Visualizing horse-rider coordination patterns using bivariate functional principal component analysis

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Summary

This study used bivariate functional principal component analysis to explore horse-rider coordination during rising trot. Vertical acceleration signals from rider pelvis and horse trunk IMUs were analyzed. Reconstructed components illustrated horse and rider amplitude and phase variability within the gait cycle, providing an interpretable method to understand horse-rider coordination dynamics.

Introduction

The horse-rider interaction represents a complex, coordinated system. Characterizing this interaction is particularly challenging due to its high-dimensional nature, where the horse's four limbs and multiple degrees of freedom interact dynamically with the rider's similarly intricate movements, necessitating coordination despite their independent control systems. While previous studies have utilized inertial measurement units (IMUs) on the horse's trunk and the rider's pelvis, existing research is often constrained by coordination measures that focus on discrete stride events [1] or rely on coordination metrics that are difficult to interpret [2], limiting their applicability for actionable insights. Additionally, rising trot, where the rider sits and rises from the saddle on alternating diagonal stance phases, requires the rider to move vertically, a half cycle out of phase with the horse, presenting a complex coordination task. This study aimed to investigate whether bivariate functional principal component analysis (*bf*PCA) of the vertical acceleration signals from the horse and rider in rising trot could provide meaningful insights on horse-rider coordination within the context of the horse's stride.

Methods

Three professional riders (1 male, 2 female) each rode two of their horses in rising trot on the left rein in an arena. Inertial measurement units (IMUs ±16g acceleration range; IMeasureU Blue Trident) sampling at 240 Hz were placed on the rider's sacrum, the horse's girth strap, and the medial aspect of the horse's cannon bones. Vertical acceleration signals (m/s^2) were extracted from the first left diagonal rising trot pass, processed in Python (v3.12.7). Strides were defined as intervals between peak left hind limb decelerations. The girth and pelvis signals were split into strides, mean-centered, and scaled to the range between -1 and 1. Ten strides per horse were used for *bf*PCA analysis (sci-kit FDA v-0.9.1). Horse and rider signals were smoothed separately using a B-spline basis with 25 basis functions. The smoothed signals for horse and rider were concatenated into a single feature vector per stride by stacking and flattening the smoothed signals. *bf*PCA was applied to these 60 vectors, retaining the components that explained 90% of the total variance. The first two principal components were reconstructed as mean, 5th percentile, and 95th percentile timeseries of all horse-rider combinations as per [3] for visual interpretation.

Results and Discussion

Ten bivariate principal components (*bf*PCs) explained 90% of the variance in the dataset. The first three *bf*PCs explained 32, 24, and 15% of the variance, respectively. This suggests that the horse-rider interaction is highly complex, however, some high-level patterns exist between horse-rider combinations.

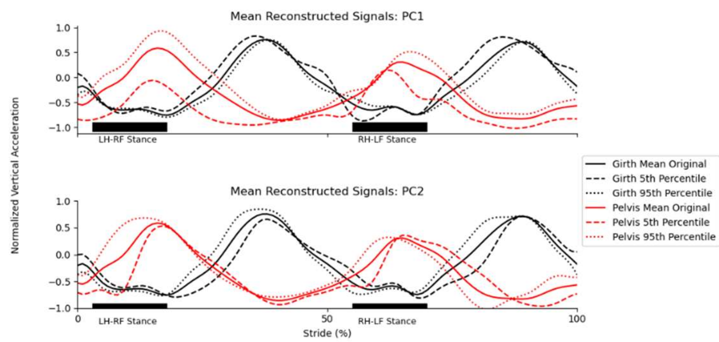

Figure 1: Reconstruction of the girth (black) and pelvis (red) vertical acceleration signals for the first two *bf*PCs.

Key features of the *bf*PCA reconstruction are highlighted in Figure 1: *bf*PC1 reflects differences in amplitude and phase of peak trunk acceleration, with double peaks during stance linked to hind and front limb contact, potentially showing diagonal advanced placement. Low *bf*PC1 scores indicate greater right hind deceleration and earlier peaks. For the rider, *bf*PC1 relates to the magnitude and timing of pelvic rise and fall during trot, with advanced riders leveraging the horse's momentum to rise. Greater variability during the rise phase (5–20%) is evident in the 5th–95th percentile range. *bf*PC2 primarily captures pelvic amplitude and phase shifts during stance and swing.

Conclusions

This approach offers a novel method to quantify horse-rider coordination with potential applications in training optimization, performance evaluation, and injury prevention.

References

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