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A simple method for equine kinematic gait event detection

Summary

Background: Previous studies have validated methods for determining kinematic gait events using threshold-based methods, however a simple method is yet to be identified that can be successfully applied to ~~all equine gaits~~walk, trot and canter.

Objectives: To develop a simple kinematic method to identify the timing of hoof-on, peak vertical force and hoof-off, which can be applied to ~~all equine gaits~~walk, trot and canter.

Study Design: The horses (*n*=3) were ridden in walk, trot and canter down a runway with four force plates arranged linearly. Three-dimensional forces were recorded at a sampling rate of 960 Hz and were synchronised with a ten-camera motion analysis system sampling at 120 Hz.

Methods: Events identified from the vertical ground reaction force (GRFz) data were hoof-on (GRFz>50N), peak vertical force (GRFz$_{peak}$) and hoof-off (GRFz<50N). Kinematic identification of hoof-on and hoof-off events was based on sagittal planar angles of the fore and hindlimbs. Peak metacarpophalangeal/metatarsophalangeal (MCP/MTP) joint extension was used ~~Two kinematic methods were used~~ to assess the time of GRFz$_{peak}$. ~~: a vertical orientation of the third metacarpal/metatarsal (MCIII/MTIII) and peak extension of the metacarpophalangeal/metatarsophalangeal (MCP/MTP) joint.~~ The accuracy (mean) and precision (SD) of the time difference between the kinetic and kinematic events were calculated for the fore and hindlimbs at each gait.

Results: Hoof-off was determined with better accuracy (range: -3.94~~35~~ to 8.33~~3~~ms) and precision (5.43 to 11.39ms) than hoof-on across all gaits. Peak MCP angle (5.83 to 19.65 ms) was a more precise ~~/MTP angle (-0.298 to -62.5ms) was a more accurate~~ representation of GRFz$_{peak}$ than peak MTP angle (11.49 to 67.75 ms)~~than MCP/MTP inclination (-217.593 to 54.018ms)~~.

Main Limitations: The sample size was small and, therefore, further validation is required. The proposed method was tested on one surface.

Conclusions: A simple kinematic method of detecting hoof-on, hoof-off and GRFz$_{peak}$ ~~has been identified~~is here proposed for ~~all gaits~~walk, trot and canter. Further work should focus on validating the methodology in a larger number of horses and extending the method for use on surfaces with varying compliance.

Introduction

Equine biomechanical studies rely heavily on determination of gait events and subsequent stride cycles for the accurate analysis of kinematic and kinetic variables [1]. However, a standardised, evidence-based method to objectively determine gait events using motion capture data is yet to be defined ~~under~~ for over ground, ridden conditions~~field conditions~~ [2,3]. Previous studies reported that limb force and timing of initial hoof impact can be difficult to identify using kinematic data, with force plates being widely accepted as the “gold standard” for identifying hoof contact (hoof-on) and lift off (hoof-off) [2,4,5]. Force plates are, however, rarely used outside laboratory conditions~~in field conditions~~, so a reliable kinematic method of defining the time of hoof-on, hoof-off and peak vertical force (GRFz$_{peak}$) in field studies would be useful [2,6].

Previous validations of kinematic gait events against force data have reported high accuracy and precision [2,3,6,7,8,9]. Most of these studies use hoof markers for event detection but precise visual determination of hoof contact and lift off are difficult, especially on compliant surfaces [2, 10]. The objective was to use force data to evaluate a straightforward kinematic method to identify the time of hoof-on, hoof-off and GRFz$_{peak}$, which can be universally applied to all limbs of the ridden horse in walk, trot and canter.

Methods

Horses

Three Lusitano stallions (height at withers: 1.61–1.65m; mass: 535.5 - 585kg) trained to advanced level dressage were ridden by their usual trainer (mass: 65 kg). The horses were assessed by a veterinarian to be sound at walk and trot on a straight line.

Data Acquisition

Retro-reflective 3D markers were applied to the left and right side of the horse (Figure 1). A static trial of each horse standing square and at least 6 successful walk, trot and canter trials were recorded. The horses were ridden in walk (1.66 ± 0.22 m/s), trot (2.44 ± 0.25 m/s) and canter (2.95 ± 0.69 m/s) down a runway with a poured rubber surface. Speed was measured using the first derivative of a marker on the sacrum in the direction of motion. Kinematic data were captured at 120 Hz with a ten-camera motion analysis system (Eagle cameras, Motion Analysis Corp.; Cortex 1.1.4.368, Motion Analysis Corp.) and synchronised kinetic data with four force plates arranged linearly along a runway (Bertec Corporation, USA) at 960 Hz.

Data Processing

Kinematic and kinetic data were analysed using Visual 3D (C-Motion Inc.). Kinematic data were interpolated (maximum gap 10 frames) and then filtered with a low pass zero lag 4th order Butterworth digital filter (cut off frequency of 10 Hz). The same filter was also applied to the kinetic data with a cut off frequency of 100 Hz in accordance with [11]. The timing of hoof impact, lift off and peak vertical force was calculated using GRF and kinematic data.

Gait event detection using GRF data

Footfalls were rejected if the hoof was not entirely on the force platform or if another hoof was in contact with the same force platform simultaneously. The vertical ground reaction force (GRFz) data were used to detect the time of hoof-on (GRFz>50N), peak vertical force ($GRFz_{peak}$) and hoof-off (GRFz<50N).

Gait event detection using kinematic data

To determine the kinematic hoof-on and hoof-off events for the forelimbs, a sagittal plane angle was computed using the following markers: 1) centre of rotation of the MCP joint; 2) centre of rotation of the distal interphalangeal (DIP) joint; 3) the lateral epicondyle of the humerus (Figure 1a). The hindlimb events for hoof-on and hoof-off were also identified by creating a sagittal plane angle, using the following markers: 1) centre of rotation of the MTP joint; 2) the talus representing the centre of rotation of the tarsal joint; 3) the hind DIP joint (Figure 1b). Planar angle-time curves were plotted for the fore and hindlimbs. A threshold of 0 degrees was used to define events when the two segments were aligned, with hoof-on ~~(0 degrees) being~~ coinciding with descent through 0 degrees and hoof-off on ascent through 0 degrees.~~followed by extension of the MCP/MTP joint, and hoof-off (0 degrees) being followed by flexion of the MCP/MTP joint.~~ The time of $GRFz_{peak}$ was identified with the kinematic data using maximum MCP and MTP joint extension, where maximal MCP extension has previously shown a strong correlation with peak vertical force [12].

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Figure 1a) The sagittal plane angle used to identify hoof-on and hoof-off events for the forelimbs; 1) MCP joint; 2) fore DIP joint; 3) lateral epicondyle of the humerus. The MCIII was created using markers on the proximal end of metacarpal IV and MCP joint. The MCP joint was created using the MCIII and fore pastern segment, which was made using the centre of rotation of the MCP joint and fore DIP joint markers. Figure 1b) The sagittal plane angle used to ~~create~~ identify hoof-on and hoof-off events for the hindlimbs; 1) MTP joint; 2) talus; 3) hind DIP joint. The MTIII segment was created using the talus and MTP joint markers. The MTP joint was created using the MTIII and hind pastern segment, which was made using the centre of rotation of the MTP joint and hind DIP joint markers.

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~~The time of $GRFz_{peak}$ was identified with the kinematic data using two methods. The first method identified a vertical orientation of the MCIII and MTIII segments in the sagittal plane, which has previously been used in the forelimbs [12, 13]. The second method used maximum MCP and MTP joint angle, where maximal MCP extension has previously shown a strong correlation with peak vertical force [13].~~

Gait event timings were derived using the GRF and kinematic methods. The accuracy and precision of the kinematic gait events at representing the GRF events were calculated for the fore and hindlimbs at each gait in accordance with [3]. Accuracy is defined as the mean difference between kinematic and GRF events (bias) and precision as the standard deviation (SD) of the mean difference (accuracy) [3]. The smallest difference was considered the best accuracy and precision.

Results

A total of 227 stance phases (walk: 113; trot: 80; canter: 34) were analysed across all subjects. Accuracy and precision of the kinematic gait events for all gaits and individual limbs (Table 1) showed that hoof-off was identified more accurately than hoof-on, as shown by a much smaller deviation from the GRF event (Figure 2). Accuracy (difference in timings closer to zero) and precision (smaller standard deviation of the difference in timings) were higher for hoof-on in canter compared to walk and trot. Accuracy for hoof-off was highest at trot, but precision was highest at walk. The time of $GRFz_{peak}$ corresponded well with maximal MCP/MTP extension. ~~but not with vertical inclination of MCIII/MTIII.~~

Table 1: The accuracy (mean) and precision (standard deviation) between events detected kinematically and using ground reaction force data for forelimbs and hindlimbs of all horses at each gait. Canter was categorised further into leading (Le) and trailing (Tr) limbs. Positive values indicate that the kinematic event occurred before the GRF event and vice versa for negative values. Negative values for stance duration indicate that the kinematic method generates a longer timing.

Figure 2: The accuracy and precision of the kinematic gait events for fore and hindlimbs on a GRF trace at walk, trot and canter. The solid black lines on each graph represent the GRF events at hoof-on (GRFz>50N), $GRFz_{peak}$ and hoof-off (GRFz<50N) from left to right respectively. The dotted lines represent the events identified using the kinematic methods; from left to right: hoof-on, peak MCP/MTP extension and hoof-off. The shaded areas represent the precision of each kinematic event. The canter data from the leading and trailing limbs has been grouped for the purpose of this graphical representation.

Discussion

This study evaluated a kinematic method for determining the timing of hoof-on, GRFz$_{peak}$ and hoof-off events in walk, trot and canter. The method is simple, can be applied to two dimensional or three dimensional kinematic data and can be used under most field conditions, provided the coronary band is visible. The hoof-off event was detected with better accuracy and precision than hoof-on, which was generally within one to two frames of the GRF event. The timing of GRFz$_{peak}$ also corresponded closely with maximal MCP/MTP extension~~ but not with verticality of MCIII/MTIII~~.

Hoof orientation during impact was not taken into account for this study. The hoof sole has been observed to be completely flat on the ground within several milliseconds of initial impact [~~14~~13], which suggests that the effect of hoof orientation on impact timing should be minimal. The distal interphalangeal joint markers are also at the centre of rotation, which therefore should make the detection method less sensitive to hoof orientation on landing. The horses in this study were also tested during collected canter and further work is required to investigate the accuracy and precision of the kinematic detection methods in horses travelling at faster velocities.

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Precision as low as 2 ms or less than one frame of data has been reported [9] for hoof-on at walk and trot using a velocity threshold method, which appears to be the most accurate to date. A greater sample of footfalls were analysed (360-800 hoof-on events for walk and trot in a straight line), however it is important to note that differences were calculated by averaging the within-horse mean values, which will lower the overall differences between footfalls [9]. Nevertheless, the hoof-off kinematic detection method reported here demonstrated better accuracy at trot in the hind limbs than the methods used by [9]. The hoof-off event at trot was comparable to some of the methods described by [3], however the detection methods used appear to be more complex to ~~administer~~ execute in comparison to this study.

Some methods [3,7,9] are also dependent on velocity thresholds. Surface properties can influence parameters such as hoof landing velocity [10], which may affect the repeatability of these methods if used on compliant surfaces. Forelimb landing angle is affected by surface stiffness [10], which suggests that the angles used to calculate the kinematic events during this study may also be affected by the surface properties. Surface effects are not well documented [3], so pilot work is recommended ~~when~~ before testing on compliant surfaces [9].

Peak vertical force~~Mid-stance~~ is commonly identified in research because it is associated with the risk of musculoskeletal injuries and can be used during lameness assessments [14]. The ability to calculate the timing of this in the absence of force data could constitute a useful tool when quantifying the entire kinematic profile of a horse during such assessments.~~the peak forces experienced during support can be associated with generating a risk factor for injury [15].~~ In this study, peak MCP was found to be a more precise and MTP extension was found to be a more accurate method for $GRFz_{peak}$ detection than MTP extension, which is in agreement with [13] where a ~~A~~ very strong positive correlation between MCP joint angle (49.4% stance) and GRF (47.7% stance) was found during *in vitro* loading [12]. In contrast, [~~16~~15] suggested that maximal fetlock extension and peak force in the forelimbs during trot occur more independently. A delay in fetlock extension has been observed during trot in the forelimbs of ridden horses ~~[17]~~where it was proposed that the dynamic effect of the rider may have a greater influence after mid-stance when the horse's centre of gravity is rising [16]~~, which~~. This could ~~may~~ explain why peak MCP and MTP extension occurred ~~these events were~~ was after $GRFz_{peak}$ ~~synchronized~~ in the present study.~~ It was proposed that the dynamic effect of the rider may have a greater influence after mid-stance when the horse's centre of gravity is rising [17], which could explain the delay in the kinematic mid-stance event. Previous studies have used MCIII inclination to represent the transition between braking and propulsive longitudinal forces in the forelimbs [12] but the data presented here shows that peak MCP extension is a more appropriate method of identifying the time of peak force. This can be further supported by [18] where the change in longitudinal force in the forelimbs at walk occurred after the vertical orientation of the MCIII and coincided with peak MCP extension.~~

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Conclusions

A simple method of detecting force gait events using kinematic data has been identified for ~~all gaits~~ridden walk, trot and canter~~of the ridden horse~~. Further work must focus on validation using a greater sample size to establish the effect of a larger population of horses on the accuracy and precision of the detection methods under a ~~number of different~~variety of ridden and un-ridden conditions.

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Ethical Considerations

All procedures were approved by the Michigan State University Institutional Animal Care and Use Committee, protocol #02/08-020-00.

Conflicts of Interest

The authors have declared no conflicts of interest.

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