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COMPARISON OF VHS VIDEO RECORDING SYSTEM WITH APPLE MACINTOSH-BASED IMAGE ANALYSIS AND MODIFIED CODA-3 SYSTEMS IN EQUINE MOTION ANALYSIS

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A VHS video - computer-based image analysis combination is described as a low sampling rate motion analysis system. Video recordings were taken indoor without any artificial illumination at 25 fps sampling rate. The horse studied was running on a high-speed treadmill and observed at 1.6, 4 and 7 m/s velocities at walk, trot and canter, respectively. Left forelimb and hindlimb were recorded separately from lateral view. For comparison, parallel CODA-3 recordings were taken at the same time from the same position. Joint angles were expressed and compared in angle-time diagrams. Sampling of both systems has been synchronised by a timer device at ± 1/300 s error level. Results obtained with the two different recording systems were comparable in all joints measured with the exception of the fetlock. Inaccuracies in fetlock recordings are thought to be eliminated by measuring at controlled illumination. As a conclusion, the VHS-Macintosh setup appears to be promising as a simplified system for gait analysis.

Key words: Horse, low-speed recording, VHS video, image analysis, motion analysis

Requirements for equipment used in motion analysis such as high optical/geometrical accuracy and high sampling rate exceed the technical background of the practitioner. This limits the spreading of this method and explains the paucity of data collected so far.

Using a normal speed video, Clayton (1990, 1991) has shown that 25 frames/s frequency of VHS (Video Home System) looks satisfactory for temporal variable analysis, but not for taking angular or positional parameters. These publications give descriptions of simple methods which can be performed with the assistance of commercially available VCRs. Current inexpensive computers, however, enable such studies to be performed automatically. Recently high-

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performance systems enable users to perform detailed examinations on fast moving fine structures of limbs or particular joints. Thus fine intralimbic locomotion patterns (Peham et al., 1999) or rather global parameters such as individual optimal trotting speed (Peham et al., 1998) can be studied. The rapid development of informatics in the past decade also enables us to adapt mathematical methods such as Fourier analysis on enormous data matrices in order to yield coherent data sets on movement of body segments (Peham et al., 1996).

Thus, our study focused on the comparison of segments of angle-time diagrams and temporal video data with CODA results (Back et al., 1993) at walk, trot and canter. In this comparison an industrial standard high-performance active sensor scanning system (CODA) was positioned in contrast to a home video camera. We also checked the video camera-computer system for optometric accuracy.

Materials and methods

Parallel recordings were taken with both systems of a 5-year-old Dutch Warmblood gelding after 5-min warming up on a treadmill from 8 m distance perpendicular to the plane of locomotion at lateral view during walk, trot and left lead canter at 1.6, 4 and 7 m/s speed, respectively. For general stride element comparison, simultaneous strides were studied from each gait type. Fore- and hindlimbs were observed in separate recordings. For checking of accuracy at 4 m/s trot 10 seconds (13 strides, markers on the forelimb only) were recorded and compared in frame by frame mode. Synchronisation and identification of the same events were assisted by a timer device connected to CODA which was visible on the video screen (Fig. 1). This timer device displayed ones, tenths, hundredths and thousandths of seconds as digital characters and running light emitting diodes (LED) simultaneously. The device was synchronised in triggering with CODA data acquisition. On video still images either digital characters or LED dots were well recognisable up to thousandths of seconds.

In the CODA recordings eleven photodiodes on the forelimb and ten on the hindlimb were glued to the skin above the anatomical features described in Table 1. To aid in recognition of temporal data an accelerometer was fixed to the dorsal wall of the hoof (Back et al., 1995*a,* 1995*b*).

The same markers were visually emphasised by gluing 40 × 80 mm light yellow TESA adhesive tape strips perforated in the centre allowing light transmission for the CODA photodiodes. The size of the markers has been defined as optimal for recognition.

Video recordings were taken with an MS1 Panasonic CCD VHS camcorder (Matsushita Electric Industrial Co. Ltd., Japan) used in VHS mode under normal day light circumstances. Indoor lighting was measured at 1000–1500 lux by illuminometer (Model 5200, Kyoritsu Electrical Instruments Works Ltd., Japan) (Fig. 1). The single camera was fixed on tripods by the side of the treadmill with manual focus. Shutter speed was set to 1/500 s, the diaphragm had to be adjusted to changes of background light. Because of recordings with CODA-3, extra illumination was avoided.

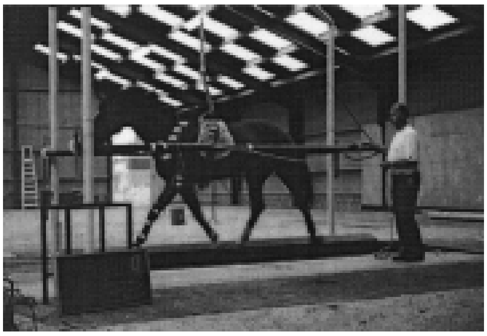

Fig. 1. A photograph taken near (left) to the place of recording. The horse is running on the treadmill and the forelimb is equipped with sensors of CODA visualised with pieces of adhesive tape for better identification in video images. In the left bottom corner the timer device is situated for purposes of synchronisation

Table 1

Anatomical features visualised by markers

Forelimb		Hindlimb	
1.	Heel	1.	Heel
2.	Toe	2.	Toe
3.	Coronary band	3.	Coronary band
4.	Distal end of the metacarpus	4.	Distal end of the metacarpus
5.	Proximal end of the metacarpus	5.	Proximal end of the metacarpus
6.	Lateral styloid process of the radius	6.	Lateral malleolus
7.	Attachment of the collateral ligament of the elbow	7.	Attachment of the collateral ligament of the stifle
8.	Lateral epicondyle of the humerus	8.	Lateral epicondyle of the femur
9.	Caudal part of the greater tubercle on the humerus	9.	Cranial part of the greater trochanter
10.	Distal end of the spine of the scapula	10.	Tuber coxae
10/a.	A marker in between		
11.	Proximal end of the spine of the scapula		

Video recordings were played back in freeze-frame mode by a 4-headed Sony VCR (Sony Corp., Tokyo, Japan). This recorder supported jitter- and shift-free display of still images. The digitising board was a standard model of Macintosh AV computers. Image size was 367 × 288 pixels at 8 bit grayscale colour depth and 72 dpi of resolution. The relative size of the horse within the still image was approx. 60%. This way both the fore- and hindlimb extension maxima were visible in the field of view. At higher velocities a wider field of view (approx. 200%) was recorded. The application NIH Image 1.59 (Wayne Rasband, National Institutes of Health, USA) was used for image analysis. Recognition of markers appearing in 8×8 pixel size was carried out manually. Identification of marker position was carried out by clicking at their centre at the lightest area. Connection of the clicked markers and angle measuring were carried out by a Pascal like macro, developed by us for this purpose. Scapula rotation was calculated as an angle between the axis of the scapular spine and horizontal plane of the environment. Pelvic rotation was also related to the horizontal plane. Difference between the value of horizontal planes of both systems was balanced by transformation of video data: the difference of the means was added to video data in averaged stride curves.

As a result, an Excel compatible file was created. For further procedure these data files were loaded as spreadsheets into Microsoft Excel 4.0 (Microsoft® Microsoft Corporation, Soft-Art, Inc.), and StatView SE+Graphics™ (StatView®, Abacus Concepts, Berkeley, California, USA) for data management, evaluation and visualisation.

In 13 strides at the trot detection of impact and lift-off was carried out by sight on video recordings based on the experience of the analysing person, so its reliability was checked statistically. In CODA recordings stance and swing phases were distinguished by change of amplitude of the accelerometer signal in synchrony to changes of fetlock curves. Paired Student's *t*-test was used in temporal data analysis (Linford, 1994).

In checking for accuracy synchronised data were compared. The sampling frequency of VHS systems is 0.04 sec (1/25 fps) while the CODA system records 3,000 moments in a second. This difference was synchronised mathematically with finding the best fitting synchronous CODA curves to video data with the method of least squares. Synchronised average curves of 13 strides were examined in angle-time diagrams and tested with paired Student's *t*-test.

Results

Angle-time diagrams

Markers on the forelimb were well recognisable. Except the limb ends, the contrast between the marker and its neighbourhood was high. Minima and maxima of standard deviation in scapular rotation and elbow angles fitted well (Fig. 2). The carpus curves were showing some 'oscillation' around the flexed position. The highest difference of values was observed at the fetlock joint. Characteristic details of curves could be recognized at walk and trot but not at canter.

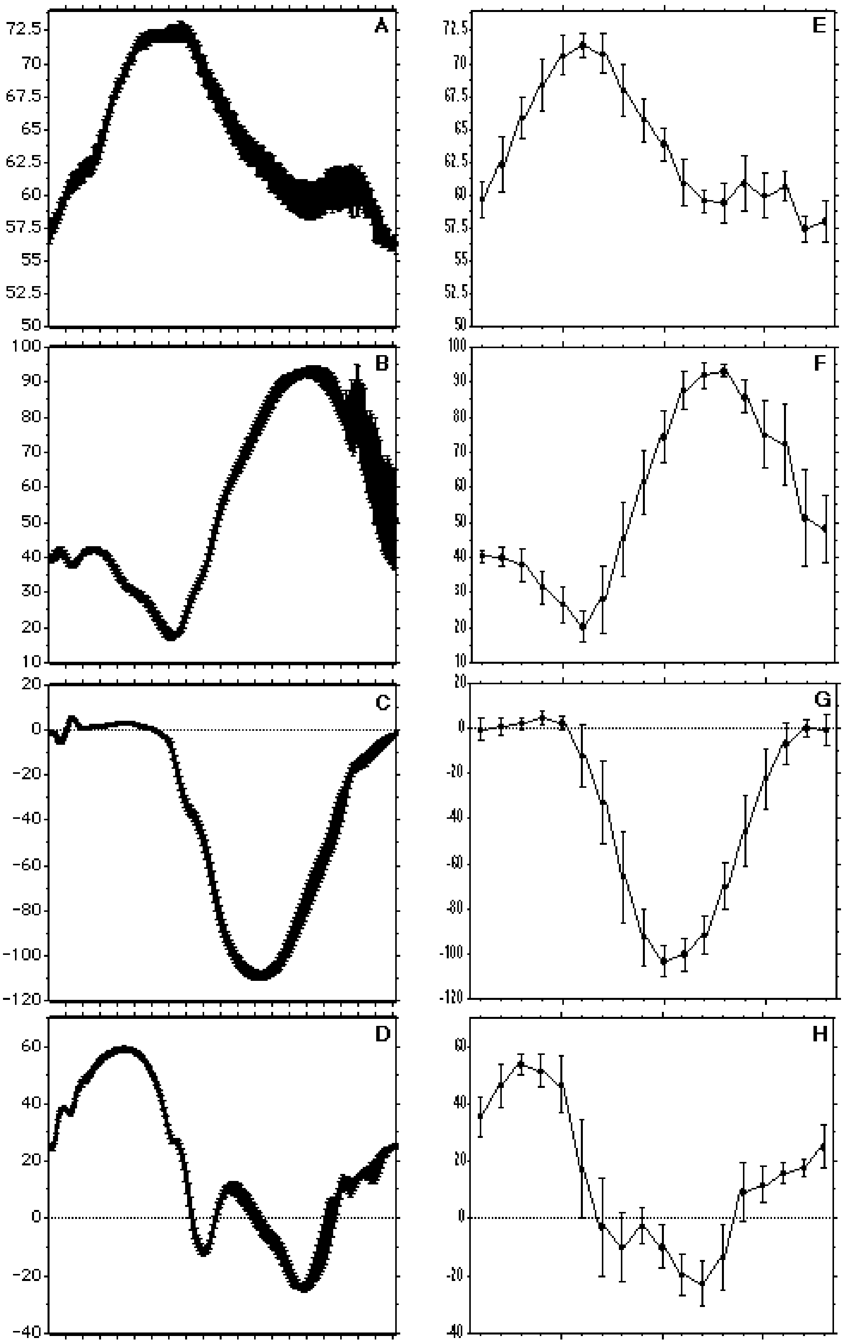

Fig. 2. Angle-time diagrams at trot (4 m/s, 13 strides) of A) scapula rotation, B) elbow, C) carpus, D) fetlock angles from modified CODA-3 system and E) scapula rotation, F) elbow, G) carpus and H) fetlock angles from video recordings. Means and standard deviations (vertical lines) are indicated

Values of hindlimb data had a moderately higher deviation from CODA curves. A small degree of shift to the left occurred on each curve, the cause of which is obscure. Characteristics were obvious at the hip and stifle joints at each gait type. The trend of tarsal joint data followed CODA findings with the exception of some frames. Fetlock data deviation was surprisingly small at walk but increased at higher velocity. Averaged differences belonging to the scapular curves showed rather high difference before data transformation, but their standard deviation was similar. Changes of standard deviation at the elbow and carpus joints showed similar distribution. At the flexion of the carpus higher deviations can be detected on video curves. Fetlock data produced the highest deviation. Distribution of deviation within the curves was very similar in all strides.

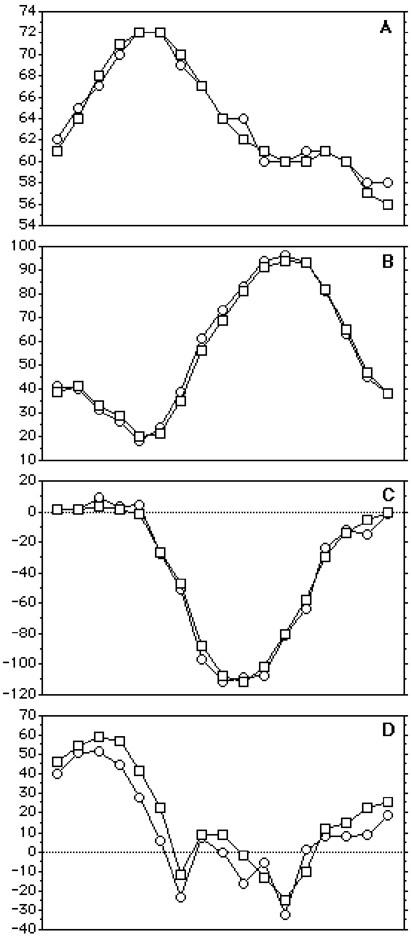

Fig. 3. Overlapped angle-time diagrams of A) scapula rotation, B) elbow, C) carpus and D) fetlock joint angles in average of 13 synchronised strides. Paired *t*-test showed significant deviation ($p < 0.05$) at the fetlock curves only. Circles = video data, squares = CODA data

Test of geometrical accuracy

Average stride of 13 strides from CODA and video recordings was also calculated and compared at trot on the forelimb. Comparing to non-averaged video values, data deviation was reduced. Figure 3 describes overlapped synchronised average curves with their standard deviation. Synchronisation was based on the timer and refined by shifting of data set. Curves of the scapula, elbow and carpus show small deviations. Significant difference could be detected between the fetlock curves only. Analysis of subsequent strides showed similar appearance of deviations within the same joints at the moments of extension.

Temporal variables

Temporal variables were compared to check the investigator's ability to detect different moments of stride. Most important was the detection of impact. A distinct pilot study under the same conditions was performed where 13 strides at 4 m/s trot were recorded with both systems. Time resolution of VHS devices calculated from frames is 40 ms, so the difference between the two systems should not to be higher than 40 ms. Our average deviation for 13 strides was 0.028 s (± 0.015, SD).

Duration of stance and swing phases were also compared (Table 2). On video recordings the duration of these phases was calculated from the number of frames. The time unit was 40 ms as it has been at impact detection. Separation of phases on CODA recordings was assisted by accelerometer fixed on the hoof.

Table 2

Temporal data describing phases of stride from both systems
(n = 8 at 1.6 m/s, n = 13 at 4 m/s, n = 16 at 7 m/s)

Speed	1.6 m/s	(SD)	4 m/s	(SD)	7 m/s	(SD)
Video						
Stride duration (sec)	1.04	(0.03)	0.70	(0.02)	0.59	(0.02)
Stance duration (%)	59.41		34.67		27.38	
Stance duration (sec)	0.62	(0.02)	0.24	(0.01)	0.16	(0)
Swing duration (sec)	0.42	(0.02)	0.46	(0.02)	0.43	(0.02)
CODA						
Stride duration (sec)	1.03	(0.02)	0.69	(0.01)	0.58	(0.01)
Stance duration (%)	63.18		37.05		30.21	
Stance duration (sec)	0.65	(0.01)	0.26	(0.01)	0.17	(0.003)
Swing duration (sec)	0.38	(0.02)	0.44	(0.01)	0.40	(0.007)

Significant differences at p = 0.05 were not found between the systems for any parameters. SD: standard deviation

Discussion

Theoretically, more strides give more information about events between two recorded video frames. These data, however, represent different moments, so their sum in an averaged curve is misleading. Averaging of data produces smooth curves, but hides smaller characteristic peaks. Due to this some fine details may disappear. On the other hand, with averaging the analyser is able to dispose random errors. With a carefully selected averaging method (e.g. floating average within 3–5 neighbourhoods) better fitting data set might be obtained. This problem may affect the results of the analysis and requires further investigations.

In a general analysis of strides, scapula rotation after data transformation showed satisfactory results. Elbow angle was also acceptable, though the consequent 'vibration' became smooth. Among joints, the carpus produced the best fitting curves. The oscillation around zero degree during stance phase was compensated by averaging more stride curves. During hyperextension and when the joint turns to flexion video data described positive and negative peaks as well, so their average would be a misinterpretation. On the lifted forelimb the antebrachium shaded the distal part of the leg, especially parts close to the flexion point. This problem will be avoided by usage of directed illumination.

Fetlock angles on the forelimb did not follow reliably CODA results. In our opinion this was due to the poor intermittent illumination positioned on the roof. These circumstances could not be changed because of the high sensitivity of the CODA system. The dorsoventrally directed light beam projected shadow in some phases of stride onto the distal limb, blurring contours of markers in video still images. Under any other circumstances where CODA is not used this problem can be avoided. We concluded this from the following consideration. It was surprising that the high standard deviations of video data showed a constant cyclic pattern. The location of coincidences within the stride curve was also constant. The theoretical consideration that the more distal segment has the higher angular speed and acceleration and due to the blurring of the picture of the distal section which produces the highest deviations from CODA curves turned to be false. The 1/500 of shutter speed provided a blur-free image but due to insufficient illumination images were dark and poor in details. Analysing more subsequent strides, there were some moments when deviations regularly occurred. The plateau in the middle of the stance phase showed oscillation. Such a high deviation could not be recognised in other joints at the same phase of the stride, so the difference had to come from a marker which was not used in other cases. The only marker like this was on the hoof. The probable reason was inadequate light reflection of the hoof marker due to poor illumination because of the simultaneous usage of CODA.

Hindlimb data showed a bit higher deviation as compared to the forelimb. Since the forelimb and hindlimb recordings were separate in time, change of illumination could also influence results. Hip angle as well as stifle and hind fetlock showed acceptable results at walk and trot, but not at canter. Surprisingly, the tarsus yielded the best results at all gaits. It is an interesting coincidence that the best results on the forelimb and the hindlimb were at the same horizontal level.

Results of comparison of averaged data showed sometimes less deviation but also less details. Because of imperfect synchronisation, averaged data could never fit perfectly. Scapular curves of CODA and video recordings were similar. Deviation of values at the end of the swing phase were usually influenced by the side bar on the treadmill. On the lifted forelimb the antebrachium shaded the distal part of the leg, especially close to the flexion point of the carpus which caused some deviation at maximum flexion. When selecting the accurate measurements, the fetlock curve seemed to be shifted. On the other hand, differences occurred at moments when the fetlock joint was mostly accelerating and getting shaded, so the phenomenon of being pushed leftwards was not necessarily caused by time shifting.

In the comparison of an industrial standard high-performance system (CODA) to VHS recordings some differences were obvious. In the VHS recordings the sampling frequency is limited, therefore fine details cannot be studied which may exclude this method from certain examinations. Introduction of further synchronised cameras cannot enhance details but may give synchronous information on both sides of limbs which might be essential in recognition of interlimbic asymmetries in lameness. It must be emphasised that handling three or four cameras at the same time makes performance of analysis difficult and disables its application under field circumstances.

The acquisition of both motion analysis systems requires remarkably different financial background. However, it can be concluded that the standard deviations of data from subsequent strides showed a similar pattern to the average stride deviation and the occurrence of coincidences was also constant.

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