Multi-dimensional, time continuous ground reaction force vector analysis

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Abstract

This protocol describes a method of collecting, displaying and analysing ground reaction force (GRF) vector patterns in horses during locomotion. The method may be applied to other quadrupeds.

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Protocol

GRF Data Collection

Step 1.

Ideally, a series of force platforms in line should be used for this type of analysis, but if speed is controlled well (ideally within 0.1 $m.s^{-1}$), then consecutive trials from one force platform collecting GRF data from left and right limbs can be compared. GRF data should be collected at an appropriate sampling frequency (typically 960 or 1000 Hz) in three dimensions. Only clean hits should be used in the analysis and stance phases should be separated using a threshold of between 50 and 100 N. Noisy force data should either be removed from the dataset or filtered appropriately (typically a 4th order Butterworth filter with 100 Hz cut off frequency is used). All trials should be collected without interference from the handler and the horse should be habituated prior to data collection.

Force vector analysis

Step 2.

For visualization, forces that are to be used in the analysis should be downsampled (typically between 120 and 250 Hz). Three dimensional GRF and centre of pressure (COP) data should be extracted in columns (text, ASCII etc. formats are common).

A vector diagram can then be plotted for each vector across the stance phase for each plane. Each vector had its origin at its centre of pressure on the force plate (that is the point of application of the GRF vector), with magnitude and orientation scaled to the planar GRF. This can be achieved using the example file, found at: DOI: 10.7717/peerj.4399/supp-6.

Two summary vector variables can be calculated from the force data; the vector magnitude (VecMag)

by vector summation of the individual vectors divided by the number of samples contributing to the value. The angle of the summary vector (VecAng), which is determined from the components of the vector magnitude using trigonometry and expressed relative to the vertical with positive values being directed cranially. The summary vector variables can either be plotted on the vector diagram or analysed using traditional statistical methods.

Statistical Parametric Mapping (SPM)

Step 3.

SPM analysis can be used to analyse GRF data, this can be 1, 2 or 3 components of the GRF. For this analysis each stance phase must be normalized, typically to 101 points, and a mean calculated for each limb. These data should then be assembled into vector fields for example, 10 horses, 101 data points per stance phase, two GRF components would be a 10 * 101 * 2 vector field. The open-source spm1d package (www.spm1d.org, v. M.0.4.1, Pataky, 2012) can then be used to conduct the SPM analysis in Matlab or Python. For a multivariate analysis of the vector fields of left and right forelimbs or left and right hindlimbs, Hotelling's T2 test can be used. For a univariate analysis of a single GRF component for each limb a t-test is more appropriate. SPM analysis utilizes Random Field Theory to determine the critical threshold at which only alpha % of equivalently smooth random data would cross. This ensures a tight control of the type I error rate (Pataky, Vanrenterghem & Robinson, 2016). Any crossings of the critical threshold therefore by definition have a probability of occurrence less than alpha %.

It is advisable to include plots of the SPM trace(s) and comparisons of left and right limbs for each GRF component in the results.