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An Apparatus to Evaluate the Pace of Baseball Field Playing Surfaces

ABSTRACT: During a baseball game, the ball will strike the playing surface at a variety of speeds and angles. The speed at which the ball travels after impact with the playing surface has been referred to as the pace of the surface. Wide variations in pace can reduce the safety and playability of baseball field surfaces. Pace can be quantified by measuring the coefficient of restitution. The coefficient of restitution is defined as the ratio of two velocities; the velocity of a baseball after impact with the surface divided by the velocity of the ball prior to impact. An apparatus was developed to measure the coefficient of restitution of a baseball striking various playing surfaces. The apparatus, termed Pennbounce, uses infrared screens to measure the coefficient of restitution of baseballs propelled at varying angles and velocities. Pennbounce was used to measure the pace of traditional synthetic turf (Astroturf), infilled synthetic turf (Fieldturf), natural turfgrass, and skinned infield surfaces. Baseballs were propelled at the surfaces using two velocities and impact angles. Surface pace was highest on traditional synthetic turf, skinned infield, infilled synthetic turf, and natural turfgrass areas, respectively.

KEYWORDS: coefficient of restitution, COR, bounce, turfgrass, skinned infield, playing surface pace, Pennbounce, Fieldturf, Astroturf

Introduction

Baseball is a popular sport in the United States and is played by numerous individuals. During a baseball game, the ball will strike the playing surface at a variety of speeds and angles. The speed at which the ball is moving after impact with the playing surface can be referred to as the pace of the surface. Wide variations in pace can reduce the safety and playability of baseball field playing surfaces.

Baseball playing surface pace has rarely been measured directly. Rather, it has been indirectly evaluated through measurements of vertical ball rebound and ball-to-surface friction [1–10]. Surface pace has also been characterized qualitatively by asking players to rate surfaces as having a "fast" pace or a "slow" pace [11,12].

Indirect measurements of surface pace have been historically conducted via vertical drop tests [1,2]. During these tests a ball is dropped onto a surface and the height of vertical ball rebound is measured. Variation exists in the methods used to measure ball rebound as well as the manner in which data are presented.

Langvad [13] dropped soccer balls from a height of 7.0 m. Stewart and Adams [3,11] measured the height of vertical ball rebound of cricket balls dropped from a height of 4.88 m. Holmes and Bell [4] measured the vertical ball rebound height of tennis balls dropped from a height of 2.54 m. A drop height of 3.0 m has been standardized in Great Britain [5] and widely used in evaluations of soccer, cricket, tennis, and field hockey playing surfaces [6–9,12]. The ASTM Standard Test Method for Vertical Rebound Characteristics of Sports Surface/Ball Systems; Acoustical Measurement (F 2117) [14] calls for a drop height of 1.8 m. Drury and Drury [9] determined that if rebound height is expressed as a percentage of the drop (release) height, the actual height of release is irrelevant.

The methods used to record ball rebound height include visual (photometric) and acoustical techniques. Researchers have visually recorded the maximum height of vertical ball rebound [6–9,12]. ASTM F 2117 [14] uses acoustical measurements to record the time between the first two impacts of the ball and the testing surface. Time intervals are then converted into vertical ball rebound height measurements after accounting for the effect of gravity on the ball.

The value used to represent ball rebound has varied. Numerous researchers have expressed vertical ball rebound as a percentage of the release height [6–9,12]. ASTM F 2117 [14] requires that vertical ball rebound height be measured on a reference surface every 30 min during testing. A vertical ball rebound ratio is then calculated by dividing the vertical ball rebound height measured on the testing surface by the vertical ball rebound height measured on the reference surface.

Attempts have been made to correlate vertical ball rebound height to the pace of the playing surface as perceived by players. Stewart and Adams [11] and Drury [12] found that increased vertical ball rebound height values were correlated with opinions of pace as recorded using player surveys. Stewart and Adams [3] found that surfaces having a "very high" pace measured greater than 15.6 % in vertical ball rebound height. Those rated as "high" had rebound values between 13.0–15.6 % and those rated as "low" had ball rebound values less than 7.8 %. Recent research by Adams et al. [15] found visual ratings of cricket surface pace by umpires to be unreliable.

The pace of a playing surface has also been inferred through measurements of the frictional properties between the ball and the surface. These frictional properties are comprised of both static and dynamic components. Static friction is a measure of the force required to initiate movement of a ball contacting the surface. Dynamic friction is a measure of the force required to impede the movement of a ball in contact with the playing surface. Baker et al. [16] developed methods for evaluating friction characteristics on

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playing surfaces used in cricket. Static friction was measured using four cricket balls mounted onto the bottom of a steel plate weighted to 40 kg. The rotational force required to initiate movement of the balls against a surface was measured with a torque wrench. Dynamic friction was measured using a ball mounted to the end of a pendulum released from a height of 1.50 m. The angle reached by the pendulum after contact with the surface was recorded. Goodall et al. [10] modified the apparatus to measure the frictional properties of baseball field playing surfaces by replacing the cricket balls in Baker's devices with baseballs. Both researchers [10,16] observed relationships between soil characteristics and surface friction. The forces generated during ball-to-surface impacts in these studies are small compared to those generated during actual play. It is unknown whether the reported effects of surface characteristics on surface pace will be the same at higher impact forces.

Researchers have measured surface pace directly. Using forces similar to those experienced during play, researchers measured the coefficient of restitution of balls impacting tennis and cricket surfaces. The coefficient of restitution is defined as the ratio of two velocities; the velocity of a ball after impact with a surface divided by the velocity of the ball prior to impact [17]. Thorpe and Canaway [18] and Baker et al. [16] measured the coefficient of restitution of tennis balls and cricket balls, respectively, in an attempt to divide pace into horizontal and vertical components. Horizontal pace refers to the speed at which a ball changes location in a horizontal plane, while vertical pace refers to the speed at which a ball changes location in a vertical plane. Adams et al. [15] developed a mathematical model explaining the relationship between the horizontal and vertical components of pace and exit angle. Thorpe and Canaway [18] and Baker et al. [16] concluded that dividing the coefficient of restitution into its horizontal and vertical components yielded no more information than measuring the total coefficient of restitution.

Thorpe and Canaway [18] reported that the coefficient of restitution varies with the impact angle of the ball. Dunlap et al. [19] found the coefficient of restitution changed depending on the inbound velocity and the impact angle of the ball. The authors suggest future research measuring the coefficient of restitution should include varying initial velocities and impact angles.

Researchers have attempted to assess baseball playing surface pace using indirect measurements. The ability of these methods to accurately model impact dynamics similar to those experienced during actual play is suspect. There is currently no method to measure the coefficient of restitution of a baseball impacting the playing surface. A method to directly assess baseball playing surface pace would allow researchers to determine how surface pace is affected by changes in surface conditions. This information could ultimately increase baseball field safety and playability.

Objective

The objective of this study was to develop a method to accurately assess the pace of baseball field playing surfaces by measuring the coefficient of restitution at multiple ball velocities and impact angles.

Materials and Methods

Testing Apparatus Development

The authors developed an apparatus (termed Pennbounce) shown in Fig. 1. Pressurized CO_2 was used to generate a force that propelled baseballs through the barrel of a 74-mm air cannon (Model # Storm 300, Air Cannon Inc., Denver, CO) (Fig. 2). The device was designed to operate at pressures ranging between 896 and 2070 kPa. On average, a pressure of 2070 kPa propelled balls at a velocity of 40.2 m s^{-1}, while a pressure of 896 kPa propelled balls at a velocity of 31.0 m s^{-1}.

FIG. 1—*Pennbounce apparatus for measuring playing surface pace.*

Testing velocities of 40.2 m s^{-1} and 31.0 m s^{-1} were selected to represent common ball velocities experienced by middle infielders during play. The National Collegiate Athletic Association's Baseball Research Panel [20] stated that the velocity of a baseball immediately after striking the bat is a function of both the velocity of the bat, the physical characteristics of the bat, and the velocity of the ball at impact. Given that a baseball will lose velocity at a rate of 0.447 m s^{-1} for every 2.386 m of travel after impact with the bat [21], the following Eq 1 was used to predict the velocity of a ball striking a surface 30.67 m from the point of contact with the bat.

$$V_{\text{test}} = (BESR + 1/2)V_{\text{bat}} + (BESR - 1/2)V_{\text{pitch}} - 5.75 \text{ m s}^{-1} \quad (1)$$

where V_{test} represents the velocity of the ball at impact with the surface, V_{bat} represents the velocity of the bat at impact with the ball, V_{pitch} represents the velocity of the ball prior to contacting the bat, and *BESR* represents the ball exit speed ratio. The ASTM Standard Test Method for Measuring High Speed Baseball Bat Performance Factor (F 2219) defines ball exit speed ratio (*BESR*) as a ratio of the speed of the ball before and after contacting a bat, plus one half [22]. For this evaluation a ball exit speed ratio (*BESR*) of 0.728 was selected, as it is the maximum standard set by the National Collegiate Athletic Association [20].

FIG. 2—*Storm 300 Air Cannon used to propel baseballs.*

FIG. 3—*Model M-57 ballistic screen.*

Pennbounce measured the velocity of baseballs propelled by the air cannon using ballistic screens (Model M-57, Oehler Research, Austin, TX) (Fig. 3). Each screen stood 914-mm tall and 457-mm wide, with a testing area of 609 mm by 406 mm. Screens contained a circuit board that housed a line of 72 infrared emitting diodes that created a plane of infrared light (Fig. 4). When a baseball was propelled through the screen, the plane of infrared light was broken sending a signal to a chronograph (Oehler Research, Austin, TX) mounted above the screen (Fig. 5). Screens were powered using 120-V ac power supplied using a standard 12-V automobile battery (Type 31T190, New Castle Battery Mfg, New Castle, PA) and a pure sine wave power inverter (Model# PST-30S-12A, Samlex America, British Columbia, Canada).

By propelling a ball through two ballistic screens placed a set distance apart, a velocity was measured. As the ball broke each plane of light a pulse was sent to the chronograph. The chronograph calculated velocity from the time difference between these pulses (the time required to break both planes of light). Pennbounce used four ballistic screens. One pair of screens was used to measure the velocity of the ball prior to impacting the playing surface and the second was used to measure the velocity after impact (Fig. 6).

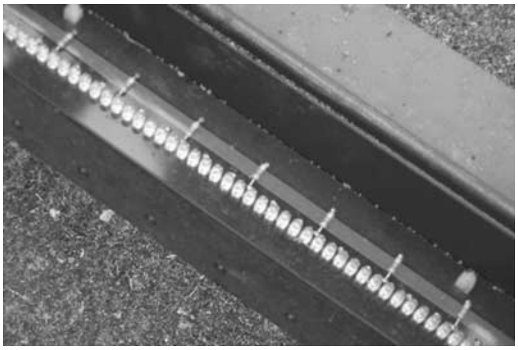

FIG. 4—*Circuit board with infrared emitting diodes.*

FIG. 5—*Chronograph used to calculate velocity values.*

Each set of screens was mounted inside a 3.17-mm thick angle iron box that positioned the screens at a set distance of 30.5 cm. The boxes were fastened inside a frame (2388 by 483 mm) on a pivot that allowed each box to rotate from 0 to 1.57 radians (0 to 90 degrees). Steel pins were inserted into the frame in order to secure the boxes at three testing angles: 0.26, 0.44, 0.61 radians (15, 25, and 35 degrees), respectively (Fig. 7).

The air cannon was positioned perpendicular to one set of screens using a holster mounted on one box (Fig. 8). The holster was a pipe (216-mm long, 72.6-mm diameter) attached to four 305-mm long pieces of angle iron (Fig. 8). When a baseball is propelled through the screens, the distance between the point of surface contact and each set of boxes could be adjusted by securing the holster at varying points along the edge of the box. A holster position was selected for each test angle to create a point of contact that was an equal distance from each set of boxes.

The frame was equipped with four 254-mm diameter wheels fastened to lever arms. During transport, these lever arms were pinned to the frame elevating the apparatus off the surface. During testing the pins were removed to lower the frame to the surface. A 51-mm diameter roller (Fig. 9) was attached to the rear of the frame allowing the operator to elevate only the front of the device when

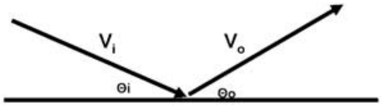

FIG. 6—*Schematic of ball velocity prior to (V_i) and after impact (V_o) with the playing surface, as well as impact angles before (Θ_i) and after (Θ_o) impact.*

FIG. 7—*Pennbounce configured to collect data in the 0.44 radian (left) and 0.61 radian (right) impact angle positions.*

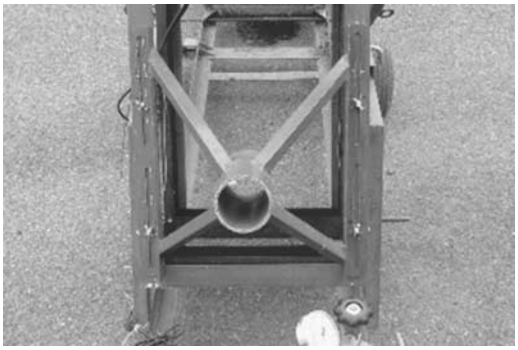

FIG. 8—*Holster for air cannon.*

moving the apparatus to a new test location. The roller prevented the frame from cutting into the test surface. A net attached to the rear of the frame collects balls after impact.

Experimental Design

A study was conducted in April 2005 to determine the pace of four playing surfaces used in baseball. Two synthetic turf surfaces, one traditional ("Astroturf," SRI Sports, Dalton, GA 37021) and one infilled surface ("Fieldturf," FTOS1-F, Dalton, GA 30721), were evaluated at the Joseph Valentine Turfgrass Research Center, University Park, PA. Two other surfaces (natural turfgrass and skinned infield) were tested at Penn State's Beaver Baseball Field, University Park, PA. The coefficient of restitution of baseballs striking these surfaces was measured at two angles (0.44 and 0.61 radians) and two velocities (31.0 m s^{-1} and 40.2 m s^{-1}).

FIG. 9—*Roller mounted to the rear of the frame.*

TABLE 2—*Mean surface pace values (coefficient of restitution) tested on different playing surfaces in 2005.*

Surface	*N*	Coefficient of Restitution
Astroturf	12	0.562a[*]
Skinned infield	12	0.537b
Fieldturf	12	0.487c
Natural turfgrass	12	0.378d
LSD ($p \leq 0.05$)		0.020

[*] Means with different letters are significantly different from one another ($p \leq 0.05$).

Statistical Analysis

Three experimental blocks were randomly selected within each of the four playing surfaces. Six "sub-sample" evaluations were made at each angle-velocity combination in each block, resulting in 72 coefficient of restitution measurements characterizing the pace of each playing surface.

Mean values were analyzed using a combined analysis of variance (ANOVA), with the factor of block within surface tested as a random variable. Fisher's least significant difference (LSD) was calculated when the F-ratio was significant at the 0.05 level (SAS Institute, Cary, NC).

Results and Discussion

Differences in surface pace (coefficient of restitution) due to playing surface type and impact angles were detected (Table 1). Balls striking traditional synthetic turf (Astroturf) measured higher than those striking skinned, infilled synthetic turf (Fieldturf), and natural turfgrass surfaces, respectively (Table 2). Thorpe and Canaway [18] also found balls striking synthetic and grass-free surfaces (e.g., skinned infield) to have a higher coefficient of restitution than those striking natural turfgrass. This relationship was consistent across both angles and testing velocities.

Coefficient of restitution varied with impact angle. Balls contacting the surface at an angle of incidence of 0.44 radians had a higher velocity after impact than those striking the surface at 0.61 radians (Table 3). A similar relationship was observed measuring the coefficient of restitution of tennis balls [18]. This is because shallower angles of inclination result in less of the surface area of the ball contacting the testing surface. Also, the total time in which the ball is in contact with the testing surface is reduced. These two factors result in less energy loss to the surface.

Although the relationship between the various testing surfaces

TABLE 1—*Analysis of variance of surface pace (coefficient of restitution) by sources and interactions.*

Source	DF	P-value
Surface (S)	3	***[a]
Replication (Surface)	8	Ns[b]
Angle (A)	1	***[a]
Velocity (V)	1	Ns[b]
S × A	3	Ns[b]
S × V	3	***[a]
A × V	1	Ns[b]
S × A × V	3	Ns[b]
Error	24	…

[a] Significant at $P \leq 0.001$ levels.

[b] Ns = Not significant.

TABLE 3—*Mean surface pace values (coefficient of restitution) tested at different angles velocities in 2005.*

Angle of Incidence	N	Coefficient of Restitution
0.44 radians	24	0.539a*
0.61 radians	24	0.443b
LSD ($p \leq 0.05$)		0.014

*Means with different letters are significantly different from one another ($p \leq 0.05$).

was consistent at each testing velocity (Table 4), a significant interaction between surface and velocity was detected (Table 1). For traditional synthetic turf (Astroturf) and skinned infield surfaces, coefficient of restitution values at a velocity of 40.2 m s^{-1} measured greater than those at a velocity of 31.0 m s^{-1} (Table 4). On infilled synthetic turf (Fieldturf) and natural turfgrass surfaces, coefficient of restitution values at a velocity of 40.2 m s^{-1} measured lower than those at a velocity of 31.0 m s^{-1} (Table 4). Natural turfgrass and infilled synthetic turf surfaces (Fieldturf) are less dense than traditional synthetic turf and skinned infield surfaces. Balls projected at 40.2 m s^{-1} likely penetrate deeper into the surface than they do at 31.0 m s^{-1}. Deeper penetration causes more energy to be absorbed by the surface, resulting in lower coefficient of restitution values. At the lower testing velocity (31.0 m s^{-1}) balls are likely only reacting with the uppermost portion of the surface, not the entire profile. Therefore, a 40.2 m s^{-1} testing velocity should be used to provide more representative surface pace data

TABLE 4—*Mean surface pace (coefficient of restitution) values for each surface-velocity combination.*

Surface	Velocity	N	Coefficient of Restitution
Astroturf	31.0 m s^{-1}	6	0.555
Astroturf	40.2 m s^{-1}	6	0.568
Fieldturf	31.0 m s^{-1}	6	0.502
Fieldturf	40.2 m s^{-1}	6	0.472
Natural turfgrass	31.0 m s^{-1}	6	0.403
Natural turfgrass	40.2 m s^{-1}	6	0.355
Skinned infield	31.0 m s^{-1}	6	0.511
Skinned infield	40.2 m s^{-1}	6	0.564
LSD ($p \leq 0.05$)			0.028

The testing apparatus provided repeatable measurements of playing surface pace (coefficient of restitution). Repeatability was estimated on each surface by calculating the standard error of *COR* and velocity measurements for each angle-velocity combination (Table 5). Across all surfaces, standard error estimates averaged 1.0, 0.6, and 0.022 for velocity prior to impact (V_i), velocity after impact (V_0), and the coefficient of restitution (*COR*), respectively (Table 5).

Conclusion

Very few studies have directly measured playing surface pace. It has often been inferred through measurements of other ball-to-surface interactions, such as vertical ball rebound and ball-to-surface friction. Studies in tennis and cricket have evaluated playing surface pace through measurements of the coefficient of restitution, yet baseball playing surface pace has not been investigated.

An apparatus, termed Pennbounce, was developed to directly measure the pace of baseball field playing surfaces. Pennbounce can operate at varying angles and ball velocities. In this study Pennbounce was able to detect differences among the various surfaces currently used in baseball. These differences were consistent regardless of velocity or ball impact angle. Testing at higher initial velocities likely resulted in balls reacting with the entire surface

TABLE 5—*Standard error of COR and velocity measurements for each angle-velocity combination on each surface.*

Angle-Velocity Combination	N	Skinned Infield			Natural Turfgrass			Fieldturf			Astroturf		
		V_i	V_0	*COR*	V_i	V_0	*COR*	V_i	V_0	*COR*	V_i	V_0	*COR*
0.61 rad-40.2 m s^{-1}													
Block A	6	37.4	19.8	0.535	37.6	10.6	0.283	40.0	16.6	0.417	38.2	19.5	0.513
Block B	6	40.1	20.5	0.512	39.0	10.6	0.272	38.5	16.4	0.426	36.5	19.5	0.537
Block C	6	38.6	19.6	0.506	37.6	10.7	0.289	36.3	16.4	0.452	39.2	19.3	0.491
0.61 rad-31.0 m s^{-1}													
Block A	6	30.8	13.4	0.424	28.7	9.9	0.347	29.3	13.2	0.452	29.0	15.8	0.551
Block B	6	31.6	15.2	0.478	32.7	11.8	0.367	31.5	14.3	0.456	30.7	16.2	0.530
Block C	6	30.9	16.0	0.512	32.7	11.7	0.361	33.6	14.2	0.429	28.9	13.8	0.481
0.44 rad-40.2 m s^{-1}													
Block A	6	38.5	23.1	0.600	37.2	14.8	0.411	38.9	19.4	0.502	38.0	24.9	0.662
Block B	6	36.7	22.9	0.631	38.2	17.2	0.451	37.1	19.3	0.525	39.3	23.7	0.602
Block C	6	37.4	22.3	0.598	38.6	16.2	0.423	39.7	20.3	0.513	37.9	22.8	0.604
0.44 rad-31.0 m s^{-1}													
Block A	6	31.2	16.4	0.525	35.3	15.3	0.434	33.8	18.2	0.541	32.4	18.7	0.579
Block B	6	30.2	17.0	0.574	34.8	15.9	0.456	34.1	18.5	0.543	32.9	18.9	0.573
Block C	6	30.8	16.9	0.548	35.1	15.8	0.453	29.2	17.1	0.589	32.7	19.9	0.619
Standard Error		± 0.9	± 0.6	± 0.023	± 1.2	± 0.8	± 0.026	± 1.2	± 0.5	± 0.018	± 1.0	± 0.5	± 0.022

V_i=Velocity of baseball prior to contacting the testing surface measured with Pennbounce (see Fig. 6).

V_0=Velocity of baseball after contacting the testing surface measured with Pennbounce (see Fig. 6)

COR=Coefficient of restitution=(V_0/V_i).

Standard Error=$\sigma/\sqrt{N}$.

profile, not just the uppermost portion. Thus, within the conditions of this study, Pennbounce can be used to evaluate surface pace using only one angle and initial ball velocity.

With a portable and accurate device to evaluate the pace of baseball playing surfaces in situ, researchers can determine how playing surface pace is affected by changing surface conditions. As new surfaces are introduced into the industry, information about their surface pace can be easily generated. Field managers can use this information to maximize both the safety and playability of playing surfaces.

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