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Review

On the brink of daily clinical application of objective gait analysis: What evidence do we have so far from studies using an induced lameness model?

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ABSTRACT

Quantitative gait analysis has the potential to offer objective and unbiased gait information that can assist clinical decision-making. In recent years, a growing number of gait analysis systems have come onto the market, highlighting the demand for such technology in equine orthopaedics. However, it is imperative that the measured variables which are used as outcome parameters are supported by scientific evidence and that the interpretation of such measurements is backed by a proper understanding of the biomechanical principles of equine locomotion. This review, which is based on studies on experimentally induced lameness, summarises the currently most widely used methods for gait analysis and the available evidence concerning gait parameters that can be used to quantify gait changes due to lameness. These are discussed regarding their current and future potential for routine clinical application.

Introduction

The primary uses of the horse as sport and leisure animal are based on the capacity of its locomotor system. Disorders of that system, which become almost invariably clinically manifest as lameness, are one of the main reasons for equine veterinary consultation (Nielsen et al., 2014). It has also been reported that equine practitioners spend most of their working time on lameness examination (Loomans et al., 2007). Lameness can affect horses from all equestrian disciplines, leading to a financial loss for horse owners, days lost in training and/or competition (Jeffcott et al., 1982; Murray et al., 2006; Dyson et al., 2008; Egenvall et al., 2008, 2013).

In the context of this review, it is essential to define the term 'lameness' as a clinical interpretation of one or more signs indicating a pathological condition of the locomotor system (van Weeren et al., 2017). It is hence an alteration of the normal gait due to a functional or structural disorder in this system (Buchner, 2013), making it a clinical entity that is more than just a deviation of what can be seen as optimal gait. This definition of lameness challenges the veterinarian to discriminate between normal and abnormal (i.e. pathological) gait for a specific subject presented with a complaint of lameness. When confronted with animals without complaints, the challenge may be two-fold. First, to decide whether some gait irregularity and/or asymmetry is present. Second, to judge whether there is an underlying pathological condition or not, hence whether or not the irregularity/asymmetry should be considered a subclinical sign of lameness. In the majority of cases, standard practice has been and still is to accomplish this by subjective assessment of gait.

Although it is widely recognised that most gait events can be assessed efficiently by experienced clinicians through subjective visual examination (Dyson, 2014), any observer is hampered by limitations of the maximal temporal resolution of the human eye, limits to the perception of asymmetry (Parkes et al., 2009) and memorisation. Partially related to these limitations, a subjective visual evaluation suffers from some substantial drawbacks which are reflected in the low inter-observer agreement (Fuller et al., 2006; Hewetson et al., 2006; Keegan et al., 2010; Thomsen et al., 2010; McCracken et al., 2012; Keegan et al., 2013; Hammarberg et al., 2016) and the difficulty of consistent and interchangeable documentation of gait alterations. The latter is mainly due to the lack of uniformity in lameness rating scales (Wyn-Jones, 1988; AAEP, 1999; Dyson, 2011; Ross, 2013). A detailed overview of the limitations of subjective lameness assessment can be found in the review of Keegan (2007).

There is also a potential bias in the interpretation of nerve/joint blocks (Arkell et al., 2006), which can be aggravated by false

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positive and false negative results (Schumacher et al., 2014). An additional confounding issue may be the effect of nerve blocks in sound horses, although the few studies available (Kübber et al., 1994; Keegan et al., 1997; Drevemo et al., 1999; Liedtke et al., 2012) have reported somewhat contradictory results (Van de Water et al., 2016), and further investigation of the effect of diagnostic analgesia in sound horses is warranted.

These issues complicate lameness examinations and form confounding factors affecting clinical decision-making and hampering clinical orthopaedic research on the evaluation of diagnostic procedures, treatments and rehabilitation protocols.

Long restricted to sophisticated gait labs due to financial and practical constraints, measurement systems for equine gait are becoming more affordable and practically applicable, paving the way for routine application in daily clinical practice. This development raises new issues about the reliability of available systems and the validity and usefulness of the output of such systems. This review aims to summarise and critically evaluate current evidence related to methods of objective gait analysis in horses. This review is limited to techniques of gait analysis with potential for practical daily use in a clinical setting, of which evidence regarding the relevant outcome parameters and the applications and limitations are discussed. The emphasis is on data regarding objective gait parameters associated with lameness based on induced lameness models and the interpretation of objective gait assessment measurements. Essential areas for future development are also identified.

Searches

PubMed and Google Scholar were used as search engines to find suitable references for this review. The terms 'horse' and 'equine' were used in combination with the keywords 'kinematics'; 'kinetics'; 'gait analysis'; 'motion capture'; 'objective lameness'; 'lameness'; 'force plate'; 'pressure plate'; 'treadmill'; 'sensor'; 'IMU'; 'inertial measurement unit'; 'agreement'; 'assessment'; 'observer'. Articles were first selected based on their relevance to the topic of this review. Only manuscripts in the field of equine gait analysis were selected; studies using quantitative gait analysis tools for purposes other than lameness evaluation were excluded; as well as studies using theoretical models of lameness. Subsequently; the references in all selected articles were screened for further possibly relevant articles. As our purpose was the identification of the best parameters to give information about lameness; the majority of studies concerned experimental studies in which lameness was induced. This eliminated bias from possible multi-limb lameness; any disagreement regarding the exact location of pain; or inconsistencies of diagnostic methods to correctly identify the lame limb(s); as often encountered in clinical studies. No meta-analysis or statistical analysis was performed; this article constitutes a descriptive review.

Measuring techniques for objective gait assessment based on quantification of either forces (kinetics) or motion (kinematics)

Kinetics

In kinetic studies, the internal and external forces resulting from musculoskeletal work are analysed. The stationary force measuring platforms were among the first instruments used for objective lameness assessment (Morris and Seeherman, 1987; Aviad, 1988; Merkens and Schamhardt, 1988a) and are still considered as the 'gold standard' for kinetic gait analysis and the detection of (weight-bearing) lameness. They measure the three components in which the ground reaction force (GRF) can be decomposed in a Cartesian coordinate system. Force plates are precise and accurate instruments, but the data collection process is laborious and time-consuming.

Pressure measuring plates (van Heel et al., 2004) overcome some of these limitations by allowing collection of consecutive strides (if plate size is appropriate) and detailed mapping of the force distribution underneath the hoof. However, the sensors of a pressure plate cannot decompose the GRF in the three constituting elements and outcome will to a certain extent be influenced by shear forces as well. Furthermore, pressure plates are not as accurate and precise as force plates that use piezoelectric sensors (Oosterlinck et al., 2010) and this might be due to the lower sampling frequencies when compared to force plates and in some extent, to sensor activation thresholds (Oosterlinck et al., 2012). An alternative to force or pressure plates is the force measuring horseshoe. This idea dates from the late 50s (Björck, 1958), but was only further developed in the 90s (Roepstorff and Drevemo, 1993). Several types of force shoes have been developed and have been used successfully for measuring ground reaction forces (Kai et al., 2000), however, in most cases, size and weight of the shoe were critical limiting factors for their clinical applicability. More recently, a more advanced, lighter version has been used successfully during athletic activity (Munoz-Nates et al., 2015), but the technology is not yet widely available.

An attempt to overcome most of the limitations associated with stationary force plates was the development of a force measuring treadmill (Weishaupt et al., 2002), which allows measurements of consecutive strides of all four limbs simultaneously. The method enables accurate, quick and practical determination of GRF, but is only available in one specialised lab (University of Zurich, Switzerland), solely measures the vertical GRF and requires horses being accustomed to locomotion on a treadmill.

Overall, the currently available kinetic methods for the assessment of lameness are not ready for widespread clinical application, due to complexities in data collection and analysis. Hence, there is a need to develop measuring systems for quantifying kinetics in a clinical setting. In the meantime, the existing methods remain highly valued tools for researchers in the field of equine gait analysis.

Kinematics

Kinematics is the study of the movement of body segments during locomotion. The movement can be described as the displacement/velocity/acceleration as a function of time, of a body segment relative to a reference coordinate system, or it can represent the relation (i.e. angle) between body segments. Since their development, serial photography and cine film were almost immediately used for equine gait analysis (van Weeren, 2013) and in the so-called modern era of equine gait analysis, high speed film was the first technique used for recording equine locomotion using reflective skin markers, initially based on two-dimensional (2D) analysis (Fredricson and Drevemo, 1971). Further technological developments led to the introduction of more sophisticated methods of gait analysis (Kastner et al., 1990; van Weeren et al., 1990b) that allowed for higher recording speeds (up to 300 Hz) in three dimensions (3D). Nowadays, the most widely used systems are the Oqus/Qhorse (Qualisys AB) system, the Vantage (Vicon) system and the Motion Analysis (Motion Analysis Systems) system. Three-dimensional optical motion capture (OMC) uses several (mostly infrared) cameras positioned around a calibrated measuring volume and records and automatically tracks the position of several reflective markers simultaneously, correcting for perspective and distortion errors and other artefacts that might influence single-camera 2D systems. The 3D systems are highly accurate and precise and are therefore considered the 'gold standard' for kinematic analysis.