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Article

Fetlock Joint Angle Pattern and Range of Motion Quantification Using Two Synchronized Wearable Inertial Sensors per Limb in Sound Horses and Horses with Single Limb Naturally Occurring Lameness

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Simple Summary: The incidence of disease affecting fetlock joint and associated structures is high in the equine athlete due to the large loads acting on the joint during athletic activity. Therefore, study of the movement of this joint (flexion and extension) is a significant matter of interest. To date, fetlock joint angle pattern and range of motion in horses have been quantified using optical motion capture (OMC). These systems use a number of cameras to film the subject and reconstruct the movement trajectories into a computer model. They are very accurate and precise but require expensive equipment and a laboratory setting. The use of inertial measurement unit (IMU) systems in the field of motion analysis is now widespread. IMU systems use a number of sensors in order to derive the position of the body in the space; they have the advantage of being able to collect kinematic spatio-temporal data when the animal is moving overground with fewer constraints than in a gait lab. To the authors' best knowledge there are no studies using IMUs sensors in order to record relative fetlock joint angles in horses moving overground. In this study, we wanted first to validate the use of IMUs for kinematic detection of fetlock joint movement on the sagittal axis comparing it to the OMC. Then, we intended to discuss fetlock joint range of motion variability quantified by the IMU system under investigation in lame and sound horses. The IMU system was able to record fetlock joint range of motion just as does the bi-dimensional OMC at walk and trot, in both sound and lame horses. IMU system quantification of fetlock joint range of motion confirmed that the variability was mainly due to lameness in our population of horses. Quantifying joint angle patterns with an IMU system instead of using OMC has the advantage of furnishing real-time bio-feedback of kinematic data. The system can handle various equine gaits and clinical and training conditions outside of expensive laboratory circumstances.

Abstract: Fetlock joint angle (FJA) pattern is a sensitive indicator of lameness. The first aim of this study is to describe a network of inertial measurement units system (IMUs) for quantifying FJA simultaneously in all limbs. The second aim is to evaluate the accuracy of IMUs for quantifying the sagittal plane FJA overground in comparison to bi-dimensional (2-D) optical motion capture (OMC). 14 horses (7 free from lameness and 7 lame) were enrolled and analyzed with both systems at walk and trot on a firm surface. All enrolled horses were instrumented with 8 IMUs (a pair for each limb) positioned at the dorsal aspect of the metacarpal/metatarsal bone and pastern and acquiring data at 200 Hz. Passive markers were glued on the center of rotation of carpus/tarsus, fetlock, and distal interphalangeal joint, and video footages were captured at 60 Hz and digitalized for OMC acquisition. The IMU system accuracy was reported as Root Mean Square Error (RMSE) and Pearson Correlation Coefficient (PCC). The Granger Causality Test (GCT) and the Bland–Altman analysis were computed between the IMUs and OMC patterns to determine the agreement between the two systems. The proposed IMU system was able to provide FJAs in all limbs using a patented method for sensor calibration and related algorithms. Fetlock joint range of motion (FJROM) variability of three consecutive strides was analyzed in the population through 3-way ANOVA. FJA patterns

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quantified by IMUs demonstrated high accuracy at the walk (RMSE 8.23° ± 3.74°; PCC 0.95 ± 0.03) and trot (RMSE 9.44° ± 3.96°; PCC 0.96 ± 0.02) on both sound (RMSE 7.91° ± 3.19°; PCC 0.97 ± 0.03) and lame horses (RMSE 9.78° ± 4.33°; PCC 0.95 ± 0.03). The two systems' measurements agreed (mean bias around 0) and produced patterns that were in temporal agreement in 97.33% of the cases ($p < 0.01$). The main source of variability between left and right FJROM in the population was the presence of lameness ($p < 0.0001$) and accounted for 28.46% of this total variation. IMUs system accurately quantified sagittal plane FJA at walk and trot in both sound and lame horses.

Keywords: kinematics; joint angles; biofeedback; locomotion; fetlock; IMU; variability; range of motion; gait analysis; lameness

1. Introduction

Equine fetlock is the rotary joint which experiences the largest load during locomotion, irrespectively of the gait [1]. Functionally, the fetlock joint is part of the equine limb elastic suspensory apparatus whose biomechanical behavior is explained by the distal spring-mass model [2]. Based on this, horses can run in an almost passive manner, thanks to the elastic energy storage properties of the suspensory ligament and digital flexor tendons [1–3]. Movement in the sagittal plane predominates in the fetlock joint and consists in flexion (during most of the swing phase of the stride) and extension (during the end of the swing phase and the stance phase) [4]. The extension of the joint determines the load on associated tendons and ligaments and, as a consequence, the incidence of disorders affecting the fetlock is reported to be high in the equine athletes [5–7].

Dynamic changes of sagittal fetlock joint angle (FJA) during locomotion, also referred to as fetlock joint angle pattern (FJAP), have been described at walk and trot in sound horses and in horses with experimentally induced forelimb lameness [8,9]. Of note, these observations have not been validated in a cohort of horses with naturally occurring lameness to date. All currently available data on FJAP have been acquired/obtained by means of 2-D and 3-D optical motion capture (OMC) technology, whose application requires highly standardized laboratory settings and is limited by space constraints, lighting conditions, and the possibility to perform only specific tests [10] There is growing interest in portable devices that can be used as OMC surrogates for gait assessment/analysis, in both research and clinical settings, and new scientific evidence on this subject is warranted.

Inertial sensors are devices characterized by small size and limited cost where an accelerometer or a gyroscope are used to transduce the orientation and the inclination of a body segment into measurable spatio-temporal kinematic signals at high sampling rates (~200 Hz) [11]. Wearable inertial sensor measurement units (IMUs) allow wireless data transmission with the advantage of bypassing high costs and technical limitations associated with OMC technology. For these reasons, they have been largely employed in equine gait analysis and, more recently, as an aid in equine lameness detection in the field [11,12]. IMU systems (IMUs) have been placed on the distal extremity to assess distal limb displacement [13], translation of metacarpus as a rigid segment [14], protraction and retraction angles [15], as well as for temporal and spatial variables detection of the strides during different gaits [16–18]. To the authors' knowledge, there are no reported data investigating FJAP using IMUs in horses.

The present work was undertaken under the hypothesis that equine gait analysis data concerning FJAP acquired with commercially available IMUs are comparable to those obtained with 2-D OMC. Based on the current literature, and on the possible relevance of FJAP asymmetry in equine lameness, we also hypothesized that FJAP differed in sound horses vs. horses with naturally occurring lameness. To pursue these aims, we have described and compared FJAP data from 7 sound and 7 lame horses, contemporarily acquired using a wireless 8-sensor IMU-system and with a 2-D OMC.