Hemispherical retro-reflective markers (3 cm in diameter) were placed on the right side of the horses over the following easily identifiable anatomical references (Fig. 1): Withers, Tuber spina scapulae, Tuberculum majus humerus (pars caudalis), Ligament collaterale cubiti laterale, Procesus styloideus lateralis radii, Basis os IV metacarpale, Ligament collaterale metacarpophalangi laterale, margo coronalis (fore limb) at the foot axis, Tuber coxae, Trochanter major femoris (pars caudalis), Ligament collaterale geni laterale, Malleolus lateralis tibiis, Basis os IV metatarsale, Ligament collaterale metatarsophalangi laterale, and Margo coronalis (hind limb) at the foot axis.

Three digital cameras (SONY HCR 23E) placed on the right side of a flat track were used simultaneously, a usual practice for biokinematic analysis under field conditions (Fig. 2). A camera for 2D analysis was placed at 11 m to the plane of displacement, in the bisector line perpendicular to the centre of the displacement line on the track. The other two cameras were placed diagonally with respect to the plane of movement on the right side. The same track area, measuring at least seven meters was visible from all cameras, and a 3D structure of known measurements was placed in the recording area for calibration purpose, taking coplanar control points for 2D calibration and non-coplanar ones for 3D calibration. The horses were recorded at a hand-led trot, guided by an experienced handler at a comfortable speed on a 20m-length-1m-width track, limited by a cotton wire. Six strides per horse were analyzed. Every stride was selected from the centre of the field of vision in the six different trials chosen. A lighting device was used to synchronize the recording sequences in all the cameras (Deguerce et al. 1996).

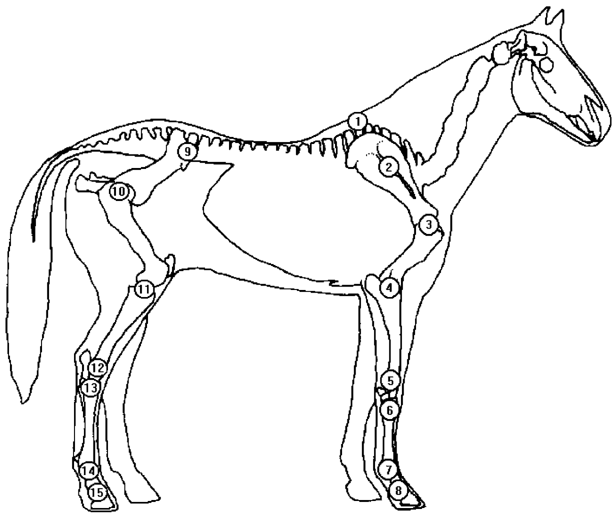

Fig. 1 Schematic representation of the position of the markers. 1. Withers, 2. Tuber spina scapulae, 3. Tuberculum majus humerus (pars caudalis) 4. Ligament collaterale cubiti laterale, 5. Procesus styloideus lateralis radii, 6. Basis os IV metacarpale, 7. Ligament collaterale metacarpophalangi laterale, 8. margo coronalis (fore limb) at the foot axis, 9. Tuber coxae, 10. Trochanter major femoris (pars caudalis), 11. Ligament collaterale geni laterale, 12. Malleolus lateralis tibiis, 13. Basis os IV metatarsale, 14. Ligament collaterale metatarsophalangi laterale, 15. Margo coronalis (hind limb) at the foot axis

For each sequence obtained by each diagonally placed camera, the position of the markers in the first frame of sequence was automatically recognized by the system using a thresholding method (Medina-Carnicer and Madrid-Cuevas 2008). The threshold obtained for the first frame was used as a fixed one for all frames in this sequence. These positions were used to calculate 3D data by means of the Direct Linear Transformation method (Abdel-aziz and Karara 1971). Results were smoothed by using a digital Butterworth filter with a cut frequency of 10 Hz, and data of each stride were normalized through linear interpolation to 100%. In addition, information was obtained from the camera placed perpendicularly for 2D data.

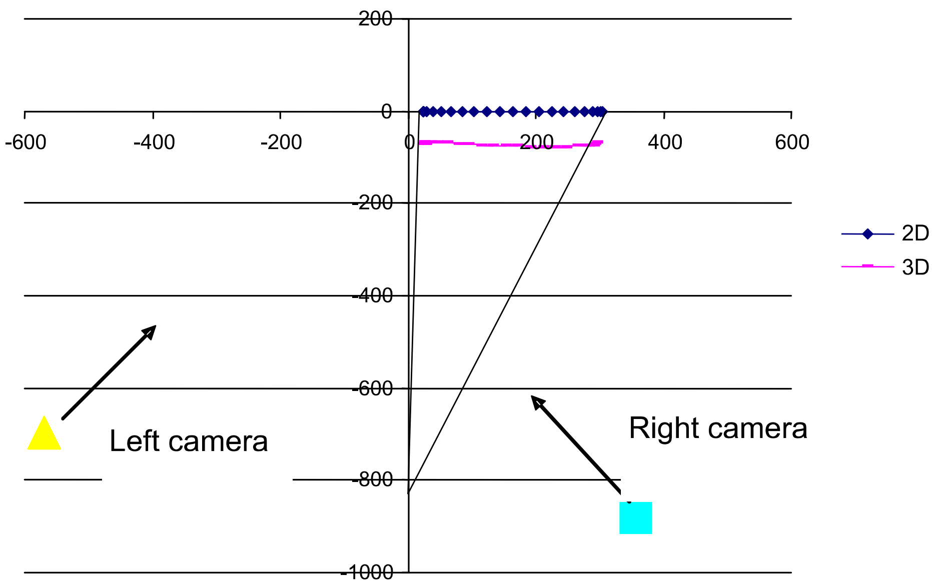

Fig. 2 Schematic representation of the effect of the 2D error in stride length measurement when comparing 2D vs 3D methodologies

Stride length and maximal height of hoof trajectories were calculated in both right fore and hind limbs under both conditions (2D and 3D). Angular range of motion of fore and hind limb angular variables was calculated by the capture system based on the position of the the corresponding three or four markers, depending on the angle. The inclination values of bone segments with respect to the horizontal plane were also measured. Means, standard deviations, and variation coefficients were calculated per horse from the 6 recorded strides. In order to identify significant differences between the two methods, a paired *S*tudent T test was performed comparing the results stride per stride (n=18).

Results

Statistics (mean, standard deviation, and variation coefficients) for angular range of motion in fore and hind limb are shown in Tables 1 and 2, respectively. With regard to the forelimb, significant differences ($p<0.05$) were found in the scapula and cannon inclination and shoulder range, and highly significant differences ($p<0.001$)in the protraction-retraction angle. Low to moderate variation coefficient values were obtained in fore limb, but it was the scapula inclination and the shoulder angular range in the 2D method which displayed the highest coefficients. With respect to the hind limb, the variation coefficients were generally low, with the highest values being found in the pelvis inclination, and no significant differences were found in any variable.

Table 3 shows the results of the stride length and the maximum height of the hoof trajectories both in fore and hind limbs. There were statistically different results for these variables in the two methods analyzed, except for that of the forehoof maximal height trajectory.

Table 4 shows the ratio between the 2D and 3D measurements for the trot stride length of a randomly selected horse.

Discussion

In 2D methodology, a deviation of the bones from the calibration plane is supposed to cause differences between the results obtained for angular variables. To make the deviation as

Table 1 Mean, standard deviation, and variation coefficient of angular displacement range in forelimb angular parameters in 18 trials of three Lusitano purebred horses at the handled trot

Parameters	2 D		3 D		Level of significance
	Mean ± S.D.	Var.Coeff.	Mean ± S.D.	Var. Coeff.	
Scapula inclination (°)	22.71±4.38	18.3%	19.68±1.87	10%	*
Shoulder angle (°)	19.06±3.56	18.6%	20.75±2.70	13.6%	*
Arm inclination (°)	33.23±4.54	14.3%	33.28±3.12	9.6%	n.s.
Elbow angle (°)	66.70±6.35	9.3%	65.44±5.58	8.3%	n.s.
Forearm inclination (°)	85.71±6.14	7%	85.09±5.55	6.6%	n.s.
Carpus angle (°)	102.41±6.53	6.3%	100.05±8.23	8.3%	n.s.
Cannon inclination(°)	88.89±4.56	5%	87.25±4.84	6%	*
Fetlock angle(°)	97.26±11.57	12%	99.9±9.14	9%	n.s.
Pastern inclination (°)	140.47±7.04	6.6%	142.86±7.84	5.6%	n.s.
Protraction-Retraction Angle (°)	42.30±2.47	5.6%	40.77±2.38	5.6%	***

NOTE: n.s. p>0.05; * p<0.05; *** p<0.001. for a paired student T test

Results of a paired Student T test are shown comparing 2D and 3D records

Table 2 Mean, standard deviation, and variation coefficient of angular displacement range in hindlimb angular parameters in 18 trials of three Lusitano purebred horses at the handled trot

Parameter	2 D		3 D		Level of significance
	Mean ± S.D.	Var. Coeff.	Mean ± S.D.	Var. Coeff.	
Pelvis inclination(°)	6.88±1.42	21%	6.62±1.46	21.6%	n.s.
Hip angle (°)	26.55±2.48	9.3%	27.23±2.27	9.3%	n.s.
Thigh inclination (°)	28.44±2.31	8%	27.93±1.80	6.6%	n.s.
Stifle angle(°)	54.82±3.52	6.6%	54.34±3.08	5.6%	n.s.
Leg inclination (°)	63.15±2.68	4.3%	63.21±2.73	4.3%	n.s.
Tarsus angle (°)	67.36±3.41	5%	66.46±3.68	5.3%	n.s.
Cannon inclination (°)	65.81±2.76	4.3%	65.55±2.32	3.3%	n.s.
Fetlock angle (°)	117.84±2.6	2%	118.13±3.84	3.3%	n.s.
Pastern inclination (°)	132.97±5.13	3.6%	131.88±4.73	3.6%	n.s.
Protraction-Retraction Angle (°)	44.23±1.59	3.3%	44.12±1.4	3%	n.s.

NOTE: n.s. $p>0.05$; * $p<0.05$; *** $p<0.001$ for a paired student T test

Results of a paired Student T test are shown comparing 2D and 3D records

small as possible, the track had been limited laterally by a cotton wire, making the horses trot close to the calibration plane, preventing an out of plane displacement. One of the most striking findings of the study was that there were no statistical differences between the two analysis methods for most of the angular variables. The exceptions were the results referring to scapula inclination, shoulder joint, and forelimb retraction-protraction angle. Conditioned by its anatomical structure, the shoulder joint is supposed to display movements out of the sagital plane which can be recorded by a 3D method of analysis but not by a 2D one. The retraction-protraction angle is representative, with some reservations, of the whole movement of the limb and represents limb oscillation in the plane of movement. In addition to this general movement of the limb, there may be displacements outwards or inwards. The above cited movements were displayed specifically by each individual, and the fact that it was the 3D method which was able to measure them may explain those differences found with respect to the retraction-protraction between the two methods compared.

The high variation coefficients, at least those found in 2D, may have been due to oblique trajectories, not of the horse's trajectory, but that of the limb segments. However, in both methods, we found higher variation coefficients in those parameters calculated based on the

Table 3 Mean, standard deviation, and variation coefficient of linear parameters of both fore and hindlimb in 18 trials of three Lusitano purebred horses at the handled trot

Parameter	2 D		3 D		Level of significance
	Mean ± S.D.	Var. Coeff.	Mean ± S.D.	Var. Coeff	
Forelimb stride length (cm)	286.73±17.75	7.3%	279.51±18.64	7.6%	**
Forehoof max. height (cm)	23.16±4.02	17.3%	22.59±3.96	14.3%	n.s.
Hindlimb stride length (cm)	288.18 ±14.28	5%	276.97±13.58	5%	***
Hind hoof max. height (cm)	14.34±1.88	12.6%	13.63±1.59	11.3%	*

NOTE: n.s. – non-significant; * - significant; ** - very significant; *** - highly significant;

Results of a paired Student T test are shown comparing 2D and 3D records

Table 4 Established ratio between 2D and 3D measurements for trot stride length of a randomly selected horse (6 trials)

Limb	Horse	Mean 2D	Mean 3D	2D/3D Ratio
Fore	*1*	286.6 cm	277.74 cm	103.2%
Hind	*1*	288.19 cm	276.97 cm	104.05%

proximal markers. This may have been due to the fact that skin displacement is greater in the proximal part of the limb (Van Weeren et al. 1990) and that, during its movement, the scapula displaces totally over the trunk, not having a proper joint connecting both structures (Clayton and Schamhardt 2001). These authors also stated that skin displacements distal to the elbow and stifle joints are minimal. Accordingly, in the present study, the variation coefficients calculated for the more distal regions of the limbs were, with almost no exceptions, of a low level (under 10%).

As the 2D method has proved to be less expensive, simpler and to require not very complex equipment, a large number of kinematic studies in horses have been made by using it in the last two decades. The accuracy of its results heavily depends on the fact that the horses move strictly over the calibration plane. Stride length is surely one of the most traditional and most important parameters to evaluate horse locomotion. Significant differences have been found for the two methodologies studied in both thoracic and pelvis limbs ($p<0.01$ and $p<0.001$, respectively). The results of the present study would justify choosing the 3D method in any kinematic design when stride length is one of the variables to be measured. If a 2D study is planned, in our opinion, the stride length should be calculated in another way.

An interesting fact is the proportion that we have been able to establish between the two-dimension and three-dimension stride length data from the two limbs, for the three horses studied (Table 4). We found the 2D average to be 3% to 4% higher than the 3D average. This could mean that the horses became displaced between the cameras and the calibration plane, and that this influenced the 2D data, because of the 2D image-projection-on-the-calibration-plane phenomenon (Fig. 2).

Conclusion

The comparison of some data obtained by 2D and 3D methodologies led us to conclude that, for some of the parameters studied, the differences found were non significant. However, in some of the more important locomotion evaluation parameters, like stride length, the 3D methodology seemed to give more accurate results, since the phenomenon of the projection of the 2D image on the calibration plan causes errors in 2D data when the animal moves out of the calibration plane. Although the 3D method is more accurate and reliable in measuring angular variables, the results of the present study indicated that 2D analysis system could be used when economic and infrastructural conditions need to be balanced. Finally, whatever method is used, the physical and technical conditions of the recording procedure are vital to obtaining quality results.

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