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Field Measurements of Softball Player Swing Speed

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Abstract

The bat swing speed is one of the most important factors affecting bat performance. The equipment needed to measure swing speed is sophisticated and has high data reduction overhead. For this reason, relatively little data exist describing bat motion in field conditions. The following describes results of one of the most ambitious swing speed studies ever conducted. The study involved bats of nearly constant weight and varying inertia that were swung by 29 adult batters. The study was conducted using right handed batters on a regulation outdoor field with a live pitcher. Swing speed was measured by tracking markers on the bat with two high speed video cameras. The cameras were arranged and calibrated so that the bat markers could be traced in three-dimensional space. The ball's pitch speed, hit speed and inclination were also tracked and compared to a three-dimensional Doppler radar system. Comparison of the video and the known bat marker spacing showed an accuracy of 6 mm. The bat center of rotation during impact was close to the knob of the bat, while bat swing speed tended to increase with decreasing bat inertia. Bat swing speed was also shown to depend on the batter skill level. The results will be used to improve relations regulating bat performance.

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1. Introduction

To characterize the hitting performance of a bat, it is necessary to understand how fast the bat can be swung. For example, if two bats have the same performance at the same swing speed, the bat that can be swung faster will perform better in the field. The relationship between the hit ball speed, v_h, and bat swing speed, v_s, is

$$v_h = e_a v_p + (1 + e_a) v_s \tag{1}$$

where e_a is the bat collision efficiency and v_p is the ball pitch speed [1]. It is generally perceived that hollow bats outperform wood bats in the field because hollow bats are lighter and can be swung faster. Hollow bats also have less inertia than wood bats which tends to lower e_a and hence v_h. This has led to

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confusion concerning the effect of inertia on bat performance. Unfortunately, it is difficult to predict how swing speed is affected by the inertial properties of the bat. Moreover, there have been few systematic studies of bat speed in the scientific literature, reflecting the fact that bat speed is difficult to measure and can depend on conditions not easily controlled or even quantified. Despite these difficulties, previous studies [2-5] have shown a qualitative dependence of bat speed on inertial properties. Unfortunately, because of the difficulty in doing such measurements and due to the selection of bats used in these studies, the dependencies are usually not quantified nor are the effects of mass and mass moment of inertia (MOI) separately determined. The limited availability of quantitative results provided the motivation for the current study, the results of which will improve laboratory bat performance measures.

2. Field Study

The study considered the effects that bat MOI had on the swing speed of a softball bat. To this end, five aluminum bats of the same model, each 0.86 m (34 in.) in length, were used. The bats had nearly the same weight but varied in MOI in five uniform increments, ranging from 0.13 to 0.20 kg m^2 (7000 to 11000 oz in^2) where MOI was referenced to a point 0.15 m (6 in.) from the knob end of the bat.

The study was conducted on an open field during daylight hours in Oklahoma City, Oklahoma, USA. To accommodate the video camera orientation, only right handed batters were used. The batters had an average age of 33.3 yrs (8.0), an average height of 1.8 m (0.07) and an average weight of 103 kg (17)[a]. Batter skill was ranked in levels and varied from expert (1) to recreational (7). All batters swung each of the five bats. To reduce fatigue effects, the batters worked in pairs, alternating after swinging each bat ten times. Each batter was allowed a few practice swings before hitting with a new bat.

3. Speed Measurements

The batter's swing speed was measured using two high speed video cameras (720x480 pixels at 1000 fps) as depicted in Fig. 1. The cameras were approximately 45° from each other, 4.6 m above the ground and 4.6 m from home plate. Two 1.2 by 1.2 m panels with an array of equally spaced markers, comprising the tracking field of interest, were used to calibrate the camera locations. The sound of the bat-ball impact was used to trigger the cameras. Video was saved from each camera for each swing using 15 frames prior to impact and 15 frames after impact. The bats were painted black. White tracking markers were placed 0.04, 0.18, and 0.37 m from the distal end of each bat.

After the video was collected the ball and bat markers were tracked in 3-D space using commercial software (ProAnalyst 3D Professional). The coordinates for the ball and each marker on the bat were fit to second order polynomial equations. The quality of the video tracking was checked by comparing the distance between the bat markers for each video frame. The mean and standard deviation of the difference between the video and measured marker spacing was computed for each swing. Swings where the mean or standard deviation of the difference was more than 6 mm were not used. Ball results where the root mean square deviation between the tracked points and empirical fit was greater than 2.5 mm were not used.

[a] Standard deviations indicated in parenthesis.

Bat and ball speeds were obtained by differentiating the empirical equations with respect to time. In all, data from 2100 swings were collected, from which 1487 swings were used. The majority of the

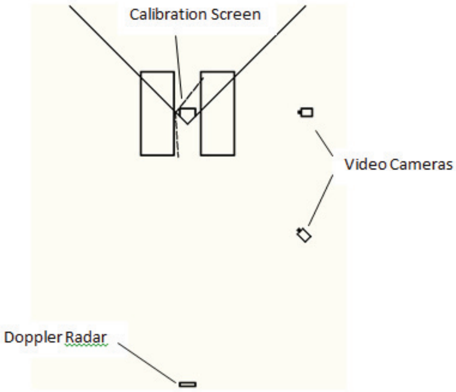

Fig. 1. Schematic of field study equipment layout

unusable data was due to a corrupted calibration file that eliminated five batters from the total of 34 batters used in the study. In addition to the video tracking, a Doppler radar system (Trackman, DN) was used to track the pitched and hit ball motion. The unit was placed 7.6 m behind home plate and was able to record ball speed and trajectory. Approximately 300 swings were captured using both the video and radar systems. A comparison between the video and radar system ball angles in the horizontal and vertical planes is presented in Fig. 2. In nearly all instances the two independent measures of ball trajectory agreed to within 5°. The agreement between the independent measures provided confidence in the ability to track the ball trajectory from a relatively small data sample (i.e. 30 frames). The magnitude of the pitched and hit ball speeds is compared between the video and radar systems in Fig. 3. The agreement is again favorable, and generally falls within 2.2 m/s.

4. Field Study Results

The location of the knob, impact location, and instantaneous bat centre of rotation are presented in Fig. 4. The impact location occurs, on average, 1.4 m in front of the plate. The batter's stride is apparently responsible for this motion toward the pitching mound. The average impact location is 0.25 m further from home plate than the average knob location. This is consistent with the left field ball placement,

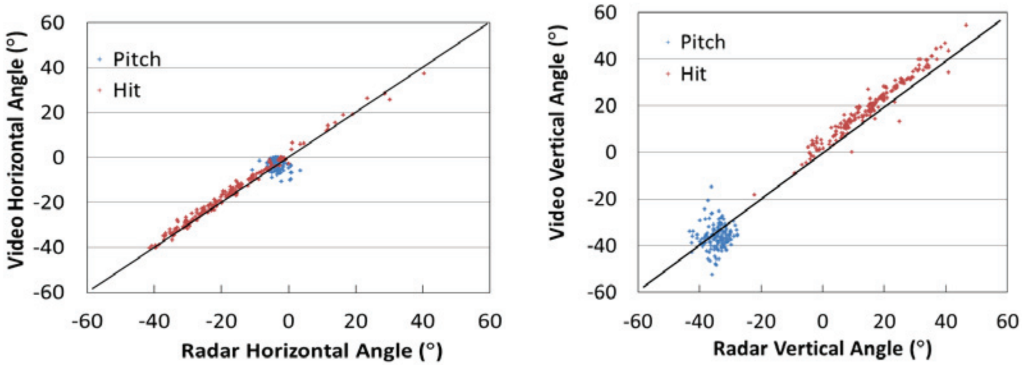

Fig. 2. Comparison of the horizontal and vertical ball trajectory angles between the video and radar. Black lines represent unit slope and ideal correlation

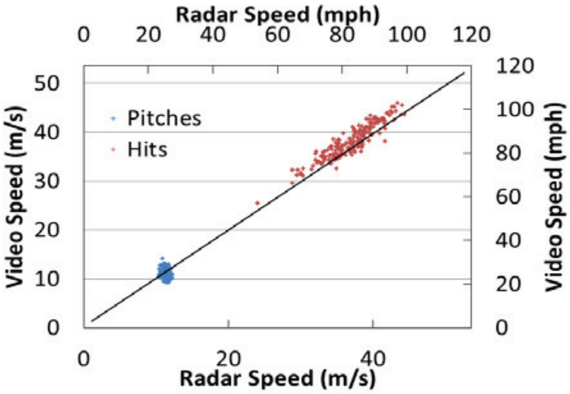

Fig. 3. Comparison of the magnitude of the ball speed between the video and radar tracking systems

typical of right handed batters. The instantaneous centre of rotation occurs just off of the knob and is close to the batter's wrist. The average instantaneous centre of rotation was 43 mm axially from the knob and 43 mm toward the batter. The errant points showing centres of rotation between 0.2 and 1 m are due to unusual batter motion, not tracking noise, and are included in the average.

The average swing speed is shown for each batter skill level in Fig. 5. As noted in the figure, higher swing speeds were generally observed for batters with higher skill level. The correlation between swing speed and player skill level ranking is not perfect, however. As swing speed is only one aspect of a batter's ability, the discrepancy could be related to other factors contributing to player ability and the accuracy of the ranking system itself. The range in average batter swing speeds is relatively large, and far exceeds the range in performance of differing bat models. Since swing speed is the largest factor contributing to the hit ball speed (eq. 1) the contribution of player ability should not be neglected when considering bat performance.

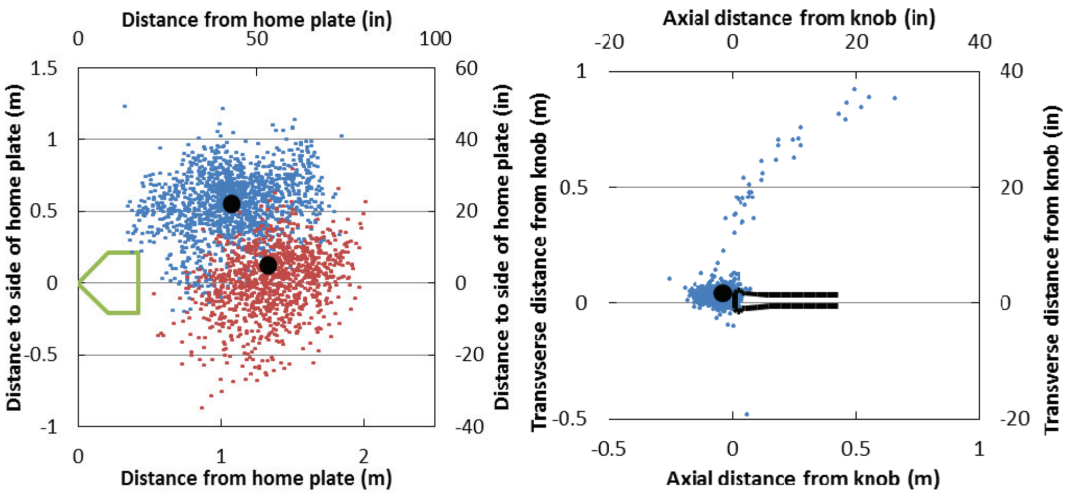

Fig. 4. Locations at impact. Left: Knob location (blue markers) and impact location (red markers) relative to home plate (green lines). Right: Instantaneous centre of rotation relative to the knob. (Blue points are from the field study, black solid circle is the average relative to the knob shown in the figure)

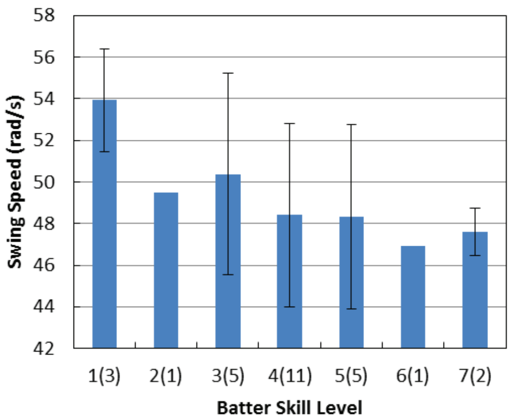

Fig. 5. Batter swing speed as a function of batter skill level. Group size indicated in parenthesis, error bars are one standard deviation

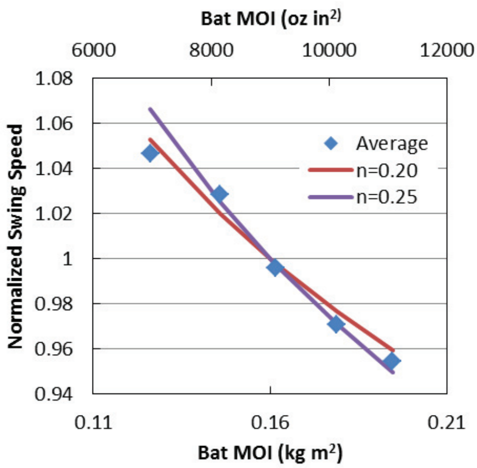

Fig. 6. Swing speed power as a function of bat inertia

Laboratory measures of bat performance can accurately determine energy dissipation from impact, but cannot describe batter swing speed. Of particular interest is the effect of the bat's inertial properties on swing speed, ω. Swing speed has been empirically described using [6,7]

$$\frac{\omega}{\omega_a} = \left(\frac{I_s}{I}\right)^n \tag{2}$$

where I and I_s are inertias of the test and standard bats, respectively, ω_a is the batter's average swing speed and the power n describes the dependence of swing speed on bat inertia. The normalised swing speed, ω/ω_a, is thus unity when $I=I_s$. Clearly Eq. (2) is a simplification of the inertial effect contributing to batter swing speed. Since Eq. (2) does not include the inertia of the batter, it incorrectly predicts an infinite swing speed as bat inertia approaches zero. It is nevertheless a convenient expression to describe bat inertia effects over a limited range. To determine the dependence of bat inertia on swing speed, each swing speed was normalised using the average from the respective batter, as described in Eq. (2). The normalised swing speeds were averaged for each bat as shown in Fig. 6. The lightest bat had considerably less inertia than most batters prefer. It is perhaps for this reason that the swing speed for this bat departs from the trend apparent from the remaining bats. The power, n, appears to lie between 0.20 and 0.25, depending on the significance applied to the lightest bat used in this study.

The results of the field study may be used to obtain the collision efficiency of each impact through Eq. (1). The peak collision efficiency of each bat in the field study is presented in Fig. 7 as a function of bat inertia. The collision efficiency was observed to increase with bat inertia as has been observed elsewhere [1]. The results of laboratory bat tests are included in Fig. 7. The laboratory tests involve co-linear impacts, and thus describe the upper limit of performance observed in the field study. The dependence of the collision efficiency on inertia showed remarkable agreement between the field and laboratory results.

Batters will often refer to the sweet spot of a bat as the location that produces the highest hit-ball speed. The hit-ball speed can be found from the collision efficiency and swing speed using Eq. (1). The peak hit-ball speed usually occurs a few inches outside of the location of the maximum collision efficiency, since the bat speed increases with distance from the knob. Interestingly, the data from the field study showed the optimal impact location moving away from the knob as the bat inertia increased. The average impact location for the top 25% hit-ball speeds of each bat is presented in Fig. 8. The peak hit-ball speed location from laboratory tests is also included in Fig. 8 and agrees with the nearly 50 mm change in impact location found from the field study. (Laboratory tests impact the bat in 12 mm increments, so agreement within less than 12 mm is not expected.)

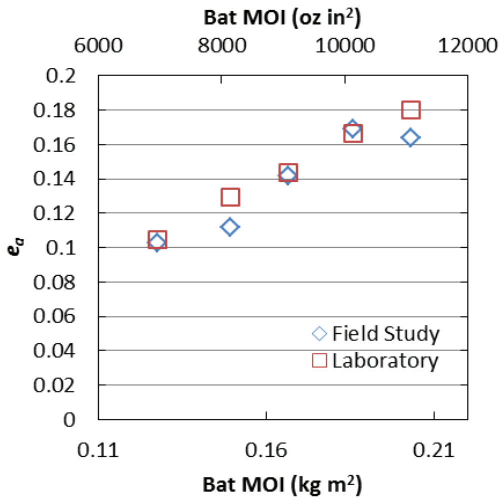

Fig. 7. Maximum collision efficiency as a function of impact location for bats of varying inertia

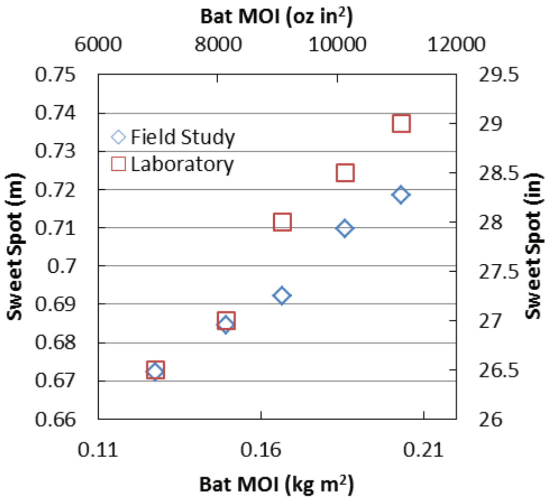

Fig. 8. Bat sweet spot (location producing the highest hit-ball speed) as a function of bat inertia

5. Summary

The foregoing has considered field measurements of softball player swing speed. Batter swing speed was measured using high-speed video in an outdoor field environment, and agreed favorably with independent ball speed measurements using Doppler radar. The average bat-ball impact was observed to occur 1.4 m in front of the apex of home plate. The average bat instantaneous center of rotation at impact was 43 mm from the knob of the bat. Batter swing speed showed a consistent dependence on bat inertia to the 0.20-0.25 power. The collision efficiency and location of maximum hit-ball speed were observed to increase with bat inertia in field and laboratory measurements.

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