The Effect of Speed for Gait Analysis in the Horse

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Here we address the following questions:

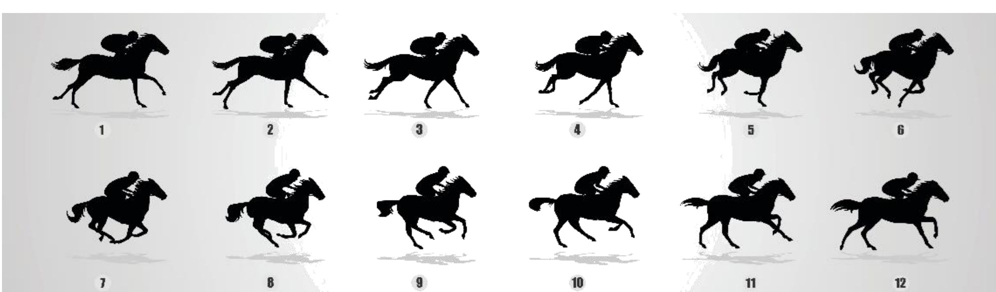
- How does speed affect gait?
- How does this matter for gait analysis?

The effect of speed for gait parameters in legged locomotion:
At first sight, it is all very intuitive: **the faster you run, the higher the forces** experienced by your legs during ground contact! This in turn affects the whole body. Forces are transmitted 'up along your legs' to provide your center of mass with support against gravity. But really: why exactly do the forces increase?

When dealing with first year university-level biomechanics, for example projectile motion, students get taught to treat vertical and horizontal movement separately. The simple reason: **gravity only acts along the vertical!**

But what does that mean for legged locomotion?

Support against gravity can only be provided when at least one of the limbs is in ground contact. Now, this gives us a crucial insight into why ground reaction forces (the force exerted from the ground onto us) increase in magnitude, the faster we move. First, our body mass remains unchanged with speed, and second, the time our feet are in contact with the ground gets smaller and smaller, the faster we run. More specifically, the proportion of time in ground contact in comparison to the time not in contact with the ground gets smaller. However, there is still the need to produce **sufficient vertical force to counteract gravity.** The only option we really have is to produce **more force in the reduced amount of time** that we have during limited ground contact!



In biomechanics, we use the term "dutyfactor" to describe the aforementioned proportion. And famously, it has been shown that "dutyfactor" and "peak vertical force" (the maximum vertical force produced in the middle of stance) are inversely related to each other[1]: when dutyfactor decreases, peak force increases! We use this relationship to predict peak forces whenever direct force measurements are tricky, for example during high speed gallop in horses[2,3].

Why do we care about speed when doing gait analysis!

The initial intuition, **increasing forces with increasing speed**, really turns out to make sense based on Newtonian mechanics. How does it matter for gait analysis in practical terms?

In the same way that force production (kinetics) changes with increasing speed, so do a whole host of gait parameters associated with movement (kinematics). Newton's second law is commonly abbreviated to "F = m ∘ a" or the acceleration a of an object with mass m is proportional to the force F acting on the object. Or even more simplistic: forces cause movement (amongst other things). So we can conclude that **with increasing speed, movement parameters change**! And it is of course **movement** that we **measure** with **gait analysis** systems!

Of course, let's just perform gait analysis at controlled, constant speed and we do not need to worry about speed! But what if we cannot do this: let's say we want to compare how a horse moves on different ground surfaces. A horse may adapt its speed to different external inputs. For example, soft, deep ground may make it harder (require more effort) to maintain speed or in contrast a different horse may not 'like' the high impact accelerations experienced on a hard surface[4]. So, if we want to draw fair conclusions about comparing two surfaces and how they affect gait, each horse may react differently. This increases the variability of our data. Even worse, some horses may change their speed within a data collection session, e.g. increasing or decreasing consistently or randomly, leading to an increased stride to stride variability. Our measurements then get more variable, resulting in reduced confidence in our results. So controlling speed as much as feasible is certainly not a bad idea!

Gait parameters that change with speed are stride length, stride frequency (the number of strides per second), stance time and duty factor (absolute or relative amount of ground contact time), protraction, retraction and joint angles. Which parameters are less susceptible to speed changes?

The Concept of Gait Symmetry

Gaits of four-legged animals are often categorized into **symmetrical and asymmetrical gaits**[5,6]. In symmetrical gaits the limbs on either side of the horse effectively "do the same thing", just shifted in time by 50% intervals. For example, take the two forelimbs of a horse in walk or trot. **Left and right limbs alternate consistently and in a symmetrical temporal manner**. In canter or gallop, however, left and right limbs behave differently: there is a lead leg and a trailing leg.

Within each gait, a horse can, however crucially the gait remains what it is, symmetrical gaits **remain symmetrical independent of speed**[7]! Combining our knowledge about the relationship between duty factor and peak vertical force[1–3] and about symmetrical gaits[5], we can conclude that the symmetry of left and right footfall timings, i.e. both limbs remaining in contact with the ground for the same length, **the left and right limb are providing equal amounts of vertical force and hence the same amount of up-down movement**. So, let's not concentrate on the kinematics of individual limbs, let's compare the left and right limb. Let's quantify movement symmetry!

Head nod and hip hike: practical examples of movement symmetry

Veterinarians have utilized the principle of gait symmetry for ever. Two commonly used parameters for detecting and grading lameness are head nod and hip hike[8,9]. Typically assessed in trotting horses, asymmetrical head movement – the head dropping to a lower height during ground contact of the non-lame leg ("down on sound") – is taken as a sign of forelimb lameness. Asymmetrical movement of the hips –increased movement amplitude of the hip on the side of the lame limb during non-lame ground contact– is a clear sign of hind limb lameness.

In a non-lame horse in a symmetrical gait, the left and right limb are supposed to do the same job (just not at the same time). Any deviation from symmetrical movement is a sign, that this is not happening. Most importantly, gravity has to be worked against, and in a 500 kg horse, this requires substantial forces. As a result, when a lame horse experiences pain (somewhere within one of the limbs), it will move in a manner that limits this pain. Wouldn't you? How do we limit pain during movement? Force is linked to movement, e.g. flexion and extension of a number of joints occurs during gait. This may either directly or indirectly be linked to pain when a joint or its surrounding soft tissues are injured . So, limiting force and hence limiting movement, appears like a smart move. Head nod and hip hike simply are visual cues of gait asymmetry that can be picked up most easily by eye. However, human perception is limited[10] and expert opinions are affected by changes in gait speed[7]. **Gait analysis provides precise values associated with head nod and hip hike and much more!**

Take home messages:

- **speed** has fundamental effects on **force** and **movement** parameters in legged animals.
- in a non-lame horse, a **symmetrical gait remains symmetrical across different speeds**. Movement symmetry parameters are consequently least susceptible to speed changes and are directly associated with principle signs of lameness: head nod and hip hike.
- our **state-of-the-art, sensor-based EquiGait** systems provide **precise and practical** measurements of **movement symmetry**.
- **EquiGait** systems go beyond head nod and hip hike: **withers and back movement** quantify **complex compensatory patterns** associated with **poor performance syndrome.**
- gait parameters such as **stride length, stride frequency** or parameters of individual limbs (e.g. **stance time, breakover time, protraction or retraction angle or time, height of the flight arc**, etc) are **highly susceptible to speed changes and require more careful consideration of speed changes**.

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