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Coordination dynamics in horse-rider dyads

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ABSTRACT

The sport of equestrianism is defined through close horse-rider interaction. However, no consistent baseline parameters currently exist describing the coordination dynamics of horse-rider movement across different equine gaits. The study aims to employ accelerometers to investigate and describe patterns of motor coordination between horse and rider across the equine gaits of walk, rising trot, sitting trot and canter. Eighteen female ($N = 18$; mean age $\pm$ SD: 37.57 ± 13.04) Dutch horse-rider combinations were recruited to participate in the study. Horse-rider coordination was recorded using two tri-axial wireless accelerometers during a standard ridden protocol. Multiple measures of horse-rider coordination were calculated to investigate the relationship between the horse and rider, while the unpredictability of the acceleration-time series of the horse and rider during task performance were determined separately by means of approximate entropy analysis. The kinematic variables of horse-rider correlation, mean relative phase, mean standard deviation of the relative phase, approximate entropy rider, approximate entropy horse and spectral edge frequency at 95% of the power in the 0–10 Hz frequency band were examined using multiple correlational analyses and multivariate analysis of variance (MANOVA). Findings showed significantly different coordination dynamics between equine gaits, with the gait of canter allowing for the highest levels of horse-rider synchronicity. It may be concluded that accelerometers are a valuable tool to map distinct coordination patterns of horse-rider combinations.

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1. Introduction

A multitude of daily activities are governed by, if not dependent on, the close interaction with others. Shaking hands in greeting, attempting to move a large, cumbersome object together or filing in through an open door are all routine examples of how people regularly engage in considerable levels of interpersonal coordination (e.g., Bernieri & Rosenthal, 1991; Chartrand & Bargh, 1999). As a result, the way two people coordinate their bodies and limbs when engaging in increasingly complex social interactions has been the subject of extensive study (e.g., Bekkering et al., 2009; Sebanz, Bekkering, & Knoblich, 2006). While earlier research focused in particular on elements of imitation as a function of social attraction and affiliation (Chartrand & Bargh, 1999; Lakin & Chartrand, 2003; Lakin, Jefferis, Cheng, & Chatrand, 2003), more recent studies have also included the dimension of temporal alignment (Goodman, Isenhower, Marsh, Schmidt, & Richardson, 2005; Konvalinka, Vuust, Roepstorff, & Frith, 2010). Interpersonal entrainment can generate feelings of rapport and connectivity and as such is thought to help build social units (Marsh, Richardson, & Schmidt, 2009). It has even been argued that it augments the memorability of an interaction (Macrae, Duffy, Miles, & Lawrence, 2008; Miles, Nind, & Macrae, 2009) and is likely to foster better team performances (Riley, Richardson, Shockley, & Ramenzoni, 2011).

While undoubtedly playing an important role in human-human relationships, the coordination of motor behavior might also be considered valuable in the interaction of human and non-human animals. The sport of equestrianism, for example, is defined through the close interaction between horse and rider, while effective training relies heavily on timing and consistency (Goodwin, McGreevy, Waran, & McLean, 2009). The governing body of the sport and participating riders stress that principles of harmony and cooperation should be paramount in all equestrian disciplines (FEI, 2009; Hawson, McLean, & McGreevy, 2010). Previous studies refer to this ideal state, which most horse-rider dyads are striving to achieve, as operating "as one" (Brandt, 2004; Meyers, Bourgeois, LeUnes, & Murray, 1997). While the notion that optimal behavioral coupling or movement synchronicity may be considered a function of harmony in human-human interactions (e.g., Miles, Griffiths, Richardson, & Macreae, 2010; Miles et al., 2009), similar assumptions about horse-human dyads pose a number of difficulties, ranging from emotional, cognitive and intellectual differences to intrinsic variations in bi- versus quadruped movement patterns. Natural, intrinsic movement patterns in animal (Bergerud, 1975) and human (Hurmuzlu & Basdogan, 1994) populations have been found to exhibit steady-state-frequencies, which may be argued to represent a function of movement efficiency and even harmony. To date, a handful of studies have investigated aspects of movement coordination between horse and rider focusing on the equine gait of trot (e.g., Lagarde, Peham, Licka, & Kelso, 2005; Peham, Kapaun, Licka, & Scheidl, 1998; Peham, Licka, Kapaun, & Scheidl, 2001; Peham, Licka, Schobesberger, & Meschan, 2004; Schöllhorn, Peham, Licka, & Scheidl, 2006). Peham et al. (1998, 2001) were able to demonstrate that an experienced, professional rider was able to ride a horse close to its limit cycle, with minimal changes in velocity and a close approximation of the ideal state-state. An additional study by Peham et al. (2004) showed that even compared to non-ridden conditions, movement stability in the horse trotting on a treadmill improved under a professional rider using a well-fitting saddle. These results were further supported by studies of Lagarde et al. (2005) and Schöllhorn et al. (2006). Their work showed that expert riders were better able to coordinate their own motor behavior with that of the horse and elicit more consistent, stable movement patterns in the horse.

Lagarde et al. (2005) argued that horse riding is dependent on riders being able to adjust their movement patterns to resonate as closely as possible with those of the horse. Furthermore, existing evidence seems to suggest that riders' adaptation to and control of the movement patterns of horses is a function of rider expertise. However, there still remains a lack of consistent baseline parameters describing the coordination dynamics of horse-rider movement for different levels of rider expertise and across different equine gaits. The equestrian discipline of dressage requires the horse to execute a variety of exercises in the three distinct gaits of walk, trot, and canter (FEI, 2009). The movement patterns of each of these gaits are inherently stable, with a loss in stability likely leading to a switching of patterns, i.e., gaits (Schöner, Jiang, & Kelso, 1990). The walk consists of a four-beat sequence with no suspension phase and an average tempo of 55 strides per minute (Clayton, 2004). Each hind limb is always being followed by the forelimb on the same side, and each forelimb being followed by the diagonally opposite hind limb. The trot on the other hand is a two-beat gait, whereby diagonal pairs of front and hind limbs move together and contralateral pairs are 180° out of phase (Dalin & Jeffcott, 1994). In each stride cycle, there are two stride-stance phases and two suspension phases. The trot is usually ridden at an average tempo of 77 strides per minute (Clayton, 2004). During "rising trot", the rider rises out of the saddle for the duration of one phase and sits down again in the saddle the following phase, thereby avoiding being "bumped" by the horse. In sitting trot, the rider sits throughout the entire stride cycle, attempting to absorb the horse's vertical movement through the pelvis. With 99 strides per minute the fastest of the three gaits (Clayton, 2004), the canter has a three-beat pattern. It is considered asymmetrical, as the limb movements of one side do not exactly repeat those at the other side. Accordingly, the canter can be initiated by either the right or left hindlimb, followed by the joint footfall of the other hind limb and opposite forelimb, and, finally, the remaining forelimb. The stride terminates with a suspension phase, whereby the horse is airborne. While both the walk and trot have a regular rhythm, the canter is considered an irregular gait. Considering the differences in rhythm and regularity, it must be assumed that motor coordination between horse and rider are likely to show divergent patterns across the three gaits. Even though the slowest in tempo, the walk has the fastest rhythm of the three gaits, and might therefore pose more of a challenge to the rider than the two other gaits. We therefore hypothesize that despite it being the fastest of the three gaits, the strongest coupling of the movements of horse and riders and the most pronounced level of coordination stability are likely to be found in the canter.

The current study subsequently aims to investigate variables indicative of motor coordination and in horse-rider combinations of varying levels of expertise and across the equine gaits of walk, rising trot, sitting trot and canter using two tri-axial wireless accelerometers, a technology that has previously only been used in human movement research (e.g., Kwakkel & Wagenaar, 2002; Mayagoitia, Nene, & Veltink, 2002). In view of previous findings relating the horse-rider coordination (e.g., Peham et al., 2004; Schöllhorn et al., 2006; Witte, Schobesberger, & Peham, 2009) it was hypothesized that coupling between the movements of the horse and rider would be tighter in more skilled riders. Furthermore, considering the temporal qualities of the different gaits, it was expected that horse-rider movement coordination would be more unstable in walk than in canter.

2. Method

2.1. Subjects

Eighteen ($N = 18$) Dutch horse-rider combinations were recruited to participate in the study. All riders were female (mean age ± *SD*: 37.57 ± 13.04) and competing in the discipline of dressage. Their level of experience ranged from novice ($N = 3$) to intermediate ($N = 12$) to advanced ($N = 3$). Novice riders were defined as riding in the lowest two levels ("B" = beginner and "L" = easy) according to the rule of the Dutch national equestrian federation. Intermediate riders were competing at the level of "M" (medium) and "Z" (advanced medium) while advanced riders were competing at "ZZ licht" (advanced national) through to Grand Prix (international). All riders rode horses (5 mares; 13 geldings; mean age: 8.36 ± 3.25) they either owned, and therefore rode almost daily, or were training on a regular basis for someone else.

2.2. Materials

All riders rode in their own standard competition tack, consisting of a dressage saddle and a bridle. Horse-rider coordination was recorded using 2 tri-axial wireless accelerometers (KinetiSense™ 6-Axis Motion Sensors).

The first accelerometer was attached to the ventral part of the skin overlying the sternum of the rider. The second accelerometer was securely tied to the girth underneath the horse's stomach to align vertically to that of the rider. The accelerometer signals (input noise <60 mg RMS) were linked wireless (2.4 GHz radio) to the laptop and sampled at 128 Hz. Data acquisition was conducted using the software program SoapSynergy® with subsequent analysis in Matlab 7.12.

2.3. Ridden protocol

The principle of "warming up" the horse is common in equestrian sports, as it is thought to impact on subsequent performance (Murray, Mann, & Parkin, 2006). Equally, all dressage tests include floor patterns ridden on both "reins", i.e., with the horse moving with either the right or the left rein being the closest to the middle of the arena (FEI, 2009). Any investigation of movement coordination in horse-rider pairs should therefore differentiate between warm-up and actual training phases as well as movements performed either on the right or the left rein.

Riders were all asked to perform the same standard ridden protocol. They were initially allowed to walk their horses on a long rein for 5 minutes. They were subsequently asked to ride a "warming-up" protocol, which included a 20-meter circle on the left rein (meaning that the rider's left hand points towards the inside of the circle) followed by a change in direction to repeat the circle on the right rein. Riders would complete circles on the left and right rein first in walk, then in rising trot, followed by sitting trot and lastly canter.

Participating riders were subsequently instructed to work their horses in their usual manner for 15 minutes. At the end of that period, riders were required to ride another series of circles in walk, rising trot, sitting trot and canter on both reins (as described above), referred to as the "performance" protocol.

2.4. Data analysis

Horse-rider coordination was calculated using the raw accelerometers signals of the *y*-axis. (Note: The accelerometer attached to the horse's girth had to be rotated by 90° in the sagittal plane, meaning that for analytical purposes, the *z*-axis was used). Horse-rider movement correlations, the continuous relative phase, and the standard deviation of the continuous relative phase were calculated after having applied a Butterworth low-pass filter with cut-off frequency of 15 Hz. Continuous relative-phase time functions were analyzed with the filtered acceleration-time and jerk-time functions as input. The resulting continuous relative phase function was visually inspected and automatically normalized for branch cut crossings. The means ($M\varphi$) and standard deviations ($SD\varphi$) of the continuous relative-phase signals were calculated by using Batschelet's (1981) procedure involving circular statistics (see Meulenbroek, Thomassen, van Lieshout, & Swinnen, 1998). Furthermore, unfiltered signals were used to calculate the approximate entropy (Pincus, 1991, 2000) reflecting the unpredictability of the fluctuations in the acceleration-time series for horse and rider. As parameters of the entropy measure we used a window length of 5 and a similarity measure of 0.5.

Welch power spectra of horse and rider movements were calculated to complement the data analysis. As spectral index we determined the spectral edge frequency 95 (SEF 95) reflecting the frequency at which 95% of the power within the 0–10 Hz band was surpassed. The spectra were all visually inspected.

2.5. Statistical analysis

In order to provide a measure of within-class reliability, intraclass correlations (ICC) were calculated for the four gaits and all participating horse-rider combinations using the following formula (Shrout & Fleiss, 1979):

$$ICC = \frac{\text{Mean Square Error (Gait)} - \text{Mean Square Error (residual)}}{\text{Mean Square Error (Gait)} + \text{Mean Square Error (residual)}}$$

Multiple correlational analyses were conducted to investigate relationships between the coordination variables of horse-rider correlation, mean relative phase, mean standard deviation of the relative phase, approximate entropy of the rider and approximate entropy of the horse. Due to the non-normal distribution of the data, Spearman's Rank-Order correlational statistics were applied.

Prior to additional analysis using inferential statistics, histograms of dependent variables were inspected for normal distribution. The following transformation algorithms were applied to compensate for non-normal distributions (also see Fig. 2): reflect and square root for the dependent variable of horse-rider correlation and mean relative phase, as well as square root for the dependent variable of approximate entropy horse. While subsequent inspection of the resulting histograms revealed satisfactory transformations of the variable mean relative phase, the distributions of horse-rider correlation and approximate entropy horse did not improve substantially. It was therefore decided to conduct a multivariate analysis of variance (MANOVA) to investigate the interactions of equine gait, treatment condition (e.g., the warming-up and performance conditions) and direction of hand with the transformed dependent variable of mean relative phase and the original variables of mean standard deviation of relative phase, approximate entropy rider, SEF95 rider and SEF95 horse. The more robust statistics of Pillai's trace was reported to compensate for any lasting issues with the data. Analysis of the variables of horse-rider correlation and approximate entropy horse were conducted using non-parametric analyses of differences (Mann-Whitney U tests) and were carried out to conduct specific assumption testing, based on relevant results from the MANOVA.

All data were analyzed using IBM Statistical Programme for Social Scientists 19.0 and an alpha level of .05 was set to denote statistical significance.

3. Results

Fig. 1 shows a 5-s time window plot of movement coordination patterns for the four different gaits studied (walk, sitting trot, riding trot, canter). Raw data values for the different gaits of individual

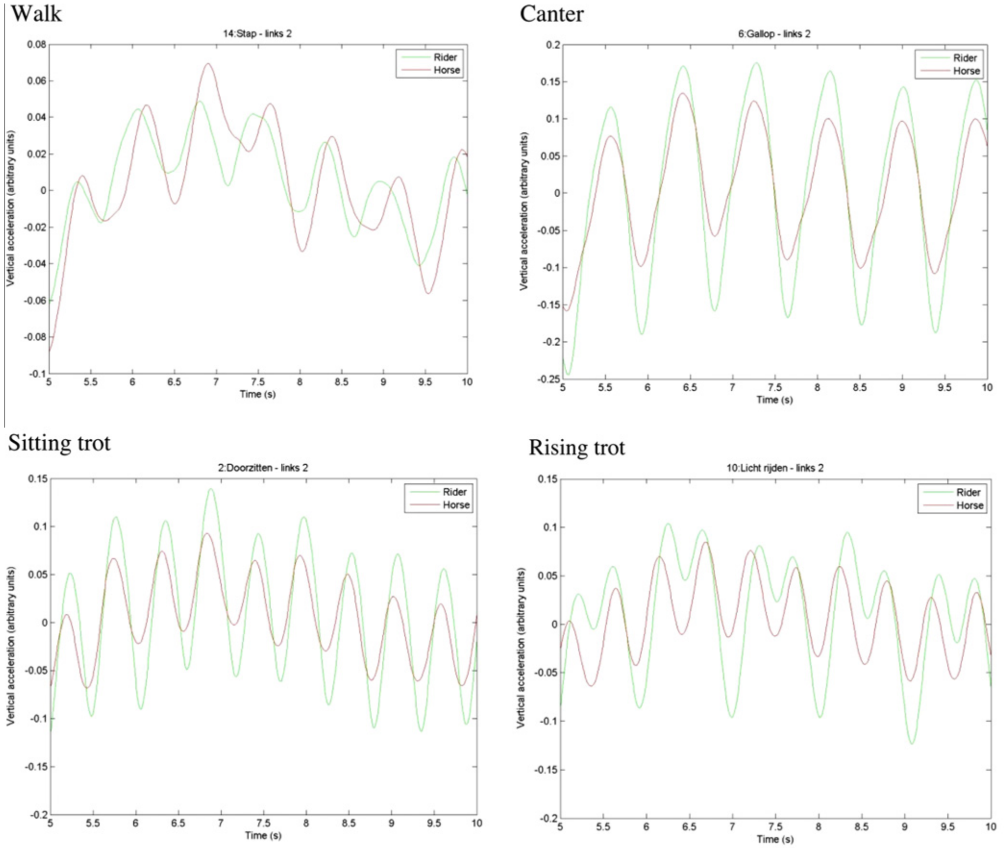

Fig. 1. Typical examples of vertical acceleration-time functions (5-s time windows) of the four different gaits studied. The samples were collected from an arbitrary rider-horse dyad in the left-rein performance protocol.

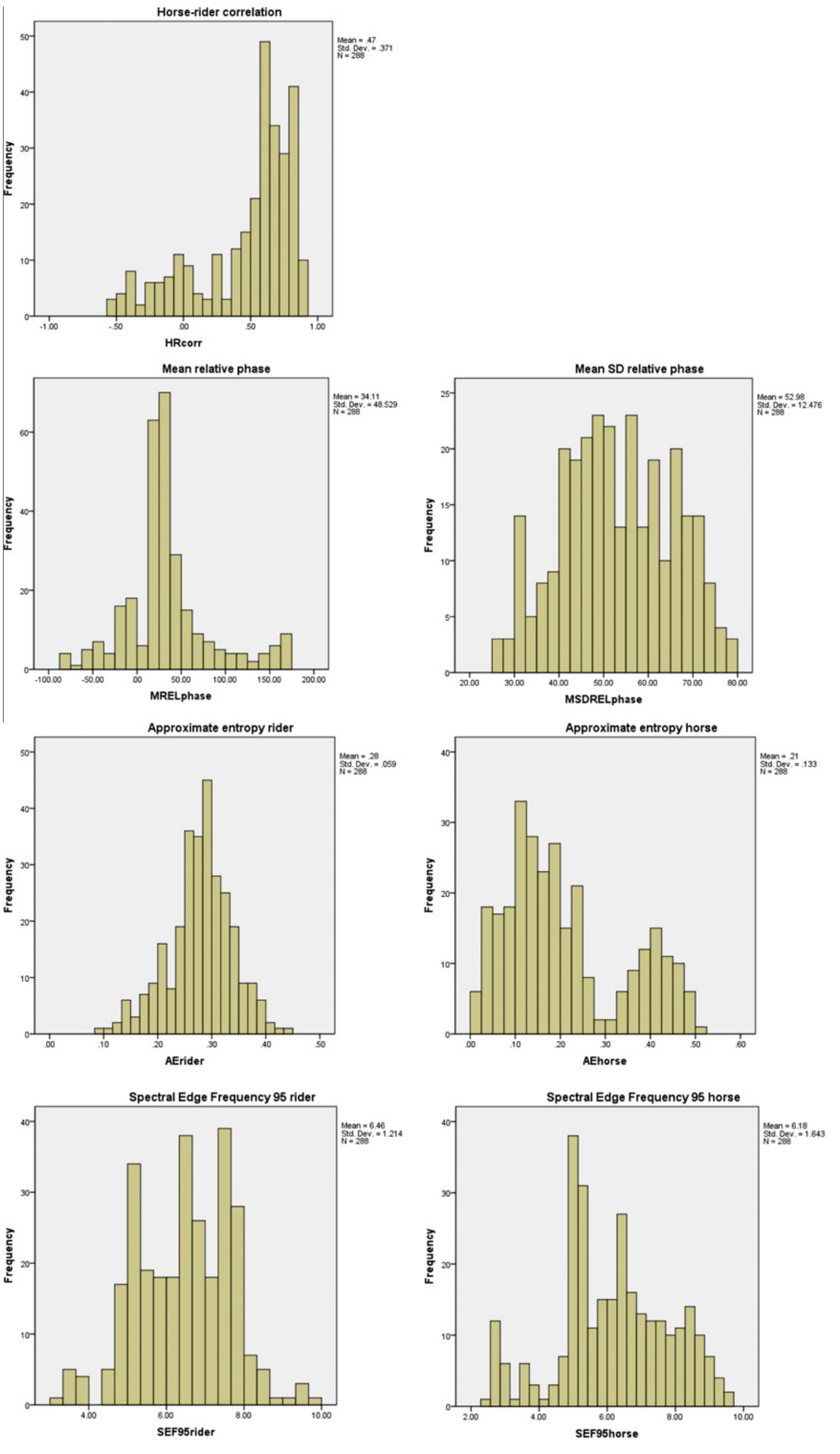

Fig. 2. Distribution of movement coordination data.

Table 1
Raw movement coordination data of horse-rider pairs during four gait patterns.

	Level (Rider/ Horse)	Horse-rider correlation	Mean relative phase	Means SD phase	Approx. entropy rider	Approx. entropy horse	SEF95 rider	SEF95 horse
Pair 1 Total	Interm./ novice	0.47 ± 0.36	41.29 ± 45.68	54.96 ± 9.57	0.26 ± 0.05	0.19 ± 0.13	5.84 ± 0.77	7.22 ± 1.16
Walk		−0.1 ± 0.06	107.99 ± 13.59	67.49 ± 1.76	0.23 ± 0.02	0.38 ± 0.03	6.41 ± 0.3	8.61 ± 0.56
Rising trot		0.56 ± 0.04	31.3 ± 15.51	54.28 ± 8.0	0.31 ± 0.03	0.21 ± 0.06	6.31 ± 0.46	6.17 ± 0.49
Sitting trot		0.62 ± 0.03	38.7 ± 4.0	44.95 ± 4.26	0.25 ± 0.04	0.18 ± 0.06	5.57 ± 0.2	6.91 ± 1.39
Canter		0.79 ± 0.05	−12.83 ± 3.91	53.11 ± 4.99	0.24 ± 0.07	0.04 ± 0.01	5.05 ± 0.99	7.17 ± 0.13
Pair 2 Total	Interm./ interm.	0.46 ± 0.39	9.11 ± 32.46	51.14 ± 9.62	0.31 ± 0.03	0.21 ± 0.16	5.5 ± 1.11	6.81 ± 1.54
Walk		−0.16 ± 0.09	−33.32 ± 18.11	66.49 ± 0.52	0.31 ± 0.02	0.47 ± 0.02	6.43 ± 0.35	9.19 ± 0.21
Rising trot		0.54 ± 0.06	31.13 ± 6.42	49.07 ± 0.13	0.33 ± 0.01	0.11 ± 0.05	6.13 ± 0.38	5.71 ± 0.24
Sitting trot		0.55 ± 0.07	43.03 ± 8.43	44.02 ± 2.47	0.30 ± 0.04	0.16 ± 0.04	5.58 ± 0.15	5.68 ± 0.23
Canter		0.88 ± 0.04	−4.4 ± 1.48	44.98 ± 4.29	0.28 ± 0.05	0.11 ± 0.06	3.85 ± 0.72	6.66 ± 0.87
Pair 3 Total	Novice/ novice	0.33 ± 0.43	51.68 ± 52.26	53.19 ± 12.08	0.29 ± 0.02	0.18 ± 0.16	6.15 ± 1.42	6.78 ± 1.42
Walk		−0.3 ± 0.11	116.94 ± 46.15	70.95 ± 6.59	0.3 ± 0.02	0.42 ± 0.04	6.91 ± 0.49	7.91 ± 0.37
Rising trot		0.47 ± 0.07	45.25 ± 6.5	49.55 ± 2.07	0.29 ± 0.02	0.1 ± 0.06	7.33 ± 0.82	6.02 ± 0.26
Sitting trot		0.33 ± 0.14	56.63 ± 17.23	48.29 ± 8.54	0.30 ± 0.03	0.16 ± 0.07	6.36 ± 0.45	5.83 ± 0.31
Canter		0.84 ± 0.03	−12.08 ± 1.19	43.97 ± 5.08	0.29 ± 0.02	0.03 ± 0.01	3.99 ± 0.34	7.36 ± 0.1
Pair 4 Total	Interm./ interm.	0.33 ± 0.5	28.74 ± 45.4	53.3 ± 9.24	0.32 ± 0.04	0.24 ± 0.14	6.66 ± 0.98	5.02 ± 2.49
Walk		−0.48 ± 0.04	27.46 ± 92.64	65.88 ± 3.46	0.28 ± 0.03	0.46 ± 0.02	6.57 ± 0.34	8.33 ± 0.32
Rising trot		0.59 ± 0.03	35.83 ± 1.77	43.22 ± 3.02	0.32 ± 0.04	0.13 ± 0.03	5.76 ± 1.07	constant
Sitting trot		0.42 ± 0.02	50.22 ± 3.99	49.52 ± 1.16	0.35 ± 0.02	0.22 ± 0.02	7.46 ± 0.06	2.92 ± 0.56
Canter		0.79 ± 0.04	1.44 ± 5.17	54.59 ± 5.98	0.33 ± 0.04	0.14 ± 0.05	6.83 ± 1.24	6.15 ± 0.99
Pair 5 Total	Interm./ interm.	0.39 ± 0.27	52.86 ± 38.5	56.49 ± 13.22	0.26 ± 0.04	0.18 ± 0.14	5.79 ± 0.71	7.57 ± 1.7
Walk		0.01 ± 0.03	102.76 ± 29.13	69.96 ± 3.37	0.3 ± 0.03	0.41 ± 0.02	6.31 ± 0.15	8.4 ± 0.59
Rising trot		0.53 ± 0.14	37.51 ± 15.34	46.44 ± 9.3	0.28 ± 0.01	0.13 ± 0.04	5.32 ± 0.06	5.99 ± 1.97
Sitting trot		0.44 ± 0.11	50.24 ± 6.87	46.73 ± 9.58	0.23 ± 0.03	0.1 ± 0.03	5.23 ± 0.08	6.81 ± 1.49
Canter		0.59 ± 0.25	20.92 ± 35.72	62.82 ± 11.24	0.24 ± 0.04	0.09 ± 0.02	6.33 ± 1.01	9.06 ± 0.21
Pair 6 Total	Novice/ novice	0.31 ± 0.44	69.65 ± 57.22	52.6 ± 8.93	0.29 ± 0.05	0.2 ± 0.15	5.68 ± 0.79	6.48 ± 1.63
Walk		−0.39 ± 0.07	162.78 ± 13.58	56.14 ± 2.93	0.29 ± 0.02	0.42 ± 0.04	5.33 ± 0.25	8.46 ± 0.25
Rising trot		0.65 ± 0.01	29.72 ± 1.43	41.69 ± 2.29	0.28 ± 0.02	0.19 ± 0.04	5.18 ± 0.15	5.1 ± 0.11
Sitting trot		0.34 ± 0.06	56.3 ± ± 6.79	48.54 ± 0.99	0.34 ± 0.05	0.19 ± 0.04	6.6 ± 0.81	4.93 ± 0.05
Canter		0.63 ± 0.06	29.78 ± 9.63	64.04 ± 3.53	0.23 ± 0.06	0.02 ± 0.01	5.61 ± 0.88	7.42 ± 1.01
Pair 7 Total	Interm./ novice	0.39 ± 0.29	10.67 ± 37.05	56.8 ± 10.82	0.32 ± 0.07	0.23 ± 0.1	8.16 ± 0.79	6.41 ± 1.61
Walk		−0.06 ± 0.14	−48.71 ± 10.25	72.34 ± 2.33	0.24 ± 0.05	0.35 ± 0.06	7.85 ± 0.38	8.92 ± 0.15
Rising trot		0.52 ± 0.06	29.62 ± 5.15	49.49 ± 7.64	0.34 ± 0.07	0.18 ± 0.07	7.76 ± 0.21	5.15 ± 0.04
Sitting trot		0.47 ± 0.03	43.51 ± 4.64	54.62 ± 4.06	0.39 ± 0.03	0.26 ± 0.08	8.13 ± 1.16	constant
Canter		0.65 ± 0.06	18.26 ± 4.01	50.76 ± 7.53	0.32 ± 0.04	0.14 ± 0.03	8.92 ± 0.72	6.52 ± 0.12
Pair 8 Total	Interm./ novice	0.37 ± 0.38	66.09 ± 41.24	56.03 ± 10.03	0.22 ± 0.06	0.21 ± 0.12	6.88 ± 0.82	5.83 ± 0.96
Walk		−0.25 ± 0.19	122.09 ± 41.49	68.76 ± 2.66	0.28 ± 0.01	0.39 ± 0.05	5.87 ± 0.54	7.21 ± 0.41
Rising trot		0.58 ± 0.02	33.83 ± 3.45	48.07 ± 2.99	0.22 ± 0.03	0.17 ± 0.08	6.85 ± 0.47	5.46 ± 0.57
Sitting trot		0.61 ± 0.01	36.89 ± 2.11	45.89 ± 2	0.17 ± 0.05	0.18 ± 0.09	7.55 ± 0.07	5.12 ± 0.05
Canter		0.55 ± 0.06	71.57 ± 4.28	61.39 ± 2.65	0.19 ± 0.06	0.11 ± 0.02	7.25 ± 0.82	5.55 ± 0.79
Pair 9 Total	Adv./ interm.	0.51 ± 0.26	45.82 ± 28.43	58.3 ± 5.79	0.22 ± 0.07	0.21 ± 0.15	6.69 ± 0.72	6.63 ± 0.99
Walk		0.11 ± 0.25	88.48 ± 22.91	63.78 ± 7.62	0.31 ± 0.01	0.44 ± 0.02	6.47 ± 0.63	7.64 ± 0.98
Rising trot		0.58 ± 0.02	26.58 ± 1.33	54.05 ± 1.92	0.19 ± 0.05	0.13 ± 0.04	6.8 ± 0.48	5.6 ± 0.41
Sitting trot		0.63 ± 0.02	25.79 ± 3.79	54.76 ± 1.69	0.14 ± 0.04	0.09 ± 0.02	7.45 ± 0.06	6.24 ± 0.18
Canter		0.69 ± 0.04	42.42 ± 5.57	60.60 ± 3.89	0.24 ± 0.03	0.18 ± 0.03	6.02 ± 0.69	7.05 ± 0.77

(*continued on next page*)

Table 1 (*continued*)

	Level (Rider/ Horse)	Horse-rider correlation	Mean relative phase	Means SD phase	Approx. entropy rider	Approx. entropy horse	SEF95 rider	SEF95 horse
Pair 10 Total	Adv./ adv.	0.64 ± 0.31	4.38 ± 34.89	46.34 ± 18.08	0.25 ± 0.05	0.25 ± 0.1	5.06 ± 0.83	4.21 ± 0.81
Walk		0.16 ± 0.19	−46.63 ± 28.28	71.49 ± 5.09	0.3 ± 0.03	0.41 ± 0.03	6.23 ± 0.38	5.24 ± 0.13
Rising trot		0.78 ± 0.04	24.17 ± 2.87	31.29 ± 3.03	0.27 ± 0.02	0.16 ± 0.02	4.95 ± 0.11	3.36 ± 0.46
Sitting trot		0.77 ± 0.04	29.34 ± 2.95	29.53 ± 1.62	0.19 ± 0.01	0.18 ± 0.04	4.85 ± 0.06	3.62 ± 0.05
Canter		0.86 ± 0.02	10.64 ± 19.92	53.02 ± 3.94	0.26 ± 0.02	0.24 ± 0.01	4.19 ± 0.64	4.62 ± 0.09
Pair 11 Total	Adv./ novice	0.49 ± 0.48	20.31 ± 45.38	50.64 ± 15.31	0.32 ± 0.06	0.23 ± 0.11	6.36 ± 0.94	6.13 ± 1.17
Walk		−0.29 ± 0.19	27.6 ± 97.1	70.21 ± 6.47	0.24 ± 0.04	0.39 ± 0.04	6.26 ± 0.58	7.32 ± 0.65
Rising trot		0.68 ± 0.09	20 ± 9.75	47.43 ± 8.21	0.29 ± 0.02	0.17 ± 0.01	7.19 ± 0.65	5.95 ± 1.28
Sitting trot		0.79 ± 0.04	28.19 ± 5.74	31.14 ± 0.96	0.38 ± 0.02	0.22 ± 0.03	5.93 ± 0.8	5.32 ± 1.17
Canter		0.81 ± 0.05	5.46 ± 17.04	53.78 ± 4.08	0.34 ± 0.01	0.14 ± 0.04	6.06 ± 1.29	5.92 ± 0.75
Pair 12 Total	Interm./ novice	0.58 ± 0.25	46.74 ± 32.14	52.83 ± 12.09	0.28 ± 0.03	0.17 ± 0.18	7.39 ± 0.47	5.97 ± 1.34
Walk		0.19 ± 0.11	98.09 ± 14.54	69.38 ± 0.9	0.3 ± 0.03	0.46 ± 0.04	6.96 ± 0.37	7.55 ± 0.61
Rising trot		0.71 ± 0.01	25.59 ± 3.31	39.41 ± 1.87	0.25 ± 0.01	0.08 ± 0.03	7.1 ± 0.44	4.42 ± 1.16
Sitting trot		0.61 ± 0.01	38.49 ± 3.29	45.02 ± 3.15	0.26 ± 0.03	0.08 ± 0.05	7.63 ± 0.13	5.51 ± 0.38
Canter		0.79 ± 0.0	24.77 ± 9.09	57.51 ± 1.09	0.29 ± 0.03	0.06 ± 0.01	7.86 ± 0.09	6.39 ± 0.06
Pair 13 Total	Interm./ interm.	0.39 ± 0.46	57.71 ± 62.99	55.75 ± 13.95	0.24 ± 0.07	0.17 ± 0.14	6.85 ± 1.36	6.63 ± 1.36
Walk		−0.17 ± 0.08	154.73 ± 13.48	72.72 ± 1.19	0.31 ± 0.02	0.39 ± 0.05	6.37 ± 0.17	7.68 ± 0.59
Rising trot		0.72 ± 0.06	25.55 ± 4.03	41.3 ± 4.21	0.22 ± 0.03	0.12 ± 0.06	5.23 ± 1.15	5.23 ± 0.09
Sitting trot		0.63 ± 0.02	33.69 ± 1.82	44.83 ± 1.74	0.23 ± 0.08	0.12 ± 0.04	7.51 ± 0.26	5.99 ± 0.89
Canter		0.39 ± 0.64	16.85 ± 52.09	64.17 ± 5.94	0.19 ± 0.07	0.05 ± 0.04	8.29 ± 0.79	7.61 ± 1.48
Pair 14 Total	Novice/ novice	0.68 ± 0.27	32.92 ± 18.18	43.47 ± 15.39	0.27 ± 0.06	0.22 ± 0.14	6.39 ± 1.14	5.42 ± 2.43
Walk		0.22 ± 0.07	60.17 ± 12.3	64.72 ± 2.7	0.34 ± 0.02	0.43 ± 0.04	7.18 ± 0.34	8.36 ± 0.35
Rising trot		0.83 ± 0.01	21.37 ± 2.51	29.44 ± 3.23	0.27 ± 0.02	0.12 ± 0.05	5.18 ± 0.05	2.68 ± 0.05
Sitting trot		0.8 ± 0.01	23.78 ± 1.81	29.99 ± 1.18	0.19 ± 0.02	0.15 ± 0.03	7.21 ± 0.52	3.86 ± 1.32
Canter		0.84 ± 0.05	26.37 ± 12.46	49.72 ± 2.51	0.26 ± 0.04	0.17 ± 0.07	5.98 ± 1.49	6.76 ± 0.67
Pair 15 Total	Interm./ interm.	0.37 ± 0.41	47.88 ± 68.2	59.62 ± 5.89	0.3 ± 0.04	0.21 ± 0.12	7.68 ± 0.57	6.46 ± 1.45
Walk		−0.29 ± 0.09	161.05 ± 3.81	64.86 ± 2.55	0.29 ± 0.0	0.39 ± 0.01	6.89 ± 0.12	8.65 ± 0.18
Rising trot		0.59 ± 0.04	14.72 ± 1.19	53.84 ± 3.32	0.27 ± 0.04	0.14 ± 0.0	7.61 ± 0.43	5.55 ± 0.07
Sitting trot		0.44 ± 0.02	15.91 ± 2.32	60.59 ± 1.81	0.36 ± 0.02	0.14 ± 0.03	8.05 ± 0.22	6.19 ± 1.01
Canter		0.75 ± 0.09	−0.15 ± 15.93	59.18 ± 8.38	0.28 ± 0.04	0.15 ± 0.08	8.17 ± 0.07	5.43 ± 0.62
Pair 16 Total	Interm./ interm.	0.53 ± 0.27	46.52 ± 39.27	54.29 ± 13.65	0.29 ± 0.05	0.25 ± 0.06	6.79 ± 1.09	5.45 ± 1.62
Walk		0.08 ± 0.02	109.73 ± 22.14	75.19 ± 2.89	0.27 ± 0.02	0.33 ± 0.03	6.22 ± 0.44	6.49 ± 0.21
Rising trot		0.65 ± 0.03	29.29 ± 5.51	43.72 ± 2.04	0.33 ± 0.03	0.24 ± 0.01	5.93 ± 0.79	3.23 ± 0.53
Sitting trot		0.63 ± 0.02	25.67 ± 2.98	44.41 ± 1.6	0.34 ± 0.04	0.22 ± 0.05	7.39 ± 0.11	7.23 ± 0.13
Canter		0.76 ± 0.04	21.29 ± 5.75	53.84 ± 7.33	0.24 ± 0.05	0.19 ± 0.04	7.64 ± 1.48	4.83 ± 0.06
Pair 17 Total	Interm./ novice	0.6 ± 0.22	−6.28 ± 31.5	48.62 ± 13.48	0.31 ± 0.05	0.19 ± 0.14	6.68 ± 1.16	6.11 ± 1.39
Walk		0.25 ± 0.09	−50.20 ± 8.37	64.12 ± 6.68	0.28 ± 0.03	0.41 ± 0.07	7.92 ± 0.68	6.66 ± 0.16
Rising trot		0.71 ± 0.03	17.2 ± 4.04	40.05 ± 3.96	0.33 ± 0.07	0.11 ± 0.02	5.77 ± 0.64	5.29 ± 1.96
Sitting trot		0.71 ± 0.04	25.39 ± 1.71	33.33 ± 1.66	0.34 ± 0.05	0.14 ± 0.05	5.91 ± 0.97	7.54 ± 0.17
Canter		0.74 ± 0.09	−17.42 ± 7.15	56.99 ± 4.69	0.3 ± 0.05	0.11 ± 0.09	7.11 ± 0.87	4.96 ± 0.12
Pair 18 Total	Interm./ interm.	0.55 ± 0.38	−12.16 ± 42.04	49.31 ± 14.04	0.27 ± 0.02	0.22 ± 0.14	5.71 ± 1.06	6.07 ± 0.97
Walk		−0.08 ± 0.04	−79.48 ± 6.84	68.4 ± 4.77	0.24 ± 0.01	0.43 ± 0.05	6.99 ± 0.36	7.09 ± 1.08
Rising trot		0.73 ± 0.04	16.89 ± 3.42	36.9 ± 5.19	0.29 ± 0.01	0.15 ± 0.03	5.99 ± 0.81	5.43 ± 0.12
Sitting trot		0.71 ± 0.02	22.31 ± 1.34	37.34 ± 2.89	0.29 ± 0.01	0.21 ± 0.05	5.15 ± 0.06	5.15 ± 0.06
Canter		0.83 ± 0.02	−8.36 ± 2.01	54.59 ± 2.78	0.28 ± 0.02	0.09 ± 0.06	4.71 ± 0.85	6.61 ± 0.1

Note: The values provided in this table are derived from the original data (not converted).

horse-rider combinations (pairs) are shown in Table 1 and distributions of data for all horse-rider combinations across all seven dependent variables are displayed in Fig. 2.

3.1. Intraclass correlation coefficient

Intraclass correlation coefficients were calculated for the dependent variables of (normalized) mean relative phase (ICC = .9), mean *SD* relative phase (ICC = .99), approximate entropy rider (ICC = .25), SEF95 rider (ICC = .22), and SEF95 horse (ICC = .97) indicating mediocre to strong internal reliability throughout.

3.2. Correlations between dependent variables

Spearman's Rank-Order correlations showed significant negative correlations between horse-rider correlations with mean relative phase ($r_s = -.44$, $p < .001$), mean *SD* relative phase ($r_s = -.62$, $p < .0005$), SEF95 rider ($r_s = -0.26$, $p < .001$ and SEF95 horse ($r_s = -0.46$, $p < .001$). Additional significant positive correlations were found between approximate entropy rider and approximate entropy horse values ($r_s = .23$, $p < .0005$), between approximate entropy horse with mean relative phase ($r_s = .2$, $p < .001$) and mean *SD* relative phase ($r_s = .43$, $p < .0001$), between SEF95 rider with mean *SD* relative phase ($r_s = .28$, $p < .0001$) and between SEF95 horse with approximate entropy horse ($r_s = 0.27$, $p < .0001$) and with mean *SD* relative phase ($r_s = .56$, $p < .0001$).

3.3. Main and interaction effects

A main omnibus effect of gait was noted for the combined experimental factors with $F(15,810) = 22.11$, $p < .0001$, partial eta^2 = 0.29. No further main or interaction effects were noted.

3.3.1. Main effect of gait on dependent variables

When the effect of gait on the dependent variables was considered separately, the dependent variables of mean relative phase, $F(3,272) = 19.17$, $p < .0001$, partial eta^2 = 0.18, mean *SD* relative phase, $F(3,272) = 153.03$, $p < .0001$, partial eta^2 = 0.63, and SEF95 horse, $F(3272) = 66.08$, $p < .0001$, partial eta^2 = 0.42 reached statistical significance. Tables 1–3 summarize the means and standard deviations of the different variables.

3.3.1.1. Differences in mean relative phase values. For the component mean relative phase, Bonferroni post-hoc tests detected significantly higher values in walk compared to rising trot (60.08 ± 85.86 vs. 27.54 ± 9.67; $p < .0001$), sitting trot (60.08 ± 85.86 vs. 35.78 ± 12.99; $p < .05$), and canter (60.08 ± 85.86 vs. 13.03 ± 26.55; $p < .0001$). Differences between sitting trot and canter were approaching significance (35.78 ± 12.99 vs. 13.03 ± 26.55; $p = .08$).

3.3.1.2. Differences in mean SD relative phase values. Furthermore, for mean *SD* relative phase values, Bonferroni post-hoc tests detected significantly higher values in walk compared to rising trot (67.94 ± 5.61 vs. 44.40 ± 8.22; $p < .0001$), to sitting trot (67.94 ± 5.61 vs. 44.08 ± 9.21; $p < .0001$), and to canter (67.94 ± 5.61 vs. 55.50 ± 7.56). Values for canter were significantly higher compared to rising trot (55.50 ± 7.56 vs. 44.40 ± 8.22; $p < .0001$), and to sitting trot (55.50 ± 7.56 vs. 44.08 ± 9.21; $p < .0001$).

3.3.1.3. Differences in SEF95 horse values. Bonferroni post-hoc tests also determined significantly higher values in walk compared to rising trot (7.76 ± 1.07 vs. 4.95 ± 1.34; $p < .0001$), to sitting trot (7.76 ± 1.07 vs. 5.55 ± 1.37; $p < .0001$), and to canter (7.76 ± 1.07 vs. 6.45 ± 1.24; $p < .0001$). Scores in rising trot were significantly lower than sitting trot (4.95 ± 1.34 vs. 5.55 ± 1.37; $p < .0001$), while canter scores were significantly higher than rising trot (6.45 ± 1.24 vs. 4.95 ± 1.34; $p < .0001$), and sitting trot (6.45 ± 1.24 vs. 5.55 ± 1.37; $p < .0001$). Rising trot was found to be significantly lower than sitting trot (4.95 ± 1.34 vs. 5.55 ± 1.37; $p < .0001$).

Table 2
Horse-rider movement coordination variables.

		Walk		Rising trot		Sitting trot		Canter	
		LR	RR	LR	RR	LR	RR	LR	RR
Horse-rider correlation	WU	−0.07 ± 0.25	−0.07 ± 0.17	0.62 ± 0.09	0.64 ± 0.11	0.59 ± 0.14	0.57 ± 0.16	0.74 ± 0.09	0.71 ± 0.33
	PERF	−0.11 ± 0.3	0.09 ± 0.25	0.64 ± 0.09	0.64 ± 0.13	0.59 ± 0.15	0.59 ± 0.16	0.72 ± 0.15	0.77 ± 0.1
Mean relative phase	WU	58.27 ± 80.03	62.29 ± 79.99	28.82 ± 7.91	28.73 ± 10.05	36.77 ± 12.86	37.74 ± 15.18	16.99 ± 23.88	4.57 ± 28.94
	PERF	61.02 ± 93.65	58.74 ± 95.9	26.32 ± 9.76	26.27 ± 11.2	33.93 ± 11.54	34.69 ± 12.88	20.61 ± 27.17	9.94 ± 25.19
Mean *SD* relative phase	WU	69.06 ± 6.19	69.43 ± 6.05	45.28 ± 7.17	41.99 ± 6.96	43.08 ± 8.57	43.38 ± 8.76	57.37 ± 9.42	52.76 ± 6.71
	PERF	66.23 ± 5.47	67.04 ± 4.33	46.50 ± 9.84	43.82 ± 8.58	44.48 ± 10.15	44.48 ± 9.86	58.14 ± 6.9	53.74 ± 5.91
Approximate enthropy rider	WU	0.28 ± 0.04	0.28 ± 0.05	0.26 ± 0.06	0.28 ± 0.04	0.29 ± 0.08	0.27 ± 0.08	0.27 ± 0.05	0.26 ± 0.06
	PERF	0.29 ± 0.03	0.29 ± 0.03	0.28 ± 0.05	0.3 ± 0.06	0.29 ± 0.07	0.27 ± 0.08	0.27 ± 0.05	0.25 ± 0.07
Approximate enthropy horse	WU	0.4 ± 0.06	0.39 ± 0.05	0.15 ± 0.06	0.14 ± 0.05	0.16 ± 0.07	0.17 ± 0.07	0.11 ± 0.06	0.13 ± 0.08
	PERF	0.42 ± 0.05	0.42 ± 0.04	0.14 ± 0.06	0.15 ± 0.06	0.16 ± 0.07	0.17 ± 0.06	0.1 ± 0.07	0.12 ± 0.07
SEF95 rider	WU PERF	6.62 ± 9.64	6.67 ± 0.6	6.25 ± 0.98	6.11 ± 1.15	6.59 ± 1.09	6.62 ± 1.06	6.46 ± 1.95	6.33 ± 1.92
		6.58 ± 0.85	6.61 ± 0.8	6.36 ± 0.96	6.26 ± 1.11	6.71 ± 1.37	6.65 ± 1.11	6.36 ± 1.56	6.16 ± 1.54
SEF95 horse	WU	7.55 ± 1.16	7.71 ± 1.07	4.88 ± 1.26	4.67 ± 1.33	5.37 ± 1.19	5.7 ± 1.53	6.58 ± 1.23	6.52 ± 1.39
	PERF	7.79 ± 1.03	7.99 ± 1.05	5.05 ± 1.28	5.19 ± 1.54	5.48 ± 1.24	5.65 ± 1.56	6.4 ± 1.13	6.29 ± 1.29

Note: WU = warm-up condition; PERF = performance condition; LR = left rein; RR = right rein

3.3.1.4. Differences in horse-rider correlation values. Findings from the MANOVA analysis described above indicated that coordination variables in canter differed to those in walk or trot. Subsequently, Mann-Whitney U tests were applied to test the assumption that horse-rider correlation values differed significantly between canter and the other three gaits. Results showed significantly higher correlations in canter compared to walk (0.73 ± 0.02 vs. −0.09 ± 0.03; U = 5108; $p < .0001$), to rising trot (0.73 ± 0.02 vs. 0.64 ± 0.01; U = 4030; $p < .0001$), and to sitting trot (0.73 ± 0.02 vs. 0.58 ± 0.02; U = 2523; $p < .0001$).

3.3.1.5. Differences in approximate entropy horse values. Lastly, for approximate entropy horse values Mann-Whitney U tests showed significantly lower values for canter compared to walk (0.12 ± 0.0 vs. 0.41 ± 0.0; U = 0; $p < .0001$), to rising trot (0.15 ± 0.0 vs. 0.14 ± 0.06; U = 1888; $p < .005$), and sitting trot (0.17 ± 0.0 vs. 0.09 ± 0.07; U = 1590; $p < .0001$).

4. Discussion

The aim of the current study was to investigate and describe patterns of motor coordination between horse and rider using tri-axial accelerometers, a method previously used in human movement studies (Kwakkel & Wagenaar, 2002; Mayagoitia et al., 2002).

Earlier studies investigating horse-rider movement coordination patterns have relied on the use of one or several reflective markers and high-speed cameras to measure and compare phase synchronization between the different riders (Peham et al., 1998, 2001; Schöllhorn et al., 2006; Witte et al., 2009). When affixing several markers to horse-rider combinations, subsequent analysis relies on calculation of marker velocities and body angles of both horse and rider. Such systems are relatively complex in their application and subsequent data analysis, limiting the practicability of their use across a larger population sample and examining variables relating to different equine gait patterns. Using principal component analysis to reduce movement parameters, Witte et al. (2009) showed that even the very complex, multi-dimensional system of the horse-rider dyad may be captured by using only one higher-order parameter. Furthermore, in their study Peham et al. (2004) also noted that their method of using only one marker made the analysis considerably easier and more applicable for real-life settings. Initial findings of the current study seem to suggest that accelerometers might indeed be a valuable tool to map distinct coordination patterns of horse-rider combinations. The strong intraclass correlation coefficients for mean relative phase, mean *SD* relative phase and SEF 95 variables seem to support the reliability of the methodology used in the current study.

Statistical analysis showed that gait provided the only significant effect on coordination parameters: Even though many riders acknowledge having a preferred side when riding a horse, current results do not show a significant effect of direction. Further still, warming up is considered important in order to ensure optimal physiological and psychological preparation prior to, for example, presenting a horse in a competitive setting (Murray et al., 2006). Yet current findings seem to indicate that horse-rider coordination dynamics did not markedly improve as the session progressed. Future research should endeavor to investigate whether a period of weeks or even months is likely to show an effect on the coordination parameters of the horse-rider dyad.

Table 3
Horse-rider movement coordination variables – total values.

	Walk	Rising trot	Sitting trot	Canter
Horse-rider correlation	−0.09 ± 0.24	0.64 ± 0.11	0.58 ± 0.15	0.73 ± 0.19
Mean relative phase	60.08 ± 85.86	27.54 ± 9.67	35.78 ± 12.99	13.03 ± 26.55
Mean *SD* relative phase	67.94 ± 5.61	44.40 ± 8.22	44.08 ± 9.21	55.5 ± 7.56
Approximate entropy rider	0.28 ± 0.04	0.28 ± 0.05	0.28 ± 0.08	0.27 ± 0.06
Approximate entropy horse	0.41 ± 0.05	0.15 ± 0.05	0.17 ± 0.07	0.12 ± 0.07
SEF95 rider	6.62 ± 0.72	6.25 ± 1.03	6.64 ± 1.14	6.33 ± 1.72
SEF95 horse	7.76 ± 1.07	4.95 ± 1.34	5.55 ± 1.37	6.45 ± 1.24

Most important findings were significantly higher horse-rider correlation values in canter compared to trot and walk, which support anecdotal claims that the canter is the easiest gait to sit to and the walk the most difficult gait to ride (Witte et al., 2009). The notion that horse and rider might experience a tighter or stronger movement coordination during canter as opposed to walk is further supported by significantly lower mean relative phase values, indicating smaller phase differences between the two members of the dyad. Non-significant differences between rising trot and canter might indicate that the rider lifting out of the saddle for the duration of one phasic stride and thereby avoiding being "bumped" out of the saddle, helps prevent the destabilization of movement coordination. Higher mean standard deviations of relative phase values point towards unstable phase-coupling in the walk. In fact, current findings lend further support to theories developed by Kelso (1984) that variability in relative phases provides a reliable index of coordination stability. On an abstract theoretical level the significant relationship between the variables of horse-rider correlation and relative phase variables might be considered a test-retest reliability index of the current measurement system.

What is more, mean relative phase values also provided additional indications as to precisely in what manner horse and rider interact during the different gaits. While riders seem to be following, as opposed to anticipating, the motion of the horse, the phase lag was shown to be significantly greater in walk and trot, supporting the notion of tighter horse-rider synchronization in canter. It might be argued that the suspension interval at the end of the canter stride cycle, during which the horse is airborne and which has been shown to last slightly longer than the three successive beats of the footfall (Clayton, 2004), allows riders sufficient time to ready themselves for the start of each new stride cycle. This short "preparation time" might enable riders to renew the synchronization of their motion patterns with those of their horses for each new stride, while the more rapid rhythm of the walk and trot does present more of a challenge for riders' motor coordination.

These assumptions relating to the complexity of each equine gait are further borne out by approximate entropy parameters. As a measurement unit, approximate entropy determines the predictability of movement patterns (Pincus, 1991, 2000). In line with anecdotal views that the equine walk is the most difficult pace for a rider to control, approximate entropy values show significantly less predictability than other gaits. Approximate entropy values for canter on the other hand show that this three-beat gait is the most predictable, despite the fact that it is the only irregular gait. However, seeing that the gait of canter is also the fastest of the three gaits, it may well be that increased acceleration causes successively greater stabilizing effects (Horak, Esselmann, Anderson, & Lynch, 1984). While mean approximate entropy values for riders did not show as obvious a pattern as in horses, the same general trend could be found with significant relationships between horse and rider values.

The relatively low sample size and the heterogeneous nature of the sample population might be considered limitations of the current study. While 18 horse-rider combinations may be considered acceptable compared to similar studies (e.g., Lagarde et al., 2005; Schöllhorn et al., 2006), the recruitment of sufficiently-sized sample populations nevertheless remains notoriously difficult in equestrian-related research (Blakeslee & Goff, 2007; Wolframm & Micklewright, 2011). On the one hand, the wide variety of skill level in horse and rider might be considered a plus in many respects, seeing that it allows the recording of coordination parameters across a considerable spectrum of equestrian sports. On the other hand, however, the ultimate goal of describing optimal horse-rider synchronization might be better served by focusing only on highly skilled riders or investigating differences between different levels of skill, using sufficiently sized sample groups.

Future research should therefore focus on validating current findings while also expanding and exploring differences in levels of skill in both riders and horses. Additional studies employing accelerometers on horses and riders might move another step closer to providing objective parameters to gauge the quality of horse-rider interactions.

In conclusion, current findings seem to indicate that wireless accelerometers provide a novel, yet reliable method of mapping coordination dynamics of the horse-rider system in field experiments. Inter-variable correlations may be viewed as indicators of the reliability of the methodology and related results. From an applied perspective, the current study seems to support the notion commonly accepted in rider circles, that the gait of canter is the easiest to ride, and as such encourages greater levels of horse-rider coordination than in either trot or walk.

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