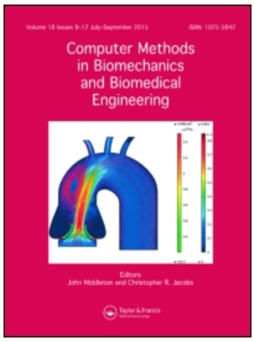

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Ground reaction force and impulses of fore and hindlimbs in horses at trot on an asphalt track: effects of an inclined (uphill) compared to a flat surface

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KEYWORDS Incline; uphill; horse; impulse; ground reaction force

1. Introduction

Trotting on incline (uphill) can be recommended in the context of rehabilitation of an injured horse. This exercise is thought to activate and train some muscles, especially in the hindlimbs, while relieving weight on the forelimbs.

Dutto et al. (2004), using a force plate, compared a flat vs. 10% inclined surface and observed a change in the force distribution between fore and hindlimbs: from 57–43 (fore-hind) % on flat to 52–48% on incline. Chateau et al. (2014) and Le Pley (2014), using 3D dynamometric horseshoes (DHS) on the same 5 horses trotting uphill and downhill along a 40 m and 7% slope asphalt area, quantified the longitudinal and vertical forces separately in the fore and hindlimbs. However the flat condition was not available for comparison. Furthermore none of these previous studies analysed the distribution of the impulses between the load-absorbing (braking) and propulsion phases of stance in each limb, which are essential parameters for assessing the interests of uphill exercises.

Therefore the objectives of the present investigation, based on the same study as Chateau et al. (2014) and Le Pley (2014), were to extend the analysis of the effects of trotting uphill by comparison with a flat surface, focusing on the distribution of forces between fore and hindlimbs and, for the first time, comparing the impulses between the braking and propulsion phases in both limbs.

2. Methods

Five clinically sound saddle horses (mean (SD): 9(3) years, 564(33) kg) were used. After trimming, the right fore and hind hooves were equipped with a dynamometric horseshoe (DHS), composed of 4 triaxial piezoelectric force sensors (9251A, Kistler) sandwiched between two aluminium plates [Chateau et al. 2014]. The ground reaction force was calculated as the sum of forces applied on each sensor, with the normal component perpendicular to the hoof's sole (positive downwards) and the parallel (longitudinal) component oriented palmaro-dorsally (positive forward). The DHS wires were connected to charge amplifiers (5073A411, Kistler) then to an analogue-to-digital converter (NI-USB 6218) plugged in a computer remotely controlled (Wi-Fi). Data were acquired at 7.8 kHz. The horse's speed was measured and recorded by a global positioning system (GPS, Racelogic RLVBSS 100) the antenna of which was glued to the horse's croup. The complete acquisition system was placed in saddle bags.

An inclined asphalt pavement (slope: 7%, i.e. 4°) of 40 m long was compared to a flat path of about the same length. After warming-up, the horses led by hand alternatively performed uphill and flat trot trials.

For each trial, speed and force data were recorded on 10 successive strides. A single trial was selected for each condition, based on the horse's average speed, in order that the

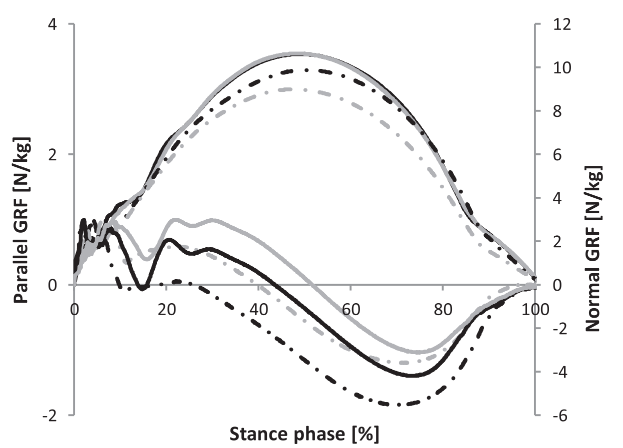

Figure 1. Mean values of the normal and parallel (longitudinal) components of the ground reaction force in the forelimb (solid line) and hindlimb (dotted line) of 5 horses trotting uphill (black) and flat (grey).

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Table 1. Means (SD) for the 5 horses of the 6 ratios calculated (expressed in %).

	Normal force distribution between fore and hindlimbs [%]		Distribution of the normal impulse between braking and propulsion phases [%]			
	Forelimb over total	Hindlimb over total	Braking over total Fore limb	Propulsion over total Fore limb	Braking over total Hindlimb	Propulsion over total Hindlimb
Flat	56 (2)	44(2)	54(8)	46(8)	37(10)	63(10)
Uphill	52(2)	48(2)	42(7)	58(7)	16(10)	84(10)

latter would be as much similar as possible between the two conditions.

In both limbs, the stance phase was delimited (100 N normal force threshold). Customised programmes developed in Matlab (MathWorks) were used to determine, for each limb, the average normal force over the stride (F_{str}), as well as the normal force impulse, total (I_t) and distinctly for the braking (I_b) and propulsion (I_p) phases of stance, integrating the normal force plot over the time period corresponding respectively to the positive and negative values of the

GRF's parallel component (Figure 1). Then the following ratios were calculated for each limb, illustrating: (1) the normal force distribution between fore and hindlimbs: F_{str} of the limb (fore or hind) over the total F_{str} (sum of the fore and hind limbs's F_{str}); (2) the distribution of the normal impulse between th braking and propulsion phases: I_b/I_t and I_p/I_t.

Linear mixed-effects regression models were used in order to compare uphill and flat conditions, taking into account repeated measurements per horse within each trial and adjusted for speed (SAS version 9.2). Significance was set at $p < 0.05$.

3. Results and discussion

The average speed was 3.3(0.4) m/s on flat and 3.6(0.3) m/s uphill. Stride parameters (time and length) were not significantly different between uphill and flat, whereas all ratios (Table 1) were ($p < 0.001$).

On flat, normal force distribution between fore and hindlimbs was 56–44%, while it was 52–48% when the horses were trotting uphill (8% average change). The uphill ratios are identical to those Dutto et al. (2004) obtained with a 10% slope over a range of speed (2.5 to 5 m/s). Incidentally, these authors chose to project the normal forces they measured (with a force-plate embedded in the inclined track) in order to obtain a 'vertical' force (Fz) to be compared with that measured on flat. For this, the following formula must be used: $Fz = Fn \cos\alpha - Fp \sin\alpha$, with Fn and Fp respectively the normal and parallel forces. In Dutto et al.' study ($\alpha = 5.7°$), $\cos\alpha$ and $\sin\alpha$ are respectively equal to 0.995 and 0.100. Therefore, as far as the normal force is concerned, being projected or not does not induce a significant difference, contrary to the parallel force. In the present study, we considered non-projected forces, i.e. forces measured in the reference frame of the shoe, which is the same as the track, as we think they are more relevant to assess the actual effects on the horse's locomotor system.

The force distribution between fore and hindlimbs on flat was slightly different from those measured by Dutto et al. (2004): 57–43% vs. 56–44% in the present study. This could be due a different format of the horses used in this previous study (3 Arabians and 1 Thoroughbred, 491(37) kg).

The effect of incline was large on the distribution of the normal impulse between braking and propulsion phases, and even larger in the hind limb compared to the forelimb, as expected. In the forelimb, the average change was 24% and the distribution actually reversed: from 54–46% (braking-propulsion) on flat to 42–58% uphill. In the hindlimb, the average change was 45%, with the normal impulse during propulsion being almost 85% of the total normal impulse when the horse was moving uphill, i.e. 5 times larger than during braking (only 1.7 times larger on flat).

4. Conclusions

Although exercising a horse uphill does not drastically reverse the fore-hind limb distribution (the normal force over the stride stays larger in the forelimb), the modification induced is significant (8%) with a shift to the hindquarters compared to flat. The major biomechanical effect of trotting uphill is a huge increase in the propulsive – i.e. muscular – effort (and a decrease in the braking effort) of the hindlimbs. The effects on the fore limbs are lesser; however trotting uphill increases the propulsive (vs. braking) part of the normal impulse, compared to flat, which has to be taken into account when rehabilitating a horse with an injured forelimb.

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