DEVELOPMENT OF A WEARABLE GAIT DETECTION SYSTEM FOR RACEHORSES

Jin-Huat Low[1], Vanessa Wei-Lin Mak[1], Bronte Forbes[2], Fernanda Sepulveda[2], and Chen-Hua Yeow[1]

Department of Biomedical Engineering, National University of Singapore, Singapore, Singapore[1]
Singapore Turf Club, Singapore, Singapore[2]

Biomechanical analysis of racehorses is important in quantifying and maintaining performance. Early detection of lameness is crucial to ensure the wellbeing and proper rehabilitation of horses, and to prevent exacerbation of the condition. The purpose of this study was to develop a limb-mounted portable wireless sensor system to investigate equine biomechanics and detect the presence of lameness in racehorses based on the lower limb kinematics. The preliminary results showed that the system can detect trotting gait cycles accurately and the lame racehorse showed a reduction in hoof flexion and extension as compared to normal racehorse.

KEY WORDS: horse, lameness, gait cycle, hoof flexion, hoof extension.

INTRODUCTION: Biomechanical analysis of racehorses is important in maintaining performance and wellbeing of the horse, as well as to identify, manage, and prevent injury. In practice, there are many methods, through observation and clinical examinations, by which veterinarians diagnose lameness. Several studies reported low reliability in subjective assessment of lameness due to bias in interpretation of results (Arkell et al., 2006; Hewetson et al., 2006). It may be difficult for veterinarians, even experienced ones, to detect mild lameness in horses due to subtle gait irregularities. Early detection of lameness is crucial to ensure the wellbeing and proper rehabilitation of horses, and to prevent exacerbation of the condition.

Dynamic analysis includes the measurement of parameters like acceleration (Burla et al., 2014), joint angles and range of motion (Galisteo et al., 1997), ground reaction force (Hodson et al., 2000) and vertical displacement (double integration of acceleration allows estimation of displacement) (Pfau et al., 2013), to evaluate lameness.

In the research field for equine biomechanics, the study of joint angle and range of motion parameters are specifically used in techniques like optical motion capture, high-speed cameras, and video-based analysis. The equipment for these methods is costly, bulky and may require a closed environment for testing. On the other hand, inertial sensors can be used to measure kinematics of movement. These sensors are small, lightweight and easily mounted on subjects. It allows for data collection outdoors to observe gait irregularities that may not surface in a closed environment, and objectively detect and evaluate lameness in a natural environment. The objective of this project is to develop a body-mounted sensors system to investigate equine biomechanics (absolute flexion and extension angles) of racehorses and detect the presence of lameness in racehorses, based on the lower limb kinematics. The preliminary results presented in this paper showed the capability of the system to detect phases of the gait cycle and the difference in hoof angles between lame and sound racehorses.

METHODS: The body-mounted sensors system comprises of four identical sensor units and a receiver that is connected to a laptop. Each sensor unit comprises of a 9 degrees-of-freedom inertial sensor (Pololu MinIMU-9 v3), XBee RF module (XBee 2mW PCB Antenna – Series 2 (ZigBee Mesh)), microcontroller (Arduino Pro Mini (3.3V, 8 MHz) with ATmega328), and polymer lithium ion battery (1000mAh, 3.7V). The sensor units (38g) were encased in a hard plastic box (20g) with dimensions of 36mm by 72mm by 55mm (height by width by depth) and weighs 58g in total. The sensor units were mounted on the horses with the use of double-sided Velcro tape and secured with Micropore surgical tape (Figure 1). The percentage error in sagittal plane motion as compared to commercial optical motion capture system (Vicon MX system, USA) is 4.67±2.53%, which means that the proposed sensors are fairly accurate for outdoor capture.

Three racehorses (two lame, one sound) were recruited in this study. The horses were led by hand at the trot with four runs on a leveled tarmac ground. The motion-sensor system recorded the movement of limbs under two test conditions of right front hoof, left front hoof, right forearm, left forearm. The four sensor units were paired to a single receiver which allows for time settings to be synchronized across all sensor units. A moving average filter was used to smooth the data, and the mean peak hoof flexion and extension (absolute angle - the angle on level ground) were obtained by averaging all cycles across all runs. The stance phase is defined as the gait phase that lasts from heel-strike to toe-off. The swing phase is defined as the non-weight-bearing phase of gait. These gait phases were determined by observation of limb movement in video recordings of the racehorses.

RESULTS: Our findings showed that the system could detect gait cycle patterns that concurred with descriptions mentioned in the literature (Figure 2; Hodson et al., 2000). The transition between stance and swing phase is indicated by the sharp increase in gradient of the hoof, when the limb is in retraction. This corresponds to heel-off and toe-off phases in the ipsilateral limb. During initial swing, retraction of the ipsilateral limb occurs as toe-down and loading phases take place in the contralateral limb. The ipsilateral limb continues to protract through mid-swing. The contralateral limb is concurrently transitioning from stance phase to the heel-off and toe-off phases. At the end of swing, the ipsilateral limb transitions into the toe-down and loading phases. The normal racehorse showed a larger hoof flexion and extension angle as compared to lame horse (Table 1; Figure 3).

Table 1
Comparison of mean peak flexion and extension values for right hoof flight arcs between racehorses during trotting

No.	Clinical Condition	Flexion (°)	Extension (°)
Racehorse 1	Lame (left forelimb)	92.26 ± 3.84	-23.22 ± 7.76
Racehorse 2	Lame	79.99 ± 3.02	-17.40 ± 2.00
Racehorse 3	Sound	94.89 ± 1.52	-28.03 ± 4.97

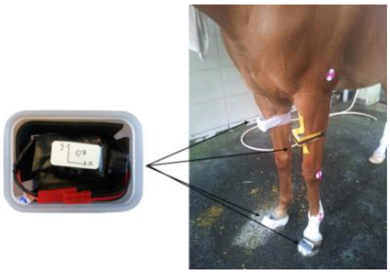

Figure 1: The sensor unit in the casing (left) and the four sensors mounted on forearm and hoof (right).

DISCUSSION:

Gait Cycle

The results (Figure 2) are consistent with descriptions from literature review (Keegan, 2005; Hodson et al., 2000; Kramer & Keegan, 2004). Maximal extension of the proximal forelimb occurs just before initial ground contact at the distal end. Rapid deceleration of the hoof occurs after initial ground contact gives rise to a shock wave that travels upwards through the bones and joints during the loading phase. The forelimb is gradually loaded during the rest of the stance phase. It slowly accepts more bodyweight and prepares for heel-off and toe-off phases. The bone and joints in the forelimb are more prone to injury during the initial ground contact. Muscles and ligaments in the forelimb are more prone to injury during the loading phase. The forearm continues to flex from the beginning of stance phase, acting as a propulsion mechanism for take-off at the end of stance phase. The elastic soft tissues in the fetlock joint are stretched, storing energy that is released to allow for the distal joints (hoof) to flex during swing phase.

During heel-off, the hoof rotates about the toe of the hoof. At the end of stance phase, the bodyweight of horse is transferred to the contralateral forelimb. During swing phase, the forelimb rotates about the shoulder. All the joints in the forelimbs are flexed as the hoof leaves the ground due to release of elastic energy in the flexor tendons and suspensory ligaments. Maximal flexion of the hoof occurs just before mid-swing. The forward momentum of the moving horse causes extension of the forearm as it rotates about the shoulder. Muscle contraction approaching the end of swing phase reduces forward movement at proximal end of the limb, allowing distal limbs to advance to maximal extension.

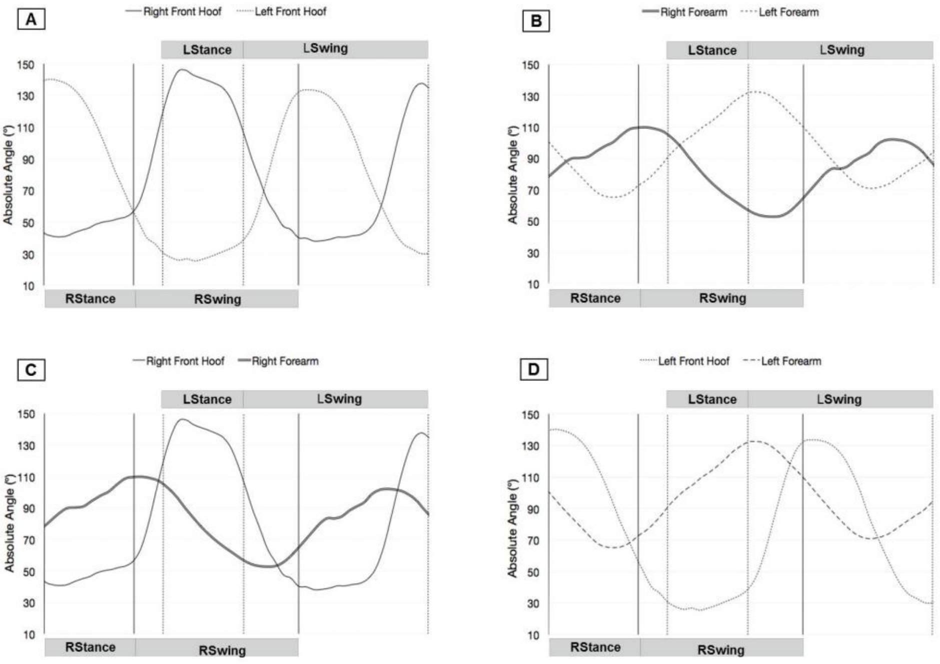

Figure 2: Hoof angle graphs of racehorse 3 at trot (A) left and right front hoof, (B) left and right forearm, (C) right front hoof and forearm, and (D) left front hoof and forearm.

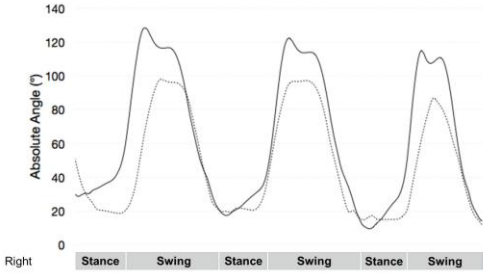

Figure 3: The representative graph of right front hoof kinematic data from sound racehorse (*solid line*) and lame racehorse (*dotted line*).

Lameness

Hoof movement has been studied in sound and lame horses to evaluate lameness using acceleration and angular range of motion as parameters (Moorman et al., 2013). Literature findings suggest that during the end of stance phase of a stride, a lame forelimb shows a reduction in extent of retraction (Kramer & Keegan, 2004). Results from a lame racehorse (racehorse 2; Table 1) showed a 15.7% reduction in average hoof flexion as compared to the sound racehorse, concurring with descriptions from literature. Results from the other lame horse (racehorse 1) show a 2.77% reduction in average hoof flexion value, which suggests that the right front limb of racehorse 1 is relatively normal which is expected, as it is known that the horse suffers from lameness in the left forelimb. A larger sample size is required to determine if the findings are consistent and repeatable.

Some kinematic parameters to consider while analyzing data in later stages include temporal parameters like duration of stance and swing phase and head movement. Horses with mild to moderate lameness show increased stance duration in order to reduce the peak amount of load on the affected limb which results in a proportional decrease in duration of swing phase (Kramer & Keegan, 2004). The trot is a relatively stable gait and little head movement is observed for sound horses. Keegan describes the head movement pattern of a sound trotting horse (Keegan, 2005). The head moves upward and downward twice during single stride. At the beginning of stance, the head continues its downward movement from the previous swing phase. It reaches a minimum during mid-stance and begins to move upwards till the starting of swing phase. The maximum upward movement is achieved just before initial ground contact of the contralateral limb. The difference between lame and sound horses is the head height at mid-stance or after toe-off.

CONCLUSION: This study developed a gait detection system to analyze the movement of racehorses and indicated the possibility to use the hoof angles as an indicator of lameness. Placement of sensors on the limbs of the horse to study gait patterns provides similar findings as reported in literature. Average hoof flexion and extension values show potential in evaluation of lameness due to consistency with literature findings. A larger sample size is required to meaningfully interpret the results. Also, apart from evaluating forelimb lameness, a study on different track surfaces will also be conducted to observe any significant differences in kinematic parameters between sound and lame horses. This will be useful for trainers to understand how different track surfaces produce different types of injuries.

REFERENCES:

Arkell, M., Archer, R.M., Guitian, F.J. & May, S.A. (2006) Evidence of bias affecting the interpretation of the results of local anaesthetic nerve blocks when assessing lameness in horses. *Vet. Rec.* 159, 346-349

Burla, J.B., Ostertag, A., Westerath, H.S., & Hillmann, E. (2014) Gait determination and activity measurement in horses using an accelerometer. Computers and Electronics in Agriculture 102 (2014) 127–133

Galisteo, A.M., Cano, M.R., MORALES, J.L., Miro, F., Vivo, J., & Aguera, E. (1997) Kinematics in horses at the trot before and after an induced forelimb supporting lameness. *Equine vet. J., Suppl.* 23 (1997) 97-101

Hewetson, M., Christley, R.M., Hunt, I.D. and Voute, L.C. (2006) Investigations of the reliability of observational gait analysis for the assessment of lameness in horses. *Vet. Rec.* 158, 852-857

Hodson, E., Clayton, H.M., & Lanovaz, J.L. (2000) The forelimb in walking horses: 1. Kinematics and ground reaction forces. *Equine vet. J.* (2000) 32(4) 287-294

Keegan, K.G. (2005) Head Movement Pattern in Horses with Forelimb and Hindlimb Lameness. In-Depth: Lameness in Motion. *AAEP Proceedings*, Vol. 52, pp. 114-120

Kramer, J. & Keegan, K.G. (2004) Kinematics of Lameness. In: *Equine sports medicine and surgery: basic and clinical sciences of the equine athlete*. St. Louis: Saunders; 2004:231-246

Moorman, V.J., Reiser, R.F., Peterson, M.L., McIlwraith, C.W., & Kawcak, C.E. (2013) Effect of forelimb lameness on hoof kinematics of horses at a walk. *Am J Vet Res.* 2013 Sep; 74(9):1192-7

Pfau, T., Starke, S.D., Tröster, S., & Roepstorff, L. (2013) Estimation of vertical tuber coxae movement in the horse from a single inertial measurement unit. *The Veterinary Journal* 198 (2013) 498-503