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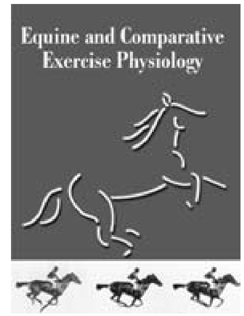

Stabilization of wrist position during horseback riding at trot

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Research Paper

Abstract

Kinematic analysis has been used to understand performance in many sports, but few objective studies of equestrian technique have been published. The objective was to describe movements of the rider's torso and arms relative to movements of the horse's pelvis and shoulder and the position of the bit during trotting. Six experienced female riders rode the same dressage horse at a sitting trot, with rider and horse kinematics collected. The trot is a symmetrical gait, which implies kinematic symmetry between the first and the second halves of the gait. Three trials of a half stride, from left forelimb lift-off to right forelimb lift-off, were analysed for each subject. In all riders, trunk angle was maximal (backward tilt) in early stance, at which time the rider's hips were closest to and the rider's shoulders were furthest from the bit. Trunk angle was minimal (forward tilt) at the end of stance when the shoulders were closest to and the hips were furthest from the bit. Range of motion of the rider's hips and shoulders varied greatly between subjects. Movements of the rider's shoulder joint and elbow joint were synchronized with the trunk oscillations, so the distance from the rider's wrist to the horse's bit changed by only 15 ± 3 mm during the stride. It is concluded that the six experienced riders were able to accommodate the motion of the horse's body while maintaining a consistent contact with the bit by minimizing changes in the distance from the wrist to the bit.

Keywords: kinematics; equestrian sport; horse; rider; trot

Introduction

Kinematic descriptions of technique have helped athletes in many sports to improve their performance[1]. One of the features of horseback riding is that it involves two athletes, the horse and the rider, which complicates the analysis of equestrian technique. Considerable research has been performed describing the gaits and the movements of horses[2–5], and it has been shown that the presence of a rider affects the horse's kinematics[6–9] and ground reaction forces[10,11]. However, few studies have evaluated the rider *per se*[12–15]. In the absence of comprehensive data describing equestrian technique, teaching of equestrian skills is based more on traditions than on science.

Dressage is one of the equestrian sports performed in the Olympic Games. In competitions, a pattern of exercises is performed at different gaits and with variations in speed within the gaits. The rider directs the horse and influences the quality of the horse's movement in an unobtrusive manner. With regard to the position and the effect of the rider, the international competition rules[16] state that 'all the movements should be obtained without apparent effort of the rider' and that the rider should 'follow the movements of the horse smoothly and freely.' The trot and the canter have aerial phases in each stride, and large vertical excursions of the horse's body during the aerial phases are regarded as a desirable trait. The bouncing motion of the horse's body is transmitted to the rider, who must learn to accommodate the vertical motion without relying on the reins to maintain balance.

The rider communicates with the horse by exerting pressure on different parts of the horse's body and the horse is trained to yield to that pressure. One of the tools of communication between horse and rider is the bit that lies within the oral cavity. Tension in the reins results in pressure being exerted by the bit on sensitive oral tissues. Horses are trained to respond to subtle changes in bilateral or unilateral rein tension. One of the challenges for a novice rider is to learn to follow the movements of the horse's body while maintaining a relative stillness among the hands, reins and bit. This is achieved by moving the trunk and arms independently, so movements of the trunk that are necessary to follow the horse's motion do not create noise in the connection with the reins. The use of instrumented reins has shown that rein tension has a consistent pattern in experienced riders that is synchronized with the regular rhythm of the footfalls and the movements of the horse's limbs and body within the gait[17].

In textbooks, several steps are described for improving equestrian skills. First, the rider has to understand how the horse moves so that they can learn to follow that motion harmoniously[18]. Secondly, the rider learns to use their weight, back, legs and arms to control the horse[19]. With further experience, riders develop a more advanced level of skills that can be applied to train the horse to respond in an appropriate manner to the rider's signals[20]. One of the effects of such training is to reduce the inherent variability in the horse's motion pattern[21]. Many talented riders interact with the horse on a subconscious level based on feeling and intuition[22], which makes it difficult to convey technical details describing equestrian skills to inexperienced riders.

Data from experienced riders will provide information on equestrian performance[23] and provide a better understanding of how the rider follows the horse's movement and influences the horse's performance. In addition, comparisons between riders will indicate which aspects of performance are consistent and which aspects vary between individuals. The aim of this study is to measure the position of the rider's hand relative to the bit and to investigate the efficiency of movements of the rider's torso, shoulder and elbow joints on hand position at the sitting trot.

Materials and methods

Subjects and procedures

Six riders (height: 1.64 ± 0.04 m, mass: 61 ± 7 kg), who were experienced in riding and training FEI (Fédération Equestre Internationale)-level dressage horses, rode the same Thoroughbred horse (height: 1.56 m, mass: 508 kg, age: 16 years) along a rubber-covered runway in a straight line at trot. The horse had competed successfully in intermediate level dressage competitions. A single horse was used to avoid variation due to differences in movement patterns between horses. Testing was performed in accordance with the University Committee on Research Involving Human Subjects and the Institutional Animal Use and Care Committee. Riders provided written informed consent.

Subjects were prepared by placing spherical, reflective markers on the rider's right side over the lateral epicondyle of the humerus (elbow) and greater trochanter (hip). Triads of reflective spheres attached securely to the dorsal surface of the rider's forearm and upper arm were used to locate virtual markers at the centres of rotation of the wrist joint (wrist) and the shoulder joint (shoulder), respectively (Fig. 1).

FIG. 1 Horse and rider during data collection

Markers were placed on the right side of the horse over the greater tubercle of the humerus (horse's shoulder), the lower part of the *tuber coxae* (horse's pelvis) and at the attachment of the rein to the bit (bit).

Data capture

Rider and horse warmed up in an arena prior to data collection. After the warm-up, the instruction to the riders was that they should ride at sitting trot with the horse moving in a straight line along a 40 m rubberized runway. Kinematic data were recorded at 120 Hz using six Falcon cameras and real-time v. 3.2 software (Motion Analysis Corporation, Santa Rosa, CA, USA) within a volume measuring 5 m long by 2 m wide by 3 m high. All trials were also filmed at 60 Hz using a GR-DVL9800 camcorder (JVC, Yokohama, Japan), and the time code of the system was used to synchronize ground contact timings of the hooves, as determined from the video recordings, with kinematic data from the motion analysis system. Three trials were recorded for each rider.

Data analysis

The trot is classified as a symmetrical gait, indicating that the two halves of the stride are mirror images of each other. Movements of the diagonal pairs of limbs are synchronized during trotting, with aerial phases intervening between successive diagonal stance phases. Data were captured for half a stride from lift-off of the left forelimb to lift-off of the right forelimb, which was 50% of stride duration. The recording time encompassed an aerial phase followed by the diagonal stance phase of the right forelimb and left hind limb. The times of occurrence of the data points were expressed as a percentage of total stride duration, based on the assumption of temporal symmetry between the left and right halves of the trot stride.

All data were analysed using custom-written code in Matlab (MathWorks Inc., Natick, MA, USA). The raw kinematic data were filtered using a 15 Hz low pass Butterworth filter before calculating linear and angular variables. Linear and angular data collected during a half stride were time-normalized to 101 data points to facilitate comparisons between individuals when plotting the data.

The coordinates of the markers on horse and riders were used to calculate the maximal and minimal heights of each marker and their times of occurrence, as well as the mean height of the marker during the trial. Distances were calculated from the bit marker to the rider's wrist, shoulder and hip. Angles were determined for the rider's trunk and forearm segments, and for the shoulder and elbow joints. Trunk angle was measured relative to the vertical for a line joining the hip to the shoulder; tilting the upper body backward was assigned a positive value. The forearm angle was measured between the vertical and a line connecting the markers on the elbow and wrist. This angle increased when the wrist was lowered relative to the elbow. The shoulder joint angle was measured between a line connecting the shoulder and hip markers to a line connecting the shoulder and elbow markers. When the elbow was posterior to the trunk, the angle was designated as extension and assigned a positive value. The elbow joint angle was measured between a line connecting the elbow and the shoulder markers to a line connecting the elbow and the wrist markers. Elbow angle was always positive, with smaller angles indicating greater flexion.

For each subject, data from the three trials were averaged. The maximum and minimum and their times of occurrence, together with the mean value and the range of motion during the half stride were calculated for each variable. Comparisons among the vertical ranges of motion of the horse's shoulder, horse's pelvis, rider's hip, rider's shoulder, rider's elbow and rider's wrist and among the ranges of distances from the bit to the rider's shoulder, elbow and wrist were made using one-way ANOVA (SPSS, Chicago, IL, USA). When significant differences were detected, Tukey's HSD *post hoc* test was applied. For all statistical tests, a probability of $P < 0.05$ was used. In the graphical representations (Fig. 2), normalization was

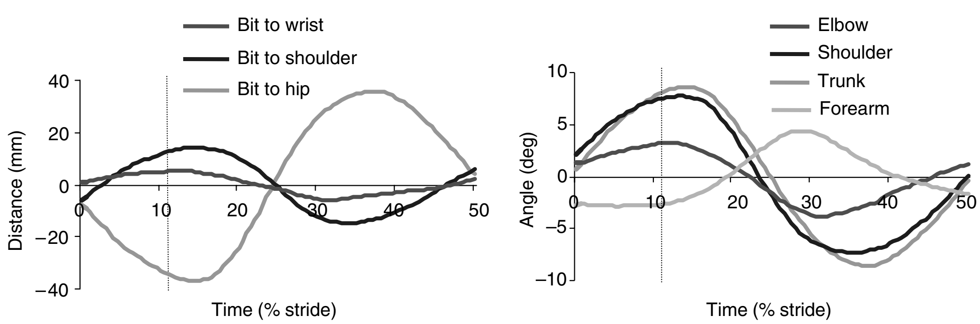

Fig. 2 Distances from the bit to the riders' wrist, shoulder and hip (left panel) and angulations of the riders' elbow joint, shoulder joint, trunk to vertical (tilting the upper body back is positive) and forearm to vertical (right panel). Curves show mean value for six experienced riders during half a stride at trot. Ground contact time of the right forelimb is indicated by the vertical line at 11% stride. The data have been normalized so the mean value during the entire trial is represented as zero for each variable

performed by subtracting the mean value for the trial from each data point to account for morphological differences between subjects. Consequently, the zero line on the graphs represents the mean value for that variable throughout the stride.

Results

The footfall of the right forelimb occurred at 11 ± 2% of stride. It can be seen from Table 1 that vertical excursion of the rider's wrist (87 ± 15 mm) was significantly smaller than that of the rider's shoulders (121 ± 17 mm), the rider's hip (134 ± 18 mm), the rider's elbow (117 ± 14 mm) or the horse's pelvis (122 ± 7 mm).

Vertical and horizontal oscillations of the rider's trunk were associated with changes in the distances from the bit to the rider's wrist, shoulder and hip, which varied with a sinusoidal pattern in each half stride (Fig. 2). The rider's hip was closest to the bit in the early part of the diagonal stance phase (14 ± 1% of stride) when the horse's body was descending. Around this time, the shoulder and the wrist were furthest from the bit. When the rider's hip was at its maximal distance from the bit in late stance (37 ± 2% of stride), the shoulder and wrist were relatively close to the bit. Thus, changes in the distances from the bit to the shoulder and the wrist were out of phase with changes in distance from the bit to the hip. The range of distances between the bit and the rider's hip (78 ± 30 mm) was significantly larger than the range of distances between the bit and the rider's shoulder (34 ± 15 mm) or wrist (15 ± 3 mm), which were not different from each other.

The mean angle of the rider's trunk was 4°. The trunk oscillated back and forth in rhythm with the horse's stride such that the angle was maximal (13 ± 4° backward tilt) in early stance (14 ± 2% of stride) and minimal (−5 ± 9° forward tilt) in late stance (37 ± 1% of stride). Oscillations of the horse's trunk were associated with significantly larger amounts of motion between the bit and the rider's hips compared with the rider's shoulders or wrist (Table 1). The shoulder joint (mean angle −6°) and elbow joint (mean angle 132°) extended as the trunk tilted backwards, and flexed as the trunk tilted forwards (Fig. 2). These movements resulted in a significantly smaller range of distances from the bit to the rider's wrist than from the bit to the rider's shoulder or hip. Variability in the range of distances from bit to wrist was also lower than variability of distances from bit to hips.

Although all riders maintained a consistent distance from bit to wrist, there were some marked differences in ranges of motion between individuals (Table 2). For the different riders, vertical motion of the horse's shoulder ranged from 92.4 to 105.7 mm and vertical motion of the horse's pelvis ranged from 107.1 to 127.4 mm, with vertical excursion of the horse's pelvis being greater than that of the horse's shoulder for all riders. In most of the subjects, vertical excursions of the rider's hip and shoulder were larger than those of the horse's pelvis or shoulder, the exception being Rider 2, who had a much smaller vertical excursion of the hip (104.0 mm) and the shoulder (97.8 mm) than any other rider (Table 2). By comparison, Rider 5 had the largest vertical excursions of both hip (159.2 mm) and shoulder (147.1 mm), which

Table 1 Descriptive statistics and timings of maximum and minimum values of horse and rider vertical displacements, distances from bit to rider's joint centres and rider's joint angles at trot

			Maximum		Minimum	
	Mean	Range	Value	Time (% stride)	Value	Time (% stride)
Vertical displacement						
Horse's shoulder (mm)	1045	100 (4)[ab]	1102 (4)	5 (2)	1002 (5)	33 (2)
Horse's pelvis (mm)	1347	115 (8)[c]	1405 (5)	1 (1)	1290 (12)	27 (1)
Rider's hip (mm)	1593	134 (18)[ad]	1659 (16)	7 (2)	1525 (20)	31 (1)
Rider's shoulder (mm)	1990	121 (17)[be]	2045 (14)	6 (1)	1925 (21)	29 (2)
Rider's elbow (mm)	1733	117 (14)[f]	1788 (19)	6 (1)	1671 (22)	30 (2)
Rider's wrist (mm)	1610	86 (15)[cdef]	1653 (35)	6 (2)	1566 (38)	31 (1)
Distance						
Bit to rider's hip (mm)	986	78 (30)[gh]	1025 (42)	37 (2)	947 (44)	14 (1)
Bit to rider's shoulder (mm)	1196	34 (15)[g]	1212 (70)	15 (2)	1178 (67)	34 (3)
Bit to rider's wrist (mm)	788	15 (3)[h]	795 (61)	12 (6)	780 (63)	33 (4)
Riders' angles						
Trunk (degree)	4	18 (5)	13 (4)	14 (2)	−5 (9)	37 (1)
Shoulder joint (degree)	−6	16 (6)	2 (8)	11 (4)	−14 (11)	36 (2)
Elbow joint (degree)	132	9 (3)	137 (13)	9 (6)	128 (14)	34 (5)
Forearm to vertical (degree)	58	9 (3)	63 (12)	30 (3)	54 (10)	5 (5)

Values are mean (SD). Angle conventions are: trunk backward tilt is positive; shoulder extension is positive and elbow extension is positive. Similar superscripts indicate significant differences ($P < 0.05$) in the range of values for variables within the subgroup *vertical displacement* and for variables within the subgroup *distance*.

Table 2 Mean values and (SD) of linear measurements for individual riders during one half of a stride at trot

	Rider					
	1	2	3	4	5	6
Vertical Range of Motion						
Horse's shoulder (mm)	100.4 (4.8)	92.4 (10.8)	99.5 (15.1)	99.7 (11.3)	105.7 (13.6)	102.9 (7.0)
Horse's pelvis (mm)	110.7 (3.6)	113.4 (4.0)	122.3 (5.3)	110.4 (5.3)	127.4 (4.2)	107.1 (5.0)
Rider's hip (mm)	127.8 (13.8)	104.0 (6.7)	134.9 (6.2)	142.2 (12.6)	159.2 (6.9)	136.5 (4.2)
Rider's shoulder (mm)	111.9 (3.9)	97.8 (7.9)	127.4 (7.8)	129.2 (2.3)	147.1 (4.1)	111.3 (2.0)
Rider's elbow (mm)	110.1 (4.6)	100.5 (7.1)	111.9 (6.7)	129.7 (2.5)	138.6 (1.0)	109.1 (4.6)
Rider's wrist (mm)	68.8 (4.6)	91.2 (7.1)	67.3 (7.6)	97.0 (6.6)	97.5 (11.8)	99.1 (15.8)
Range of Distances						
Bit to rider's hip (mm)	84.2 (20.7)	35.5 (8.8)	87.4 (8.1)	94.7 (26.7)	49.2 (7.4)	117.3 (26.5)
Bit to rider's shoulder (mm)	29.3 (9.8)	60.8 (16.6)	31.0 (5.5)	31.4 (7.7)	44.4 (1.1)	37.7 (18.2)
Bit to rider's wrist (mm)	13.0 (4.1)	13.6 (6.5)	18.0 (6.2)	11.5 (3.5)	15.8 (3.7)	20.4 (9.9)
Riders' Angles						
Trunk (degree)	15.2 (1.3)	14.4 (1.0)	18.8 (2.7)	22.1 (4.8)	12.9 (1.6)	24.2 (2.4)
Shoulder joint (degree)	15.5 (0.9)	5.0 (2.1)	18.9 (1.3)	22.0 (7.0)	13.8 (2.3)	23.0 (4.0)
Elbow joint (degree)	10.0 (0.8)	12.2 (3.9)	8.6 (3.7)	8.5 (1.4)	10.5 (3.1)	4.7 (2.4)
Forearm to vertical (degree)	10.5 (2.9)	4.0 (1.4)	12.1 (1.4)	9.3 (1.2)	10.5 (3.2)	5.9 (2.0)

corresponded with having the largest excursion of the horse's pelvis. Within each rider, vertical excursion of the hip was greater than that of the shoulder, implying absorption of some vertical motion by movement of the joints of the rider's trunk or pelvis. Vertical range of motion of the wrist was smaller than that of the hip, shoulder or elbow in all riders.

It is evident from Table 1 that there is more variation in the range of distances between the bit and the rider's hip or shoulder than from the bit to the rider's wrist. The source of this variation can be explored further in Table 2. In five of the six riders, there was less relative motion between the bit and the rider's shoulder than the bit and the rider's hip, which implies that hip motion was used to stabilize the shoulder. The exception was Rider 2, in whom the variation in distance from bit to hip was much less than the variation in distance from bit to shoulder. This rider stabilized her hips and compensated for the horse's movement by a rocking motion of the trunk that resulted in a larger range of motion of the shoulder joint.

Discussion

In gaits, such as the trot, that have an aerial phase, vertical motion of the horse's trunk imparts a bouncing motion to the rider that is especially obvious at sitting trot. The relative stillness of the wrist relative to the bit is a hallmark of an independent seat that facilitates communication between the rider and the horse. In a comparison of the kinematics of novice, intermediate and advanced riders[12], significant differences were identified between riders of different ability levels in walk, posting trot and sitting trot. In sitting trot, novice riders tended to tilt their trunk slightly forward, whereas advanced riders maintained an almost vertical trunk orientation[12]. Our study confirms that experienced riders adopt an almost vertical trunk orientation, in this case an average backward tilt of 4° (Table 1), and supports the suggestion that trunk angulation may be an indicator of the rider's skill level. This may be a useful measurement in a practical situation as it can be recorded using simple procedures.

Another problem experienced by the novice rider is the tendency for the trunk to be thrown backwards or forwards under the influence of unexpected translational forces[24]. The tendency to be thrown backwards is overcome by leaning forwards[12]. Riders learn to anticipate the translations and avoid perturbations by coordinated contractions of their abdominal and erector spinae muscles that allow them to follow the horse's motion[14]. The slight forward tilt of the trunk in the second half of stance anticipates the push off into the aerial phase, and may be related to contraction of the *rectus abdominis* muscle, which is active in the second half of stance[25]. The trunk is tilted backwards during the impact phase to counteract the large braking effect of the longitudinal ground reaction force in early stance.

In a study comparing the rider's position in walk, trot and canter[15], it was shown that oscillations of the trunk occur in rhythm with the stride. In walk, the trunk was tilted backwards by 1.9° at hind limb contact and forward by 3–4° at forelimb contact. In that study, however, the trot was performed 'rising', which involves rising out of the saddle during alternate diagonal stance phases. The trunk was inclined forward throughout the stride, with different inclinations on the rising and the sitting diagonals. However, data for the rising trot are not directly comparable with the study presented here, in which riders were sitting in the saddle throughout the trot stride.

The experienced riders in this study maintained a consistent distance from wrist to bit by adjusting the angles of their shoulder and elbow joints to compensate for the rocking motion of the body. As the rider's trunk tilted backward at the beginning of stance, the hip moved towards the bit, while the shoulders moved away from the bit. Conversely, as the trunk tilted forwards, the hip moved away from the bit and the shoulders moved towards it. During these oscillations of the trunk, the riders stabilized the position of the wrist and hand relative to the bit through coordinated movements of the shoulder and elbow joints. As the trunk tilted backwards in late stance, the shoulder and elbow joints were extending. As the trunk tilted forwards in late stance, the shoulder and elbow joints flexed.

Differences between individual riders in terms of relative amounts of motion of the hips and shoulders were interesting; the studies of muscular activation patterns might be useful to further understand how these differences arise. Regardless of inter-individual variations, in all subjects, the rider's wrist underwent a significantly smaller vertical excursion and showed significantly less variation in position relative to the bit than the shoulder or hip, which is indicative of the success of the movements used to stabilize the wrist. Furthermore, the low variability in the distance between wrist and bit ($SD = 0.3$ cm) indicates a level of consistency in stabilization of wrist position by the experienced riders in this study.

In conclusion, all the experienced riders in this study adjusted the angles of their shoulder and elbow joints to maintain the wrist in a consistent position relative to the bit as their trunk rocked back and forth in rhythm with the horse's stride. However, there were differences between riders in the relative amounts of motion of the hips and shoulders that are worthy of further study.

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