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Kinetics of the forelimb in horses circling on different ground surfaces at the trot

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ABSTRACT

Circling increases the expression of distal forelimb lameness in the horse, depending on rein, diameter and surface properties of the circle. However, there is limited information about the kinetics of horses trotting on circles. The aim of this study was to quantify ground reaction force (GRF) and moments in the inside and outside forelimb of horses trotting on circles and to compare the results obtained on different ground surfaces. The right front hoof of six horses was equipped with a dynamometric horseshoe, allowing the measurement of 3-dimensional GRF, moments and trajectory of the centre of pressure. The horses were lunged at slow trot (3 m/s) on right and left 4 m radius circles on asphalt and on a fibre sand surface. During circling, the inside forelimb produced a smaller peak vertical force and the stance phase was longer in comparison with the outside forelimb. Both right and left circling produced a substantial transversal force directed outwards. On a soft surface (sand fibre), the peak transversal force and moments around the longitudinal and vertical axes of the hoof were significantly decreased in comparison with a hard surface (asphalt). Sinking of the lateral or medial part of the hoof in a more compliant surface enables reallocation of part of the transversal force into a proximo-distal force, aligned with the limb axis, thus limiting extrasagittal stress on the joints.

Introduction

Trotting horses on left and right circles is considered to be a crucial step in the clinical examination of lame horses, as it often exacerbates lameness and can provide additional information on the origin of this lameness (Ross, 2011; Starke et al., 2011). However, limited information is available on equine locomotion in curves, despite the prevalence of circles, twists, turns and curves used in most equine disciplines (Hobbs et al., 2011). Due to technical constraints, kinetic and kinematic studies are mainly performed on a straight line and there is a lack of data to understand the effects of turning on the locomotor apparatus of the horse.

Kinematics and accelerometry have been used to evaluate the effects of circling on different biomechanical parameters. Starke et al. (2011), using inertial sensors to investigate adaptations of trunk movement in horses trotting in a circle, showed that trotting in a circle introduced systematic changes in the movement pattern of head and trunk landmarks, affecting most asymmetry measures. Clayton and Sha (2006), studying the movements of the centre of mass of horses trotting around small circles (~3 m radius), demonstrated that all horses leaned to the inside of the circle, with a tilt angle of 14.8 ± 2.8°. Hobbs et al. (2011) demonstrated that limb inclination and relative body inclination were significantly greater at trot and canter on a flat curve compared to a banked curve and concluded that horses negotiate a banked curve with a limb posture that is similar to straight displacement.

Limb inclination and body lean on a flat curve would be expected to provide an insight into movement adaptations in a circle. Chateau et al. (2005) investigated the three-dimensional (3D) kinematics of the digital joints of horses during a sharp turn at walk. During the stance phase in a turn, there was a high degree of adduction of the inside forelimb. In the swing phase, the inside forelimb moved towards the interior of the circle in the direction of the movement. During the stance phase, the body mass of the horse was brought over this limb, while the foot remained immobile on the ground. This movement, associated with body lean, induced alterations in the 3D kinematics of the digital joints compared to straight walking. The largest alterations were in the distal interphalangeal joint (DIPJ), which underwent combined

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movements of abduction (∼2°) and internal rotation (∼10°). There were also internal rotations of the proximal interphalangeal joint (PIPJ; ∼4°) and metacarpo-phalangeal joint (MPJ) during joint flexion.

Extra-sagittal rotations increase stress on the distal joints during weight bearing (Denoix, 1999). Kinematic findings can be used to understand the aetiopathogenesis of common injuries, such as osteoarthrosis, collateral ligament injuries and capsulitis, which are more frequent in horses that make tight turns or twisting movements (Swanson, 1988; McDiarmid, 1998; Stashak, 2002).

In addition to kinematic studies, increased insight into the effects of circling would benefit from a kinetic approach. Curve negotiation involves the production of an inwardly directed ground reaction force (GRF) during the stance phase, which results in centripetal acceleration. Kinematic studies in human biomechanics have demonstrated that, along a curved path, the runner must generate centripetal forces by applying lateral force on the ground at each step (Orendurff et al., 2006; Chang and Kram, 2007; Glaister et al., 2008; Strike and Taylor, 2009). This transversal impulse is required to change the direction of the momentum vector of the runner and to accelerate the body in the direction of the turn.

Heaps et al. (2011) measured the horizontal moment around the centre of pressure (CoP) of the hoof in six horses during right and left circling (5 m radius) at the walk using a force plate and found large inter-horse variabilities, which were attributed to mechanical asymmetries. It is difficult to acquire kinetic data during circling in horses from force plates due to technical constraints: (1) force plate measurements only allow a limited number of recordable successive ground contacts; (2) it is difficult to ensure that the horse steps on the plate; and (3) during circling, the path of progression differs from the global reference frame such that horizontal force outputs from the force plate do not correlate with the local (anatomical) reference frame, in contrast with walking in a straight line (Glaister et al., 2007).

A dynamometric horseshoe (DHS) has been used to study the effects of different ground surfaces on the kinetics of the forelimb in harness trotters and has been adapted for measurements in ridden and lunged horses (Chateau et al., 2009, 2010; Robin et al., 2009; Crevier-Denoix et al., 2010). Using the DHS, the GRF, or more accurately the hoof action force (HAF, i.e. the opposite of the GRF), can be expressed in an anatomical perspective, showing how it acts on the limb, regardless of the position of the horse.

The first aim of this study was to use the DHS to quantify 3D HAF and moments in horses trotting on right and left 4 m radius circles, and to compare the results obtained when the limb was on the inside or on the outside of the circle. The second aim was to test the hypothesis that extrasagittal forces and moments are reduced when horses are performing circles on a soft sand fibre surface compared to asphalt.

Materials and methods

Horses

Six horses (3 geldings and 3 males, mean ± standard deviation: weight 537 ± 40 kg and age 12.3 ± 4.6 years old) were used in this study. Three horses were Warmblood (French saddle) horses, two were Anglo-Arabians and one was a French trotter. Horses were selected so that the size of their front hooves was similar and matched the size of the DHS. All horses were clinically sound, with no subjectively observed gait abnormalities, and all were familiar with the technique of lungeing.

Experimental design

After both front hooves were trimmed by an experienced farrier, the right front hoof of each horse was equipped with the DHS, composed of four triaxial piezoelectric force sensors (model 9251A, Kistler) sandwiched between two aluminium plates (Chateau et al., 2009). The DHS was nailed into the hoof and its positioning, relying on the size and shape of the hoof, was adapted for each horse, in the same way as for standard shoeing. The total weight of the DHS with sensors was 490 g and its total height was 22 mm; the plane containing the sensors was positioned half way (11 mm). A non-instrumented horseshoe with matching height and weight was attached to the left front hoof. The wires were secured to the limb and connected to charge amplifiers (model 5073A411, Kistler), then to an analogue-to-digital converter (NI-USB 6218, National Instruments Corporation) connected to a notebook computer (Vaio VGN-P11Z, Sony), remotely monitored by Wi-Fi. Data was acquired at 7.8 kHz; the data acquisition system was placed behind the saddle in saddle-bags sewn to the saddle-cloth (Fig. 1). The total weight of the system, excluding the horseshoe, was ∼4.5 kg. The baseline of the charge amplifiers was set to zero with the right hoof off the ground before recording commenced.

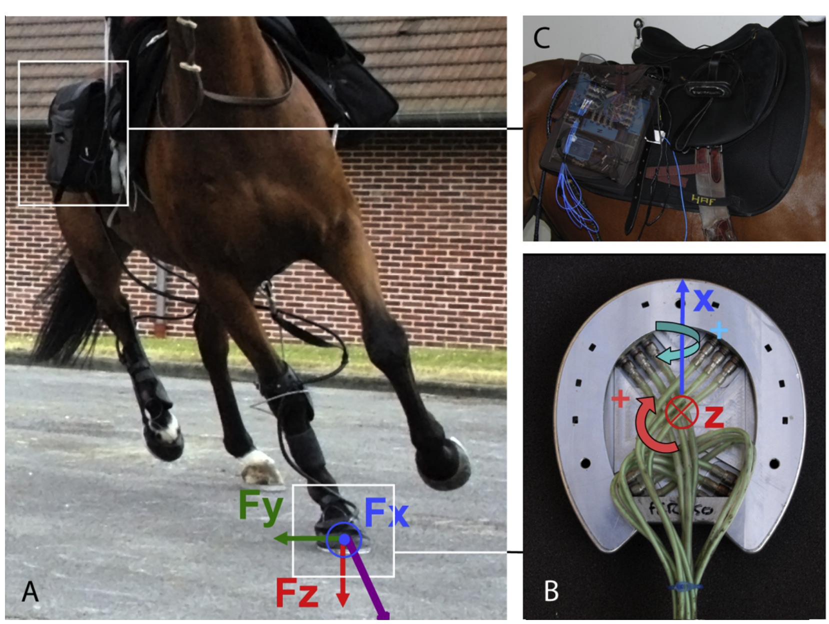

Fig. 1. Experimental set-up for the recording of hoof action force, moments and trajectory of the centre of pressure in six horses trotting on 4 m radius circles. (A) Right equipped forelimb of a horse circling on asphalt circle. Ground reaction force was expressed in a coordinate system in which the longitudinal force (Fx) was directed palmarodorsally, the transversal force (Fy) was directed medio-laterally and the vertical force (Fz) was directed proximo-distally (perpendicular to the plane of the shoe). (B) proximal view of the dynamometric horseshoe. Moments were expressed around the longitudinal (*X*) and vertical (*Z*) axes of the dynamometric horseshoe. (C) Acquisition system placed in saddle-bags.