

## Article

# A simple method for equine kinematic gait event detection

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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 ( $\text{GRFz} > 50\text{N}$ ), peak vertical force ( $\text{GRFz}_{\text{peak}}$ ) and hoof-off ( $\text{GRFz} < 50\text{N}$ ). 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  $\text{GRFz}_{\text{peak}}$ : 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: -3.9435 to 8.333ms) 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  $\text{GRFz}_{\text{peak}}$  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.

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

30

### 31 **Introduction**

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

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

47

### 48 **Methods**

#### 49 ***Horses***

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

### 53 **Data Acquisition**

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

### 62 **Data Processing**

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

#### 68 *Gait event detection using GRF data*

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

#### 73 *Gait event detection using kinematic data*

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

Commented [HC1]: coinciding with

86  
87 *Figure 1a) The sagittal plane angle used to identify hoof-on and hoof-off events for the forelimbs; 1) MCP joint;*  
88 *2) fore DIP joint; 3) lateral epicondyle of the humerus. The MCIII was created using markers on the proximal end*  
89 *of metacarpal IV and MCP joint. The MCP joint was created using the MCIII and fore pastern segment, which*  
90 *was made using the centre of rotation of the MCP joint and fore DIP joint markers. Figure 1b) The sagittal plane*  
91 *angle used to ~~create~~ identify hoof-on and hoof-off events for the hindlimbs; 1) MTP joint; 2) talus; 3) hind DIP*  
92 *joint. The MTIII segment was created using the talus and MTP joint markers. The MTP joint was created using*  
93 *the MTIII and hind pastern segment, which was made using the centre of rotation of the MTP joint and hind DIP*  
94 *joint markers.*

Commented [HC2]: identify

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96 ~~The time of GRFz<sub>peak</sub> was identified with the kinematic data using two methods. The first method~~  
97 ~~identified a vertical orientation of the MCIII and MTIII segments in the sagittal plane, which has~~  
98 ~~previously been used in the forelimbs [12, 13]. The second method used maximum MCP and MTP joint~~  
99 ~~angle, where maximal MCP extension has previously shown a strong correlation with peak vertical~~  
100 ~~force [13].~~

101 Gait event timings were derived using the GRF and kinematic methods. The accuracy and precision of  
102 the kinematic gait events at representing the GRF events were calculated for the fore and hindlimbs

103 at each gait in accordance with [3]. Accuracy is defined as the mean difference between kinematic  
104 and GRF events (bias) and precision as the standard deviation (SD) of the mean difference (accuracy)  
105 [3]. The smallest difference was considered the best accuracy and precision.

## 106 **Results**

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

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

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

131

132 **Discussion**

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

139 Hoof orientation during impact was not taken into account for this study. The hoof sole has been  
140 observed to be completely flat on the ground within several milliseconds of initial impact [4413],  
141 which suggests that the effect of hoof orientation on impact timing should be minimal. The distal  
142 interphalangeal joint markers are also at the centre of rotation, which therefore should make the  
143 detection method less sensitive to hoof orientation on landing. The horses in this study were also  
144 tested during collected canter and further work is required to investigate the accuracy and precision  
145 of the kinematic detection methods in horses travelling at faster velocities.

Commented [HC3]: remove 'therefore'

Commented [HC4]: faster

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

155 Some methods [3,7,9] are also dependent on velocity thresholds. Surface properties can influence  
156 parameters such as hoof landing velocity [10], which may affect the repeatability of these methods if

157 used on compliant surfaces. Forelimb landing angle is affected by surface stiffness [10], which  
158 suggests that the angles used to calculate the kinematic events during this study may also be affected  
159 by the surface properties. Surface effects are not well documented [3], so pilot work is recommended  
160 ~~when before~~ testing ~~on~~ compliant surfaces [9].

161 ~~Peak vertical force~~ ~~Mid-stance~~ is commonly identified in research because ~~it is associated with~~ ~~the risk~~  
162 ~~of musculoskeletal injuries and can be used during lameness assessments~~ [14]. ~~The ability to calculate~~  
163 ~~the timing of this in the absence of force data could constitute a useful tool when quantifying the~~  
164 ~~entire kinematic profile of a horse during such assessments.~~ ~~the peak forces experienced during~~  
165 ~~support can be associated with generating a risk factor for injury~~ [15]. In this study, ~~peak~~ MCP ~~was~~  
166 ~~found to occur~~ ~~and MTP is a further measure of GRF data for the MTP joint, which is not [13].~~ ~~A very strong~~  
167 correlation between MCP joint angle (49.4% stance) and GRF (47.7% stance) was found during *in vitro*  
168 loading [12]. In contrast, [4615] suggested that maximal fetlock extension and peak force in the  
169 forelimbs during trot occur more independently. ~~\_~~ A delay in fetlock extension has been observed  
170 ~~during trot~~ in the forelimbs of ridden horses [17] ~~where it was proposed that the dynamic effect of~~  
171 ~~the rider may have a greater influence after mid-stance when the horse's centre of gravity is rising~~  
172 [16], ~~which~~. This could ~~may~~ explain why ~~peak~~ MCP and MTP extension occurred ~~these events were~~  
173 ~~was after~~ GRF<sub>peak</sub> ~~synchronized~~ in the present study. ~~It was proposed that the dynamic effect of the~~  
174 ~~rider may have a greater influence after mid-stance when the horse's centre of gravity is rising~~ [17],  
175 ~~which could explain the delay in the kinematic mid-stance event.~~ Previous studies have used MCIII  
176 ~~inclination to represent the transition between braking and propulsive longitudinal forces in the~~  
177 ~~forelimbs~~ [12] but the data presented here shows that ~~peak~~ MCP extension is a more appropriate  
178 ~~method of identifying the time of peak force.~~ This can be further supported by [18] where the change  
179 ~~in longitudinal force in the forelimbs at walk occurred after the vertical orientation of the MCIII and~~  
180 ~~coincided with peak MCP extension.~~

## 181 **Conclusions**

Commented [HC5]: is associated with

Commented [HC6]: is typically reduced in lameness

Commented [HC7]: occurred



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

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## 187 **References**

- 188 [1] Leach, D. (1993) Recommended terminology for researchers in locomotion and biomechanics of  
189 quadrupedal animals. *Cells Tissues Organs*, **146** (2-3), 130-136.
- 190 [2] Hobbs, S. J., Orlande, O., Edmundson, C. J., Northrop, A. J. and Martin, J. H. (2010) Development of  
191 a method to identify foot strike on an arena surface: application to jump landing. *Comparative*  
192 *Exercise Physiology*, **7** (1), 19-25. doi:10.1017/S1755254010000097
- 193 [3] Boye, J. K., Thomsen, M. H., Pfau, T. and Olsen, E. (2014) Accuracy and precision of gait events  
194 derived from motion capture in horses during walk and trot. *Journal of Biomechanics*, **47** (5), 1220-4.  
195 doi: 10.1016/j.jbiomech.2013.12.018.
- 196 [4] Schamhardt, H. C. and Merken, H. W. (1994) Objective determination of ground contact of equine  
197 limbs at the walk and trot: comparison between ground reaction forces, accelerometer data and  
198 kinematics. *Equine vet. J. Suppl.*, **17**, 75-79.
- 199 [5] Witte, T. H., Knill, K. and Wilson, A. M. (2004) Determination of peak vertical ground reaction force  
200 from duty factor in the horse (*equus caballus*). *The Journal of Experimental Biology*, **207**, 3639-3648.
- 201 [6] Olsen, E., Andersen, P. H. and Pfau, T. (2012) Accuracy and precision of equine gait event detection  
202 during walking with limb and trunk mounted inertial sensors. *Sensors*, **12**, 8145-8156.  
203 doi:10.3390/s120608145
- 204 [7] Peham, C., Scheidl, M. and Licka T. (1999) Limb locomotion – speed distribution analysis as a new  
205 method for stance phase detection. *Journal of Biomechanics*. **32**, 1119-1124.
- 206 [8] Galisteo, A. M., Garrido-Castro, J. L., Miró, F., Plaza, C. and Medina-Carnicer, R. (2010) Assessment  
207 of a method to determine the stride phases in trotting horses from video sequences under field  
208 conditions. *Vet. Med. Austria*, **97**, 65-79.
- 209 [9] Starke and Clayton (2015), A universal approach to determine footfall timings from kinematics of  
210 a single foot marker in hoofed animals. *PeerJ*, **3**, e783. DOI 10.7717/peerj.783
- 211 [10] Burn, J. F. and Usmar, S. J. (2005) Hoof landing velocity is related to track surface properties in  
212 trotting horses. *Equine and Comparative Exercise Physiology*, **2** (1), 37-41.  
213 [doi.org/10.1079/ECP200542](https://doi.org/10.1079/ECP200542)
- 214 [11] Hobbs, S. J. and Clayton, H. M. (2013) Sagittal plane ground reaction forces, centre of pressure  
215 and centre of mass in trotting horses. *The Veterinary Journal*, **198**, e14-e19.  
216 doi.org/10.1016/j.tvjl.2013.09.027
- 217 [12] ~~Drevemo, S., Dalin, G., Fredricson, I and Hjertén, G. (1980) Equine Locomotion: 1. The analysis of~~  
218 ~~linear and temporal stride characteristics of trotting standardbreds. *Equine Vet Journal*, **12** (2), 60-65.~~  
219 ~~[1413]~~ Merken, H. W. and Schamhardt, H. C. (1994) Relationships between ground reaction force  
220 patterns and kinematics in the walking and trotting horse. *Equine Veterinary Journal*, **26**, (17) 67-70.  
221 DOI: 10.1111/j.2042-3306.1994.tb04877.x
- 222 [14] Merken, H. W. and Schamhardt, H. C. (1988) Evaluation of equine locomotion during different  
223 degrees of experimentally induced lameness I: Lameness model and quantification of ground reaction  
224 force patterns of the limbs. *Equine Veterinary Journal*, **20** (S6) 99-106. DOI: 10.1111/j.2042-  
225 [3306.1988.tb04655.x](https://doi.org/10.1111/j.2042-3306.1988.tb04655.x)

226 [15] ~~Parsons, M. (2009) The effect of rider mass on ground reaction forces and hoof forces during~~  
227 ~~events in equine locomotion. *Equine and Comparative Exercise Physiology*, 1 (2), A1- A30.~~  
228 ~~doi.org/10.1079/ECEP200419~~  
229 [17] Clayton, H. M., Lanovaz, J. L., Schamhardt, H. C., & Wessum, R. V. (1999). The effects of a rider's  
230 mass on ground reaction forces and fetlock kinematics at the trot. *Equine Veterinary Journal*, 31 (S30),  
231 218-221.  
232 [18] Hodson, E., Clayton, H. M. and Lanovaz, J. L. (2000) The forelimb in walking horses: 1. Kinematics  
233 and ground reaction forces. *Equine Veterinary Journal*, 32 (4), 287-294.  
234 DOI: 10.2746/042516400777032237  
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236 **Ethical Considerations**

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

239 **Conflicts of Interest**

240 The authors have declared no conflicts of interest.

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