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Case Study

An Application of the Principles of Projectile Motion to a Homicide Investigation

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Abstract Biomechanics testimony was sought to assess the feasibility of a claim made by the defendant that a fatal head injury sustained by the victim arose as a result of the defendant throwing a child's bicycle a horizontal distance of 7 m which accidentally struck the victim. The method of projection was claimed to involve pushing the bicycle from the chest equally with both hands from a stationary upright standing position in a manner similar to a chest pass in basketball. A further consideration in the case was that the maximum height of the projectile during flight was constrained by the presence of an overhead ceiling. Using equations for uniform motion and based on measurements made at the crime scene, it was determined that the theoretical release speed of the projectile could not have been less than 10.0–11.0 m/s and was probably closer to 14 m/s. These estimated release speeds are substantially higher than the release speeds associated with a comparable movement pattern, namely, the maximal two-handed bench throw (∼2.5 m/s), and instead approximate the release speeds recorded by the best three throwers in the Men's Shot Put at the 2004 Athens Olympic Games (13.60–13.95 m/s). It therefore seems highly unlikely that the defendant could have thrown the projectile a horizontal distance of 7 m as claimed.

Keywords release speed, head injury, biomechanics testimony

1 Introduction

The matter under investigation concerned a claim by the defendant that a fatal head injury sustained by the victim arose as a result of the defendant throwing a child's bicycle which accidently struck the victim on the back of the head. The prosecution instead alleged that the fatal injury to the victim arose from the defendant's use of the bicycle as a weapon to strike the victim. Although there was other evidence considered as part of the investigation, biomechanics evidence was sought in order to test the defendant's claims in relation to use of the child's bicycle as a projectile. An important aspect of the matter under investigation was that the defendant claimed to have projected the bicycle forward towards the victim from a fixed standing position equally with both hands from chest height in a manner similar to a chest pass in basketball. A further consideration in the case was that the maximum height of the trajectory of the projectile was limited by a ceiling under which the victim and defendant were claimed to be standing at the time of the incident. The brief was to (1) estimate the release speed required to throw a projectile in the manner claimed by the defendant based on the physical circumstances surrounding the alleged incident, and (2) provide an opinion concerning the feasibility of this release speed being achieved by the defendant in the manner claimed. Whether the bicycle thrown as claimed by the defendant could have caused the fatal head injury to the victim was not part of the brief. Theoretical release speeds were estimated using equations for uniform motion for a range of feasible release angles and for maximum horizontal distances based on measurements made at the crime scene. The feasibility of the estimated release speeds was assessed through comparison with release speeds reported in the literature for similar throwing actions, namely, the bench throw, which is used in resistance training for developing explosive power in the upper body, and the shot put, a well-known athletic field event. The bench throw involves maximally projecting a barbell from the chest using both hands while lying in a prone position [6] and is arguably the throw technique for which age and gender relevant data are available in the literature that most closely resembles the movement pattern that the defendant claimed to have used to project the bicycle. The shot put was used as a further comparison because this throw arguably defines the upper limits of feasible release speeds that can be achieved by elite athletes using a throw technique specifically designed for maximizing the range of a projectile.

2 Materials and methods

3 Assumed facts

The information provided for the purpose of the biomechanical analysis was that:

- the female victim and male defendant were standing upright in a carport with a ceiling of height 2.5 m at the time of the incident;
- the standing height of the defendant and victim were 1.95 m and 1.70 m, respectively;
- the mass and height of the bicycle were 5 kg and 50 cm, respectively;
- the horizontal distance between the defendant and the victim was 7 m;
- the method of projection of the bicycle involved standing facing the victim and pushing the bicycle from the chest equally with both hands without stepping;
- the release height of the bicycle center of mass was 1.70 m. This height estimate was based on release occurring with the arms in a fully extended position at a 10° angle above the horizontal and is consistent with the need to impart a vertical velocity to the bicycle;
- the landing height of the bicycle center of mass was 1.70 m. This height estimate corresponded to the standing height of the victim;
- the trajectory of the bicycle was described by the defendant as being "flat" with a maximum vertical displacement of 0.6 m above the release height due to constraint imposed by the height of the overhead ceiling;
- the projectile did not contact the ceiling during flight;
- air resistance was negligible and gravitational acceleration constant ($g = 9.81\,\text{ms}^{-2}$).

4 Analysis

The release speed of the projectile was computed using kinematic equations for uniform motion. Total flight time (t) was computed using equation (1):

$$t = 2\sqrt{2h/g}, \quad (1)$$

where h = maximum height of projectile above release height.

The horizontal (v_x) and vertical (v_y) components of the release speed were subsequently calculated using equations (2)–(3):

$$v_x = \text{Range}/t, \quad (2)$$

$$v_y = gt/2, \quad (3)$$

where *Range* is the maximum horizontal distance traveled by the projectile.

In the final step, the speed of release (v) and angle of release (θ) were computed using basic trigonometry. This process was repeated iteratively to compute v and θ for ranges of 5, 7, and 9 m with maximum projectile heights up to 0.8 m in 0.02 m increments.

5 Results

The kinematic solution for the release speed and angle at different combinations of range and maximum height are displayed in Figure 1. The solution demonstrates that:

- the required release speed increases as the range of the projectile is increased from 5 to 9 m;
- the greater the height reached by the projectile above the release height, the lower the required release speed for a given range;
- as the maximum height above the release height approaches zero, the required release speed approaches infinity;
- higher maximum height is achieved using larger release angles.

Given that the reported horizontal distance between the defendant and the victim was 7 m, the trajectories and corresponding initial kinematic conditions associated with this range were of primary interest. The trajectories for projectiles with a range of 7 m but different maximum heights are displayed in Figure 2. Based on a maximum possible height of 0.6 m due to the constraint of the ceiling, the slowest possible release speed was computed to be 10.6 m/s. If as claimed by the defendant the bicycle was thrown with a "flatter" trajectory, then the required release speed increases. For example, if the maximum height was reduced from 0.6 m to 0.3 m, then the required release speed for a 7 m range would become 14.4 m/s. A greater horizontal speed is required when the maximum height is reduced because of the reduction in vertical component of the release speed and hence flight time.

6 Discussion

This case study involved the application of basic principles of projectile motion to a homicide investigation in which the victim was allegedly struck on the back of the head by a child bicycle that had been projected a distance of 7 m across an undercover carport by the defendant. In the first instance, the analysis involved estimating the release speeds for a projectile thrown a fixed horizontal distance using trajectories that differed in terms of the maximum height reached above the release height. It was subsequently of interest to determine the feasibility of the defendant achieving this release speed using the claimed method of projection.

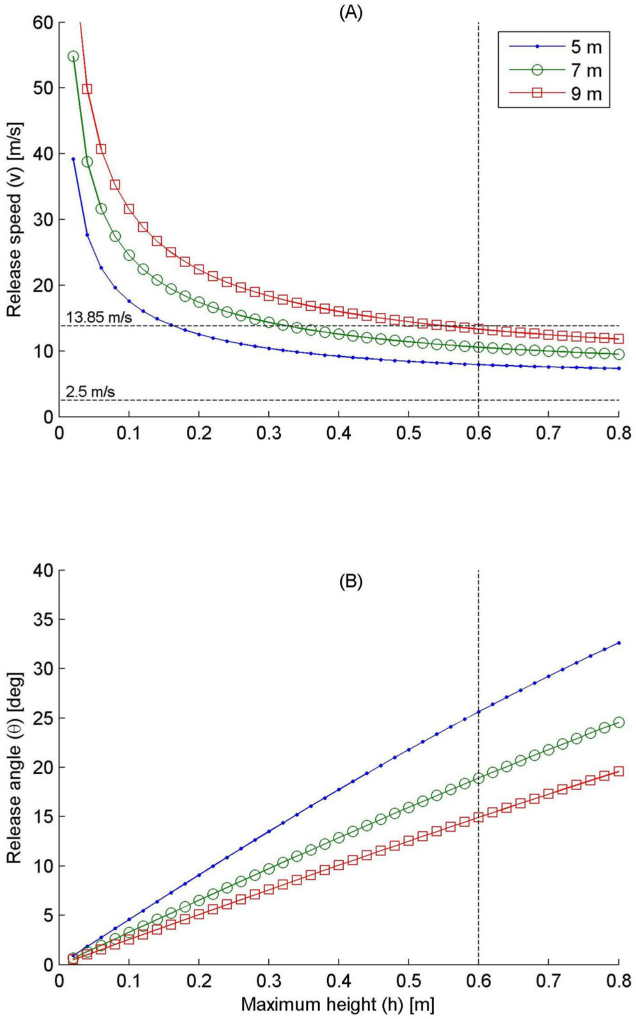

Figure 1: Theoretical (A) release speed and (B) release angle for ranges of 5, 7 and 9 m with maximum projectile heights up to 0.8 m in 0.02 m increments. The horizontal lines on (A) indicate the estimated peak concentric bar speed for maximal bench throws with a mass of 5 kg determined from [6] ($v = 2.5$ m/s) and the release speed achieved by the gold medallist in the Men's Shot Put at the 2004 Athens Olympic Games ($v = 13.85$ m/s). The vertical line on each plot indicates the estimated maximum possible height the center of mass of the bicycle could reach due to the ceiling height ($h = 0.6$ m).

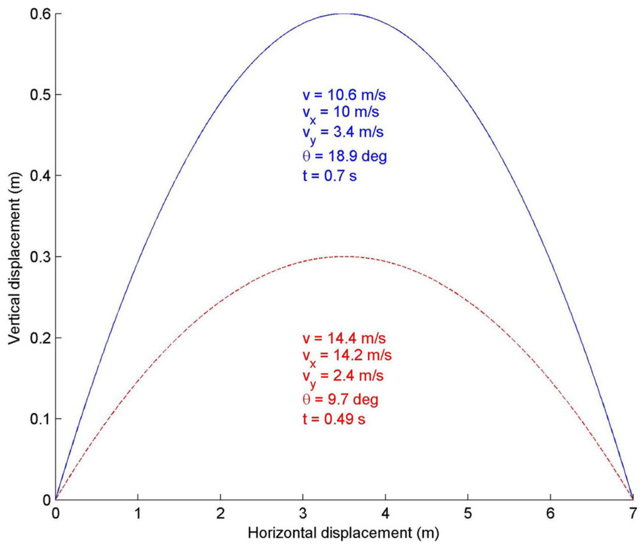

Figure 2: Theoretical trajectories and corresponding initial conditions for projectiles with the same maximum horizontal displacement (7 m) but different maximum heights. The maximum vertical displacement of the solid (blue) trajectory and the dashed (red) curve are 0.6 m and 0.3 m, respectively.

Based on the theoretical analysis presented, the lowest possible release speed required to achieve a range of 7 m, based on a maximum vertical height of 0.6 m above release was 10.6 m/s. However, as the defendant claimed to have thrown the projectile with a "flat" trajectory, the real release speed is likely to be higher than 10.6 m/s. As shown in Figure 1, the required release speed approaches infinity as the release angle approaches zero. A more realistic release speed was likely to be associated with a maximum height somewhere between 0 and 0.6 m and was calculated to be 14.4 m/s for a maximum height of 0.3 m.

The feasibility of achieving a release speed of approximately 14 m/s was assessed in the first instance through comparison with peak concentric speeds achieved by healthy young males during the bench throw. In the study by Newton et al. [6], participants performed maximal bench throws with bar loads ranging from 20–100% of their one repetition maximum strength with and without a countermovement. Irrespective of whether a countermovement was used or not, the peak velocity for the lowest load condition associated with the mass of the bar alone (approximately 15 kg) was approximately 2.2 m/s. Based on linear extrapolation of the load-velocity curve from Newton et al. [6] (see Figure 1), the maximum concentric bar speed associated with a load of 5 kg (i.e. the mass of the bicycle) was estimated to be no greater than 2.5 m/s, which represents just 18% of the release speed required to project the bicycle 7 m horizontally and would result in a horizontal distance of just 0.34 m.

To put the finding from this case study in further perspective, the measured release speeds for the three best throwers in the Men's Shot Put at the 2004 Athens Olympic Games were 13.6–13.95 m/s and resulted in throws of 21.07–21.16 m using release angles of 33–41° [1]. Although the mass of the bicycle (5 kg) is less than the mass used in the shot put (7.26 kg), there are many factors associated with the case under investigation that would limit the ability to achieve release speeds comparable with the elite male shot athletes. Firstly, elite shot athletes generate high body speeds prior to release, which compared to the defendant who was stationary, contribute at least in part to the release speed of the shot [5]. Secondly, the shot put technique involves a powerful leg drive and sequential rotations of the pelvis, trunk, and arm segments to generate high release speeds [2]. The throwing technique that the defendant claimed to have instead used involved facing the victim and pushing the bicycle equally with both hands from their chest. Such a technique would impose substantial limits on the ability to recruit the large muscles acting on proximal body segments that are designed for force production and to apply these forces over the longest practicable time to generate the propulsive impulse needed to maximize the change in momentum of the projectile [3]. Indeed, it could be argued that the throwing technique adopted by the defendant favored accuracy rather than speed. Thirdly, shot athletes are highly trained, with physical characteristics and skills that are optimized for achieving maximum horizontal throw distance [4], and so it is unlikely that an untrained individual would possess these attributes.

7 Conclusion

Based on the circumstances of the alleged incident and in consideration of the assumptions on which the analysis was based, the theoretical release speed of the projectile in question could not have been less than 10.0–11.0 m/s and was probably closer to 14 m/s, a speed in excess of the Gold medal winning performance in the Men's Shot Put at the 2004 Athens Olympic Games. Furthermore, given that measured maximal concentric bar speeds associated with bench throws of a comparable mass to the projectile in question are in the vicinity of 2.5 m/s (18% of required release speed), it seems reasonable to conclude that the defendant could not have achieved the release speed required to throw the bicycle 7 m using the method of projection claimed. Although it was suggested by the author that the claims of the defendant could be further assessed by conducting an experiment to measure throw performance under conditions that replicated the circumstances of incident, the prosecution did not consider this necessary for reasons related to the relative weighting of other evidence associated with the case, and so no further analysis was performed.

References

[1] G. Ariel, *Biomechanical analysis of the shot-put event at the 2004 Athens Olympic games. source: http://www.arielnet.com/start/apas/studies/shotfinal.pdf*, 2004.

[2] J. G. Hay, *The Biomechanics of Sports Techniques*, Prentice-Hall, Upper Saddle River, NJ, 4th ed., 1993.

[3] E. Kreighbaum and K. M. Barthels, *Biomechanics: A Qualitative Approach for Studying Human Movement*, Macmillan, New York, 3rd ed., 1990.

[4] T. A. Kyriazis, G. Terzis, K. Boudolos, and G. Georgiadis, *Muscular power, neuromuscular activation, and performance in shot put athletes at preseason and at competition period*, J Strength Cond Res, 23 (2009), pp. 1773–1779.

[5] N. P. Linthorne, *Optimum release angle in the shot put*, J Sports Sci, 19 (2001), pp. 359–372.

[6] R. U. Newton, A. J. Murphy, B. J. Humphries, G. J. Wilson, W. J. Kraemer, and K. Hakkinen, *Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation that occurs during explosive upper-body movements*, Eur J Appl Physiol Occup Physiol, 75 (1997), pp. 333–342.