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Three Impulse-Momentum Models for the Equine Rotational Fall

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Introduction

Eventing is an equestrian sport that involves competition in the three combined disciplines of dressage, cross-country, and show jumping over the course of 1-3 days. Eventing is one of the most dangerous equestrian sports due mainly to the high risk cross-country phase, with 9 rider fatalities occurring during FEI competition over the last decade. Many of these fatal accidents occur due to rotational falls, which are defined as falls in which a horse's linear momentum (i.e., forward progress) is arrested as it collides with an obstacle, causing it to violently rotate its haunches over its head, strike its head and neck on the ground, and ultimately land on its back, often on top of the rider. Accordingly, many eventing organizations have prioritized the reduction of rotational falls through risk management initiatives that involve enhanced training, improved assessment of qualifications, and the research and implementation of safety technologies.

One type of technology includes frangible and deformable structures that are incorporated into the design of obstacles. The goal of these structures is to bend, break, or otherwise activate when a rotational fall occurs. The deformation eliminates the axis of rotation for the horse and creates a safer environment for the horse and rider. The basic principle of the technology is the existence of a critical force that causes a horse to rotate as it strikes an obstacle. A collision that produces subcritical forces should allow the horse and rider to continue safely on the cross-country course, while a collision that produces supercritical forces will most likely result in catastrophic injury and should thus trigger safety measures. This critical force is the cornerstone of the design of frangible and deformable technologies. However, no published studies to date have established its magnitude through the biomechanical examination of the horse-obstacle collision. The purpose of this study was to examine the basic kinematics and kinetics of the horse-obstacle collision through the creation of three biomechanical models.

Methods

Three methods were used to model the horse-obstacle collision: (1) single point mass estimation (PM), (2) single rigid body estimation (FL), and (3) multiple rigid body estimation (MS). Values were obtained from published research using motion capture to measure kinematics of the horse's center of gravity, forelimbs, and hindlimbs at jumping takeoff. A convenience method from video evidence of rotational falls was used to estimate time of collision (Δt) and rotational velocity of the horse about the collision point.

Results

The PM model provided an initial range of resultant impact forces that, at maximum, exceeded 750% of the model horse's weight. Similar high impact forces were found across all variable relationships within the MS model. For collision time, shorter impact duration led to higher magnitude of force transfer between horse and obstacle for all models. For the MS model, the greatest impact forces exceeded 800% of the model horse weight and were found for short duration collisions occurring at the proximal brachium (i.e., humerus). For all MS model forelimb segments, more proximal impact was found to produce greater forces. The largest transfer of torque occurred for impacts at the proximal brachium, but similar magnitudes were found for almost all segments. Impacts at the distal antebrachium (i.e., radius) were found to produce the greatest tendency for natural rotation, while impacts at the proximal brachium were found to have the greatest tendency for stalling or arresting the horse's momentum.

Compared to the PM and MS models, the FL model considered only the impact of the forelimb with an obstacle. The largest impact forces were again found at the proximal brachium for all collision angles. Impacts toward the fore hoof, specifically at points on the antebrachium at angles close to 45 degrees, produced the greatest tendency for natural rotation over the obstacle and should be considered the "safest impact zones." Conversely, impacts towards the proximal brachium at 45 degrees represent the most dangerous impact as they produce the greatest tendency for stalling or arresting the horses momentum.

Discussion

The three mechanical models developed for this study used the principle of impulse and momentum to provide specific ranges and singular values for critical forces and moments involved in the collision between a horse and a cross-country obstacle immediately following jump takeoff. The developed models sequentially increased in complexity from a single point mass describing the horse (PM), to a single rigid body describing a hyperextended forelimb (FL), to a multi-segment rigid body describing the horse and all involved joint angles and body segments (MS). All models exhibit very large forces and torques during the horse-obstacle collision that exceed kinetic values found for other sports, showing that rotational falls have a very high risk for injury. All three models provided complex estimations that might be used as design metrics for the development of future safety equipment and collapsible obstacles for elite cross-country competition.

Conclusions

Based on this study, it is feasible to predict the basic variables of a horse-obstacle collision that result in a rotational fall. While further analysis is needed to more fully establish all input variables, it is clear that a single rigid body model and a multi segment rigid body model of a horse colliding with an obstacle provide similar average impact force and moment values to those already being used for safety technology in the eventing industry. A model of the hyperextended forelimb also provided insight into the conditions required for the limb to rotate about an obstacle following collision. In the future, the analysis could be used to inform the design of frangible technology for cross-country obstacles and the development of more complex and encompassing computer models of the rotational fall. Diminishment of frequency and/or severity of horse rotational falls should improve survival and injury rates of riders.

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