Simulating theoretical jerk by numerical modelling for greyhound racing

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Abstract: This paper presents the jerk dynamics of a racing greyhound running alone by simulating the centrifugal acceleration for different race scenarios and track path design options. Simulation parameters were defined from the real-world greyhound track designs and greyhound race data to provide relevant results for race conditions. Virtual race scenarios were created to achieve maximum results. By simulating greyhound strides as discrete events, the theoretical jerk was calculated. The results show how different track design conditions and race scenarios can affect greyhound dynamics for the track bends. This can be applied to better understand and improve track design for improved dynamics with a view to reduce the frequency and severity of injuries.

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1 INTRODUCTION

This paper relates track shape design variables specific to round track to greyhound centrifugal acceleration jerk dynamics. This has many implications to racing greyhound injuries during track path navigation. Researchers showed that track shape specially bends have an effect on the racing greyhound injury rates (Mahadavi et al., 2018). Jerk as the time derivative of acceleration often linked to vibration and can cause injuries (Hayati et al., 2020). A body can feel jerk as it can feel acceleration and both are different (Pendrill et al., 2020).

This is a fundamental question in greyhound racing how greyhounds are coping with a particular oval track path design. This was not explored by previous researchers to come up with a parameter which can be easily used to benchmark track path designs. Jerk is used in many areas to determine for safe operating conditions or as a measure to know the sudden force on the physical body in motion (Eager et al., 2016).

Running on a straight path is fundamentally different from running on a curved path. Many circuit tracks have both curve and straight track sections for the track path. Only a few tracks are fully circular in design so there are no straight sections. One main difference between a fully straight and oval track is in the oval track there is the dominant centrifugal force component when going around the bend. This is also accompanied by a large load on the greyhound limbs during galloping leg strikes on the track surface (Hasti et al., 2019). The centrifugal force is experienced in the form of jerk force when there is a change and when happens abruptly can raise the jerk force significantly. In an ideal world, going from straight to a curve of the constant radius would require a transition known as a transition curve as the inertia of the body would otherwise resist sudden change in the centrifugal force. However, depending on the track run path and resulting greyhound path of choice the transition curve varies greatly. Some transition curves are more prone to raise the jerk value than others. For particular track path design, a set number of dominant transition curves would satisfy track boundary conditions. As a result, depending on the track shape greyhound would experience different jerk levels from track to track.

2 METHOD

The goal of this research was to formulate and verify oval track conditions in the light of greyhound jerk dynamics by numerically modelling greyhound stride dynamics. To achieve it we used various data from the field to understand greyhound galloping as well as its trajectory when running inside oval track conditions. These data were acquired from the field and then used for modelling greyhound centrifugal acceleration jerk and greyhound trajectory for oval track conditions. Furthermore, the greyhound data from the field became the foundation for applying limit conditions for the models.

Three distinct types of data were used from the greyhound racing to extract greyhound run conditions at the track. First data came from the track survey data which were modelled in the SolidWorks software package to know the track parameters such as track bend radius, track straight length and presence of a transition curve between the bend and straight. Later, greyhound paw prints survey data from the track were measured which gave an understanding of greyhound stride lengths. Finally, greyhound location tracking in X and Y coordinates data was analysed for extracting greyhound trajectory and speed conditions.

2.1 Simulation Model

Greyhound trajectory can be represented by an arbitrary point moving in time that has a state vector that gives the direction of greyhound heading and greyhound stride length also known as tangent vector (Hossain et al., 2020). For this to work, we will have to assume n number of strides required from the start box location to complete the trajectory where the arbitrary point as defined by the state vector represents the location coordinates. With each subsequent stride commencing with a first stride the state vector is calculated that updates the arbitrary point location coordinates. If the greyhound is moving in a straight line, then the state vector retains its current direction. When the greyhound is moving in a constant radius bend the state vector also maintains a constant change in its direction. For other scenarios such as Euler transition and change in turning radius from one stride to the next the state vector direction (greyhound heading) and length (stride length) also changed accordingly. For all cases the state vector is a function of greyhound stride length, turning radius, greyhound heading deflection and heading deflection acceleration.

One way to extract greyhound dynamic states is by looking into and analysing its trajectory points. In the absence of precise trajectory points, greyhound dynamic states in each stride can be modelled by defining greyhound running path segments in terms of derivatives. Greyhound dynamic states at the track such as curvature, yaw and run distance can be calculated by modelling the rate of change of these variables for different track segments. For instance, the Eq. 1 can be used for calculating instantaneous nth stride turning curvature for any arbitrary running path segment by plugging in initial curvature, curvature rate and run distance for the segment.

$$\text{Instantaneous turning curvature} = \text{initial curvature for run path segment}_i + (\text{curvature rate for run path segment}_i * \text{run distance for run path segment}_i) \quad (1)$$

2.2 Model Scope

The simulation models allowed generating of dynamics results of case studies for different greyhound trajectories and run conditions. To apply greyhound racing track design principles, it is important to understand greyhound trajectory limitations for the track. Different data gathered from the greyhound racing including greyhound location tracking data have their limitations such as missing data points and noise in the data which restrict finding results for all scenarios and modelling of limit conditions. Emulating greyhound dynamic states through numerical modelling greatly enhanced the data and analysis of results capabilities.

The simulation models developed as described in the previous section take a certain number of input variables and generate possible outcomes at discrete greyhound strides where input variables are updated according to the greyhound racing data and different states exist in the models. As depicted in Figure 1, dynamic states as defined in the models keep track of greyhound dynamic states at a given greyhound stride number and are carried to the next stride for dynamic calculations. The dynamic states in the model are also convoluted utilising race data by using look up tables for greyhound speed, stride length and stride frequency. Randomisation to dynamic input variable states is added emulating different race scenarios. In the dynamic calculation phase, any additional dynamic change is superpositioned by utilising activity scanning functions. The activity scanning functions are plugins for applying boundary conditions for the models so that models generate valid data. For instance, an activity scanning function is for the virtualising scenario where the greyhound trajectory crosses the track outside fence.

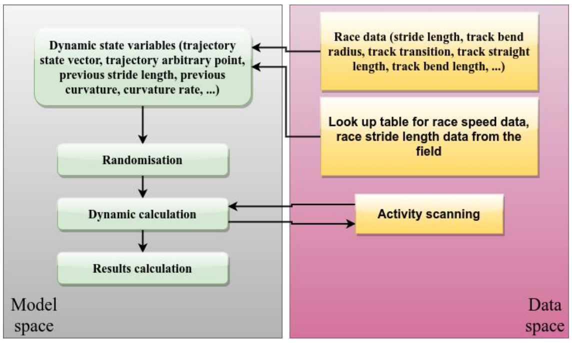

Figure 1: Primary components and their data sharing for simulating greyhound dynamics at discrete stride points.

As this research is about greyhound trajectory modelling using discrete strides as data and event points, it only answers greyhound dynamic states after each stride. Any intermediate conditions of greyhound dynamics such as greyhound bumping or crashing into an obstacle during a stride need separate models which are not part of this research. Thus, this research utilises greyhound dynamic states such as curvature, and stride length from the models to generate greyhound trajectory dynamics such as jerk for different greyhound path following conditions by applying the principle of discrete-event simulation.

3 SIMULATION PLATFORM

Discrete-event simulators often time use their special programming languages. Nowadays, general-purpose programming languages are being utilized for designing simulation programs (Liu et al., 2020). As a general-purpose programming language Python is known as versatile and has an error-free approach to coding. The simulation for this research was carried out in Python programming language. Python variables and objects were used for storing different simulation variables states and deriving results. Python built-in and custom-built methods and statements were used for randomising variables assignments, creating simulation conditions, and defining equations.

Figure 2 illustrates the main components in the Python simulation module in order.

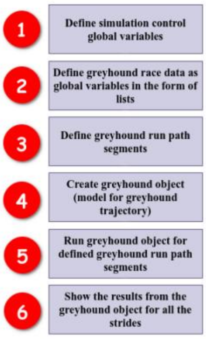

Figure 2: Steps followed for writing Python module for a simulation.

4 GREYHOUND TRAJECTORY FOR THE BEND

Greyhound location tracking data showed that greyhounds follow a smooth continuous path trajectory despite the track path being not optimised for shape continuity. For instance, track bend and straight sections meeting next to each other where there is no proper smoothing curve applied would result in a sudden change in centrifugal acceleration requirement when moving from straight to the bend. As data showed a continuous path of racing greyhound it can be said that greyhound minimises large variations of turn radius while navigating around the track. Figure 2 illustrates the main components in the Python simulation module in order.

To validate greyhound run conditions in absence of a proper track path transition curve between the bend and straight three scenarios can be considered. In all scenarios, greyhounds make a small transition for entering the bend that would allow them to enter the bend without hitting the track outside fence. It was found in the data that greyhounds make a smaller turn radius than the bend radius at different points on the track. In the first scenario, the greyhound's transition exit turn radius is smaller than the track bend radius where the greyhound continues to follow a smaller radius turn to align itself with the bend as shown in Figure 3. In the second scenario, the greyhound transition exit turn radius is the same as the track bend, but the greyhound makes a smaller radius turn after exiting the transition to align itself with the bend as shown in Figure 4. In the third scenario, the greyhound's transition exit turn radius is smaller than the track bend radius where the greyhound continues to follow the track bend radius after exiting the transition to align itself with the bend as shown in Figure 5. In Figures 3, 4 and 5 it can be seen that with a 50% smaller turn radius than the bend radius greyhound has a greater chance of aligning itself with the bend in the lack of a track transition without bumping into the track outside fence. With 65% smaller turn radius than the bend only in the first and second scenarios would allow the greyhound to align with the bend as it gets very close to the track outside fence. With a 75% smaller turn radius than the bend only in the first scenario greyhound would be able to continue to follow the track without bumping into the track outside. Finally, all three scenarios would result in different greyhound trajectory jerk outcomes based on greyhound transition length, transition exit radius and greyhound speed conditions.

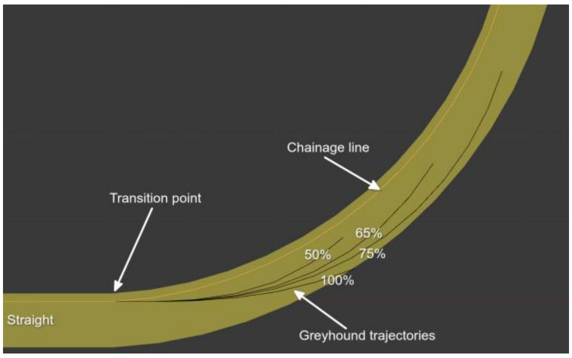

Figure 3: Greyhound transitioning into the bend with no track bend transition where the smallest radius turn is same as the transition exit radius.

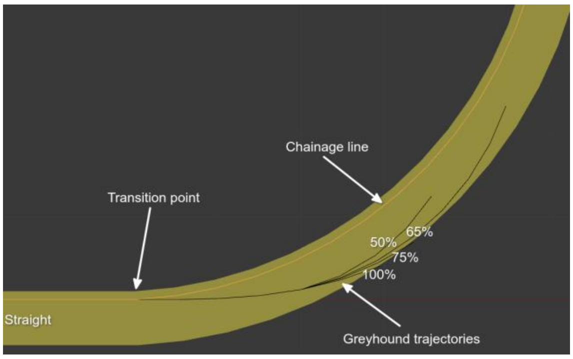

Figure 4: Greyhound transitioning into the bend with no track bend transition where the smallest radius turn is not same as the transition exit radius.

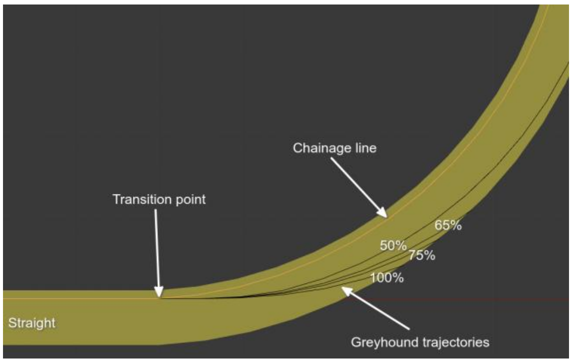

Figure 5: Greyhound transitioning into the bend with no track bend transition where the smallest radius turn is the transition exit radius.

4.1 Jerk Experienced by the Greyhound for Entering the Bend

The following major greyhound kinematics variables were analysed.

4.1.1 Influence of Speed

It is shown in the data that greyhound running speed is decreased during entering the bend. As the greyhound enters the bend it makes a transition from the straight to the constant radius bend. During this transition phase, the greyhound yaw rate changes from a lower value to a higher value. From Eq. 2 of yaw rate, we can see that if the yaw rate changes an equivalent change in the greyhound speed is required to balance the greyhound kinetic energy state. From this equation, we can tell that a transition would force the greyhound to slow down or decrease its speed for entering the bend. Also, this implies that a non-optimum transition would decrease greyhound speed significantly where a high braking force is required when entering the bend.

$$\text{Speed} = \text{yaw rate} * \text{turning radius} \tag{2}$$

As centrifugal acceleration jerk is a function of speed, a changing speed during entering the bend would imply a changing jerk value. Also, greyhound peak speed would vary based on the greyhound's start location distance from the bend which would also affect the jerk outcome.

4.1.2 Influence of Stride Length

Greyhound stride length is responsible for increasing its speed. Greyhound stride length can be described by Eq. 3. With a variable stride length for entering the bend, the requirements for turning radius and heading yaw is different from a constant stride length during bend transition. This also affects greyhound centrifugal acceleration jerk as a result.

$$\text{Speed} = \text{stride length} * \text{stride frequency} \tag{3}$$

4.1.2 Influence of Transition Length

For greyhound transition, we can assume an Euler curve as it has a continuous linear centrifugal acceleration profile where the centrifugal acceleration is zero for the straight and peak at the transition exit point. A longer Euler transition would decrease the centrifugal acceleration jerk while a shorter one would increase the jerk requirement.

4.1.3 Influence of Bend Radius

For oval shaped track, a constant radius bend is used for creating the track loop along with straight sections where track transition may or may not exist. A larger bend radius would decrease jerk requirements in the presence of a transition.

4.2 Jerk Outcome for Different Greyhound Trajectories for the Bend

Numerical simulation was carried out by defining major transition points for the greyhound trajectory for entering the bend. The transition point between straight and transition curve can be seen in Figure 6 as denoted by R_s. The transition point between the bend and transition curve is denoted by R_e. Finally, the bend radius point is denoted by R_b.

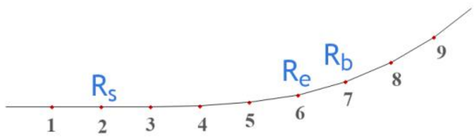

Figure 6: Transition points on greyhound trajectory for entering the bend where red dots are strides.

Now, for the scenarios explained in Section 4, the relationship between transition exit radius R_e and bend radius R_b are given below:

First scenario: $R_e = R_b$

Second scenario: $R_e > R_b$

Third scenario: $R_e < R_b$

For generating the results three variables are enumerated namely, start box distance from the bend, track bend radius and transition length. Furthermore, these variables are defined according to the existing track designs. Finally, the limit for greyhound transition length in the absence of track transition was calculated by modelling existing smallest and largest radius tracks by assuming no track transition is applied. Thus, a minimum greyhound transition length consisted of three strides. This is because a minimum of three strides are required for heading deflection angle change when it is assumed greyhound changes its heading with every stride. The maximum greyhound transition length for 70 m and 50 m radius bends are found to be 23.5 m and 20 m respectively. This is because anything greater than these values would make the greyhound bump into the track outside fence for making the transition as track transition is not present. The following sections illustrate maximum jerk values for with and without track transitions as produced from numerical simulations.

4.2.1 Greyhound Make Own Transition

When there is no track transition path segment, the greyhound still should be able to create its own transition given that it does not bump into the track outside fence. Figures 7 to 12 depict jerk outcome for greyhound transition into the bend from the straight for scenarios explained before. The figures show the maximum jerk value envelope for greyhound's different transition lengths and track bend radii. The blue dots represent the simulation run results as produced for different simulation scenarios.

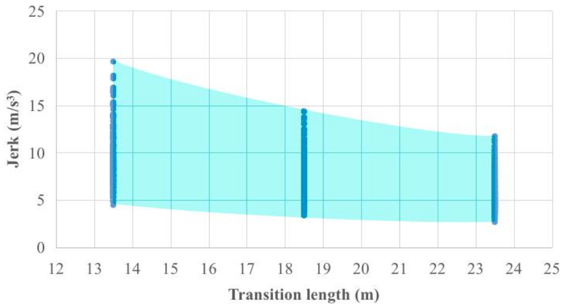

Figure 7: Maximum jerk envelope for different greyhound transition lengths from the first scenario simulations depending on track bend radius and distance of the race start from the bend.

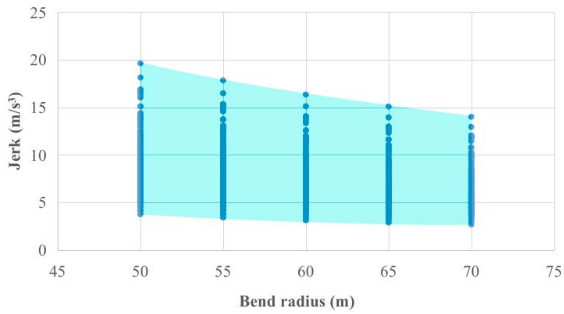

Figure 8: Maximum jerk envelope for different bend radius from the first scenario simulations depending on greyhound transition length and distance of the race start from the bend.

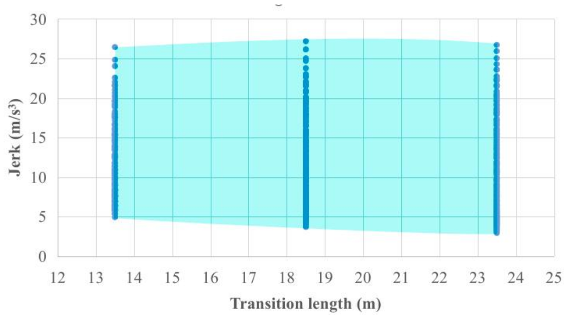

Figure 9: Maximum jerk envelope for different greyhound transition lengths from the second scenario simulations depending on track bend radius and distance of the race start from the bend.

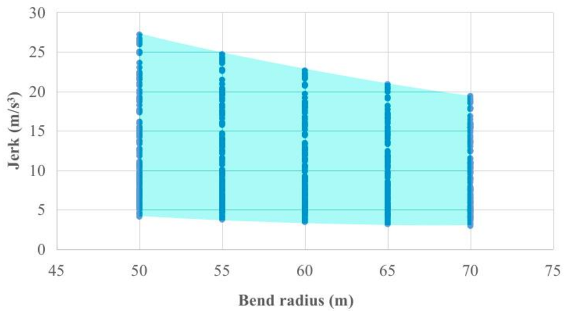

Figure 10: Maximum jerk envelope for different bend radius from the second scenario simulations depending on greyhound transition length and distance of the race start from the bend.

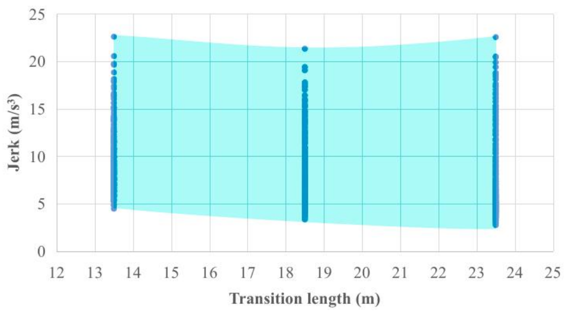

Figure 11: Maximum jerk envelope for different greyhound transition lengths from the third scenario simulations depending on track bend radius and distance of the race start from the bend.

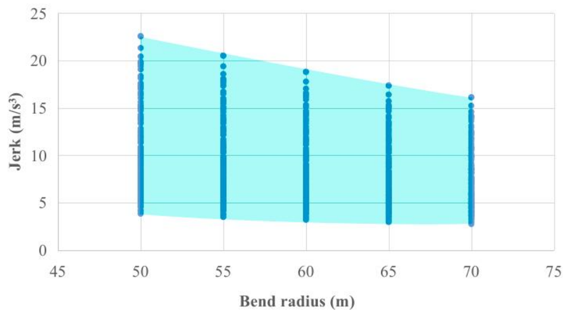

Figure 12: Maximum jerk envelope for different bend radius from third scenario simulations depending on greyhound transition length and distance of the race start from the bend.

4.2.2 Greyhound Follow Track Transition

When there is a track transition path segment it is easier for the greyhound to hold its line and follow approximately track transition. Figures 13 and 14 depict jerk outcomes for a greyhound following track transition into the bend from the straight. The figures show the maximum jerk value envelope for different transition lengths and track bend radii. The blue dots represent the simulation run results as produced for different simulation scenarios.

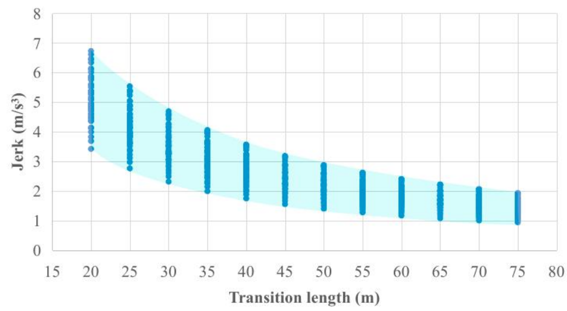

Figure 13: Maximum jerk envelope from the simulations for different Euler transition lengths path following depending on track bend radius and distance of the race start from the bend.

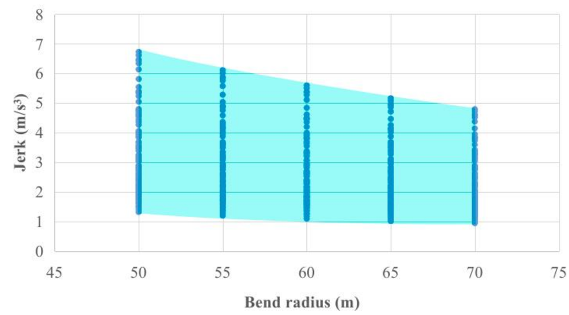

Figure 14: Maximum jerk envelope from the simulations for different bend radius depending on Euler track transition length and distance of the race start from the bend.

5 DISCUSSION

Numerical simulation of greyhound trajectory for the bend predicted greyhound theoretical jerk outcome by utilizing different parameters pertaining to greyhound strides and track variables. As can be seen from the maximum jerk value plots in the previous section greyhound would experience different levels of centrifugal acceleration jerk. For instance, jerk levels are much higher when greyhounds followed their own transitions despite the lack of track transition as depicted in Figures 7 to 12. In the first scenario, the jerk was lower than in the second and the third scenarios. The second scenario resulted in the highest jerk levels for all transitions and track bend radii run conditions. In all three scenarios, the highest jerk can go above 20 m/s^3 for the lowest transition length and turn radius while in the second and third scenarios jerk remains greater than 20 m/s^3 for all greyhound run conditions.

If greyhound followed a track transition with continuous turn radius its jerk level is under 7 m/s^3 for smallest transition and bend radius. Furthermore, with optimal run conditions the 75 m transition peak jerk remains between 1 and 2 m/s^3 as depicted in Figure 13. However, when the run conditions are not optimal a large radius bend will maintain the jerk level between 1 and 5 m/s^3 as depicted in Figure 14.

6 CONCLUSIONS

This research showed greyhound racing centrifugal acceleration theoretical jerk by modelling greyhound stride dynamics based on data and numerical simulation. By formulating various greyhound run conditions for track bends and transitions this research arrived at possible scenarios for greyhound trajectories and corresponding significant jerk outcomes. The results from the research showed the theoretical jerk levels which greyhounds face during various run conditions often time created by track variables such as less than ideal track transition design. Finally, this paper presents an idea about analysing stride dynamics using numerical modelling and simulation.

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