Exploration of Rapid Tetrapod Running Performance utilizing Inertial Measurement Units

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1 Introduction

Human athletes run only half as fast as greyhounds, maintaining constant average running speeds of circa 29 km/h versus 65 km/h [1], respectively. Rapid changes in direction during running increase the risk of injury as greater centrifugal forces act on limbs and torso. Accordingly the sudden transitions in agile manoeuvres of quadrupeds such as greyhounds results in them being more prone to sustain injuries than human athletes due to the very high peak forces developed upon contact (over a brief stance duration). Greyhounds have been a model system for several interesting and long-standing hypotheses of legged animal locomotion, such as the function of back bending. The bending axis of galloping greyhounds is “dorsal” to the thoracic activity suggesting air could be pumped in and out of the lung during each stride [2]. Back bending could result in increases in stride length via added degrees of freedom in the spine, when compared with an immobilized back.

The maximum stress exerted during galloping of each leg were calculated [3] from frozen cadavers and high video footage of greyhound’s rotatory galloping in 1982 with measurements of the linear and angular acceleration of the legs. Cadavers were also used to provide quantitative anatomical data on the muscle–tendon architecture and geometry of pelvic limb to calculate pelvic joint EMA [4]. Furthermore, to calculate peak reaction forces acting on their limbs on the bend and straight sections, the footfall timing of greyhounds was measured [5]. It is concluded that that the animals do not reduce speed or the excessive forces acting on their limbs while running around a bend [5, 6]. Stride length as another speed indicator was not taken into account, however. Current methods of studying rapid quadrupedal movement involve kinematics analysis by high speed video and the measurement of ground reaction forces using a force plate. Rapid quadrupedal movement on granular media and other irregular terrain is under-explored. To measure GRF associated with acceleration and deceleration, greyhounds, were encouraged to run across a trackway consisting of a downward and upward sloping ramp equipped with multiple embedded force plates. Although force plates provide highly accurate kinetic data in the study of animal locomotion, they are not always practical to deploy. For instance, it is often not possible to embed force plates in irregular terrains characteristic of most ecologically relevant animals’ natural habitat. An alternative method to studying rapid tetrapod running is utilizing an inertial measurement unit (IMU) equipped with a tri-axial accelerometer to analyze accelerations associated with different quadruped gaits (Fig. 1). IMUs have been previously placed on relatively large mammals, such as for analysis of equine locomotion [7], and were shown to have a high accuracy and precision in determination of hind leg footfall timing [7]. However when it comes to lighter, faster, and more agile tetrapods, such as racing greyhounds, this technique is under-explored. The purpose of this study is to study the biomechanics of rapid tetrapod locomotion and apply them to robot design where advantageous [8].

2 Methodology

In this study, a tri-axial accelerometer is utilized to analyzing rapid running locomotion dynamics of a greyhound (Fig 1. A). Kinematics data from videography of the entire race was recorded for calibration and data analysis. A paw print analysis was recorded and made in training race condition for data calibration.

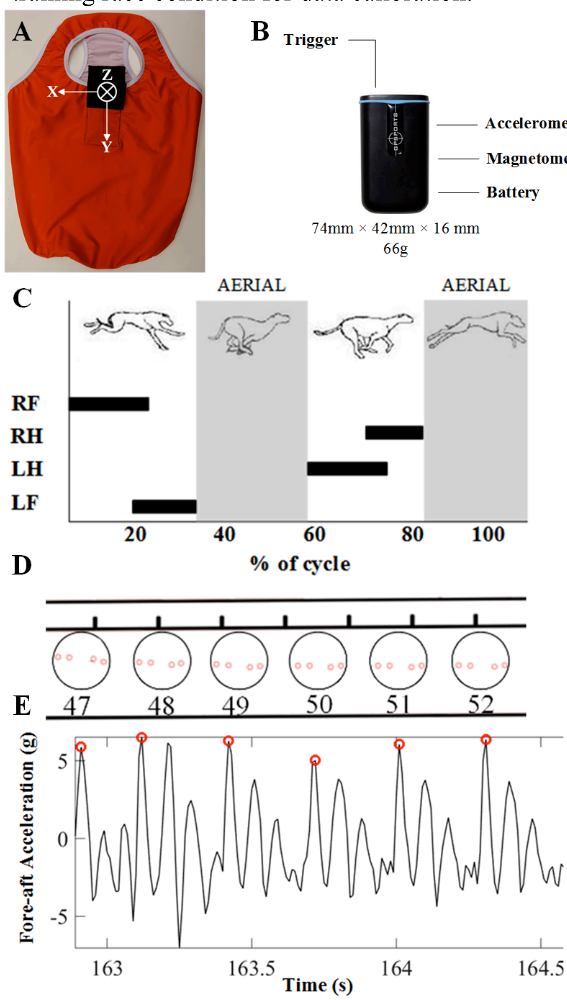

Figure 1: Racing jacket with embedded sewn pocket and corresponding axes on the body (A). Measurement instrumentation for capturing running dynamics with components of IMU (B). Footfall pattern of a stride of a greyhound running at Back

Straight (shaded area indicates purely aerial phase of the stride) (C). Paw prints during six cycles of a greyhound running at Back Straight (D). Fore-aft accelerations as a function of time coinciding with paw prints (E).

The paw prints of the greyhound on a sandy-loam surface of a race track are also analyzed to sync acceleration data with each individual paw print and to measure the stride length of the sprinting animal. Constant velocity running (defined as no more than 10% fluctuation in instantaneous speed across a minimum of three strides) was investigated through analysis of the fore-aft (Y-axis) acceleration data obtained during the greyhound running in the Back Straight. Experiments were conducted at Wentworth Park racetrack, Sydney, NSW..The distance of the race is approximately 280m in length with a duration of 26 s. A tri-axial accelerometer (GPSports/SPI Pro X with 15 Hz position GPS) capable of measuring forces up to 16G at a sampling frequency of 100 Hz and a tri-axial magnetometer with sampling frequency of 50 Hz were deployed to analyze the sprinting locomotion dynamics of a greyhound in racing condition (Fig 1.A). The accelerometer was embedded in a sewn pocket located on within the greyhound's racing jacket (Fig 1.B and C) and positioned on the animal's back near the center of mass (Fig 1.A). Videography of the entire race was carried out with a high-speed video camera at 250 frames per seconds (Sony DSC-RX10III). The full race video and high-speed video of the run at the second straight of race track were also recorded. To compare the stride lengths of the straight running and bend sections ten strides were selected from the Back Straight and ten strides from the apex of the Northern Turn. To ascertain whether there is a significant difference between the stride lengths of running versus turning, a one-way Analysis of Variance (ANOVA) was performed. The significance was set at P<0•05. Paw prints were measured firstly to obtain a track map which then facilitated alignment of each paw print with the acceleration data (Fig 1 C, D) and secondly to compare the stride length of a greyhound running in straight and bend section. The stride length is also defined as the distance from the initial contact point of one paw to the next initial contact point of the same paw for each stride. All experiments were approved by official ethics protocols. We did not observe any adverse effects on animal behavior due to wearing of the jacket, which is routine in training and race. Moreover, the weight of the device being only 0.066kg, it is two orders of magnitude smaller compared to animal body mass of 40kg.

3 Results and discussion

The fore-aft acceleration as a function of time for the first six strides of a run in the Back Straight is shown in Figure 1 E. For each stride we observe three reoccurring local peaks of descending magnitude. These maxima were mostly in the range of approximately 4.5 g to 6.5 g and corresponded to a stride each, in line with foot prints (Fig. 1 D, E). This result correlates with previous findings that fast quadrupeds have approximately three strides per second in constant average velocity running [9]. The observed three bursts in fore-aft acceleration associated with the propulsive effort of the hind-legs (Fig. 1 D, E) have also seen in cheetahs. Comparison of the high-speed video of running at the Back Straight (Fig. 1 C-E) showed that peaks in the forward acceleration were observed when the hind-legs contact the ground. Based on preliminary data from the accelerometer the mean stride frequency in Back Straight (M= 3.4 Hz, SD= 0.2) and Northern turn (M= 3.8 Hz, SD= 0.5) was calculated and did not show a significant difference in an ANOVA [F (1, 20) = 1.6, P= 0.2] and t-test [t (10) = 1.2, P= 0.1]. Comparing this with measurements of stride length in both conditions allows for an estimate of the running speed. The mean stride lengths in Back Straight (M=5.53 m, SD=0.03) and Northern turn (M=5.02 m, SD=0.08) was calculated. The result of ANOVA test showed a significant difference between the stride lengths in straight and bend section [F (1, 18) =20.7, P=0.0002]. The result of a post ANOVA analysis (t-test: Paired Two Samples for Means) suggests that stride lengths at straight section are significantly greater than those of a turn section [t (9) =4.1, P=0.001]. Results from paw print analysis suggest that greyhounds exhibit greater stride length when running in the straight section than when going around the bend.

The conventional methods of gait analysis such as using force plates are not always a feasible option in locomotion studies, particularly on irregular terrains or for animals in their natural habitats. To overcome these difficulties, which exist in studying greyhounds running on real race tracks, a tri-axial accelerometer was used in this study. Results from preliminary measurements suggest that for a given stride duration greyhounds take greater strides when running straight versus when going around a bend. Further IMU measurements are now required to focus in on within stride dynamics of the turn on the level of individual foot strikes to decipher peak forces associated with footfall patterns captured with high-speed videography.

4 Reference

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