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Launch fly balls for better batting statistics: Applicability of "fly-ball revolution" to Japan's professional baseball league

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ABSTRACT

"Fly-ball revolution" in Major League Baseball (MLB), spotlighting an underlining tenet that batters should aim for big fly balls rather than grounders, has attracted interest from countless players around the world. Its applicability, however, is not clear for players of different physical abilities or teams with different game strategies from MLB's. This paper aims to test a hypothesis that hitting fly balls do not result in better batting statistics than hitting grounders in Japan's Nippon Professional Baseball (NPB). From radar-tracking outputs collected in the official games, the speed, launch angle, and batting results of all batted balls in play were extracted (n = 39,469). In-play batting average (IPBA) and slugging percentage (IPSP) were compared between fly balls and grounders. The results showed the better batting statistics for fly balls (IPBA = 0.381 ± 0.018; IPSP = 0.730 ± 0.079) than grounders (IPBA = 0.267 ± 0.010; IPSP = 0.285 ± 0.010). Thus, our hypothesis was rejected. The balls launched at 10°–20°, called line drives, resulted in higher IPBA over the typical speed range (120 – 150 km/h), suggesting that NPB players whose ball speed was typical should aim for line drives, rather than high fly balls by accepting the tenet.

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game analysis; ball-tracking system; baseball statistics; kinematics

1. Introduction

A new trend of batting approach, known as the "fly-ball revolution", has been featured in countless stories on social and sports media of baseball (e.g. Petriello, 2017; Sawchik, 2017a, 2017b; Sheinin, 2017). The central tenet of the fly-ball revolution, named the pro-flyball principle in this study, is that batters should aim for big flies by changing the angle of swing. The fly-ball revolution has been driven by (i) the statistical findings in the official games of the Major League Baseball (MLB) that hitting fly balls led to a higher batting average and higher slugging percentage than hitting grounders (Sawchik, 2017b; Sheinin, 2017) and batted balls launched upward in the range of 26°–30°, generally categorised as fly balls, with a speed of at least 157 km/h led to a minimum 0.500 batting average and 1.500 slugging percentage (MLB Advanced Media, n.d.-a) and also by (ii) the printed inside stories about the success of MLB players, such as Josh Donaldson, Julio

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Daniel Martinez, and Justin Turner, who proclaimed that they adopted a swing suitable for hitting a fly ball (Lindbergh & Sawchik, 2019). The pro-flyball principle has attracted keen interest from players not only in MLB but also at various levels of competition, ranging from high school to professional in other countries, such as in Japan (Baseball geeks, 2019; Gondo & Ninomiya, 2019). Recently, the first coaching book specialising in hitting fly balls (Tachibana, 2019) was published in Japan and one of the most influential baseball magazines posted an article on Shohei Otani, the Japanese superstar slugger in MLB, reporting his remark that he always aims for hitting fly balls (Baseball magazine editors, 2019). These publications and other stories on various media featuring the fly-ball revolution have boosted a rapid spread of the pro-flyball principle throughout Japan.

Despite the spread of the pro-flyball principle, the applicability of the principle is debatable in MLB because the principle may not be necessarily suitable for all batters to improve batting statistics. One report of the media claimed that adopting the principle will probably increase the chance of making home runs but make only a handful of sluggers' batting statistics better in MLB (Arthur, 2017). Based on this, the principle might not lead to better batting statistics in other baseball leagues of younger age groups or in countries other than the United States. A Hall of Fame of American Baseball Coaches Association suggests the advantage of hitting grounders and line drives than fly balls to amateur players such as college players in NCAA Division I, which is the highest level of intercollegiate athletics authorised by the National Collegiate Athletic Association in the United States (Johnson, 2011). Baseball in Japan is substantially different from MLB in terms of both defensive and offensive strategies and players' physical ability to hit the ball far beyond the outfield wall. For example, the drastic defensive shifts (MLB Advanced Media, n.d.-c) commonly seen in MLB games are seldom used in high school, college, and Nippon Professional Baseball (NPB) leagues in Japan (James & Baseball Info Solutions, 2019). In addition, except for eminent sluggers in NPB, most players in Japan do not aim to hit home runs, but rather aim to reach first base or play "smallball" (Friedman, 2005), in order to produce runs by strategies, such as prioritising base hits, bunting or hitting the ball to a specific direction to advance runners, not hitting the first few pitches to provide baserunners with better opportunities to steal bases, and avoiding strikeouts. Furthermore, the players in Japan are generally shorter and smaller than their North American counterparts (Katsumata et al., 2018), and their bat head speed, which is the primary determinant of the batted ball speed (Cross, 2014), is generally lower. With slower speeds, fly balls launched in the same range of launch angle are less likely to be home runs or two- or three-base hits off the wall. This suggests that both the corresponding batting average and slugging percentage in the same range of launch angle should be lower for batters whose batted ball speed is not high enough, such a typical batter in baseball leagues in Japan. Because of these differences, the pro-flyball principle might not bring the same advantages to the baseball leagues in Japan as to MLB.

To date, no study investigated the kinematic characteristics of batted balls with respect to the applicability of the pro-flyball principle using the data from official NPB games. Evaluating the applicability of this principle can help players and coaches select an effective batting strategy in games. In this study, we described the kinematic characteristics of batted balls for each batting result (i.e. one-, two-, and three-base hits, and home run, hereinafter called single, double, triple, and home run, respectively) in official NPB games and tested a hypothesis that hitting fly balls does not result in better batting statistics than hitting grounders in NPB. Corresponding data from the official MLB games were used as a reference to reveal the uniqueness of the kinematic characteristics of batted balls in NPB.

2. Materials and methods

An NPB team provided a de-identified, anonymised data set containing the standard TrackMan (TrackMan A/S, Denmark) outputs from all official top-league games played by all 12 NPB teams during the 2019 season. The institutional review board officially exempted this study from the standard IRB review (institutional review board number: 2021-HN008) because the data set did not identify any human subject. For the initiation and publication of this study, we obtained permission and approval from the data source (i.e. the NPB team and TrackMan A/S), who had the ownership of the TrackMan outputs, provided that (a) the data was used only for academic research, that (b) there was no team or player that could be identified in the study, that (c) the research did not incur unreasonable benefits or losses to any particular team or player, and that (d) there were no commercial contents in the study. TrackMan is a 3D Doppler radar-tracking system installed at a number of home fields of professional baseball teams in Japan, Korea, Taiwan, and the United States (Huang & Hsu, 2020). It measures the trajectories of pitched and batted balls and stores selected parameters of each trajectory. In the present study, the speed, launch angle, and flight distance of each batted ball and the corresponding batting results on all balls in play ($n = 39,469$ in 760 games) were extracted for analysis. The flight distance was calculated based on where the ball landed or where it would have landed if not caught or obstructed (Woods, 2019).

A preliminary study was conducted to assess the validity of the radar-tracking outputs by comparing them with corresponding values measured by another system of known accuracy. For 34 pitched balls, the velocities at home plate were compared with a three-dimensional videography technique. The result showed that the measured magnitudes (81 − 126 km/h) and vertical directions (3°–23° downward) of pitched ball velocities at home plate were of excellent agreements between the two methods (mean of the differences ± SD: −0.9 ± 0.3 km/h, 0.2° ± 0.2° & concordance correlation coefficients [CCC, Lin, 1989]: 0.99 for magnitude and direction). The flight distances of batted balls were also compared with video footages. From the video recordings of all official games played at a ballpark in the 2019 season ($n = 70$), the batted balls caught or landed on the warning track (4-m width from the wall) or hit the wall directly were extracted ($n = 159$) and their flight distances were estimated (97 − 124 m) based on the known dimensions of the ballpark. The result showed the moderate agreement between the two sets of measurements (mean: −2 ± 3 m and CCC: 0.91). The obtained differences in these comparisons were similar to the measurement errors of a portable version of the radar-tracking system reported by the manufacturer (TrackMan, n.d.). These results demonstrate that the radar system provides measurements that are as valid as video-based methods, supporting the applicability of using the radar system measurements in the present study.

The same radar-tracking system (TrackMan) served in MLB as the ball-tracking device to feed data into Statcast from the 2015 to 2019 seasons (MLB Advanced Media, n.d.-d). The radar-tracking data publicly available for non-commercial use was collected from the online database of MLB (Baseball Savant, n.d., http://baseballsavant.mlb.com/statcast_search). The speed, launch angle, and flight distance of each batted ball and the corresponding batting results for MLB in the 2019 season (n = 125,465 balls in play in 2464 games) were collected as a reference.

The total number of batted ball records used for the analysis was 39,469 for NPB. Among these, there were 3607 cases (9%) in which the speed and/or launch angle of the batted ball were missing. This is presumably due to the radar system's weakness in tracking balls launched at extreme upward or downward angles (e.g. bunts, grounders, or pop-ups, most of which resulted in outs). A solution method named "no-null solution", developed by a senior database architect of stats for MLB Advanced Media and implemented for the MLB's 2015 – 2019 seasons (Tango, 2017), was applied in this study. With this method, the missing values of a given case were replaced by the mean values computed over those cases in which the batted ball records were complete and the batting outcomes labelled by two nominal variables of the radar-tracking output, namely batting result (i.e. "out", "single", "double", "triple", "home run", "error", and "fielder's choice"), and batted ball trajectory (i.e. "bunt", "grounder", "line drive", "fly ball", and "pop-up"), were identical (See Table A1 and Figure A1 in the appendix for the list of the values and the change in the data distribution).

The batted balls were classified into "grounders" and "fly balls" by the launch angle of the batted balls: <10° for the grounders and ≥10° for the fly balls, in accordance with an MLB News article (Petriello, 2017) and general guidelines published on the official website of MLB (MLB Advanced Media, n.d.-b). To compare the productivity of hitting fly balls and grounders into fair territory for earning more hits and bases, the following variables were computed to describe the batting statistics for each trajectory classification in accordance with the previous reports (Sawchik, 2017a; Sheinin, 2017):

- In-play batting average for fly balls ($IPBA_{FB}$) and for grounders ($IPBA_G$), defined as the number of all base hits divided by the number of balls in play with the respective trajectory classification:

$$IPBA_{FB} = \frac{\text{Fly\_Singles} + \text{Fly\_Doubles} + \text{Fly\_Triples} + \text{Home runs}}{\text{The countof the fly balls}} \quad (1)$$

$$IPBA_G = \frac{\text{Grounder\_Singles} + \text{Grounder\_Doubles} + \text{Grounder\_Triples}}{\text{The count of the grounders}} \quad (2)$$

and

- In-play slugging percentage for fly balls ($IPSP_{FB}$) and for grounders ($IPSP_G$), defined as total bases divided by the number of balls in play with the respective trajectory classification:

$$\mathrm{IPSP_{FB}} = \frac{\mathrm{Fly\_Singles}*1 + \mathrm{Fly\_Doubles}*2 + \mathrm{Fly\_Triples}*3 + \mathrm{Home\ runs}*4}{\mathrm{The\ count\ of\ the\ fly\ balls}} \tag{3}$$

$$\mathrm{IPSP_{G}} = \frac{\mathrm{Grounder\_Singles}*1 + \mathrm{Grounder\_Doubles}*2 + \mathrm{Grounder\_Triples}*3}{\mathrm{The\ count\ of\ the\ grounders}} \tag{4}$$

where BIP denotes balls in play. To evaluate how IPBA and IPSP for each trajectory classification were influenced by batted ball speed, these batting statistics were computed for nine 10-km/h intervals of batted ball speed as well as over the entire speed range. The width of the speed interval was determined by Sturges' rule. The IPBA and IPSP for each of the nine intervals were computed for each ballpark.

To describe the differences in the offensive strategies between NPB and MLB, the frequency of every result from all plate appearances (i.e. strikeouts, sacrifice bunts, sacrifice flies, walks, singles, doubles, triples, and home runs) was determined for each game and compared between NPB and MLB. The Kolmogorov-Smirnov tests revealed that the distribution across the games was not normal for the frequency of every result ($p < .001$), and also for the batted ball speed, launch angle, and flight distance for each batting result (i.e. singles, doubles/triples, home runs, and outs) ($p < .001$). The median values and interquartile ranges (IQR) were computed for these variables and the Mann-Whitney U tests were used to compare between NPB and MLB. The effect size was evaluated by computing r (Cooper & Hedges, 1994). The Shapiro-Wilk test revealed that both IPBA and IPSP were normally distributed across all ballparks for almost all speed ranges and trajectory classifications (33 out of 36 variables; the range of p-values: 0.052 − 0.978). The mean value and standard deviation of these batting statistics were computed across all ballparks. The paired t-test was used for assessing the mean differences in IPBA and IPSP between grounders and fly balls in each range of the batted ball speed. Cohen's d was computed to evaluate the effect size (Cohen, 1988).

3. Results

In the 2019 season, the NPB radar system recorded 57,665 plate appearances by 499 batters in 760 games (Figure 1). No significant differences were found in the numbers of walks and sacrifice flies per game between NPB and MLB (p = .215 and .175 for walks/game and sacrifice flies/game, respectively), whereas characteristics typical of teams adopting a smallball strategy were found in NPB: the median number of sacrifice bunts per game was significantly higher in NPB than in MLB (1 sacrifice bunt/game [IQR: 0 – 2] for NPB and 0 [0 – 1] for MLB, $p < .001$, $r = 0.41$) and the number of strikeouts per game was lower in NPB than in MLB (15 strikeouts/game [12 – 18] for NPB and 17 [15 – 20] for MLB, $p < .001$, $r = 0.23$). A total of 39,469 at-bats (77.3% of all at-bats) resulted in balls in play in NPB, among which 66.2% resulted in outs and 32.3% resulted in base hits in NPB.

A total of 39,469 balls in play resulted in 19,887 grounders (50.4%) and 19,582 fly balls (49.6%) in NPB. The ratio of fly balls to grounders was lower in NPB (0.98) than in MLB (1.13). In NPB, the batting results were 8774 singles, 2268 doubles, 218 triples, and 1525 home runs. The number of singles per game was higher in NPB than in MLB (11 singles/

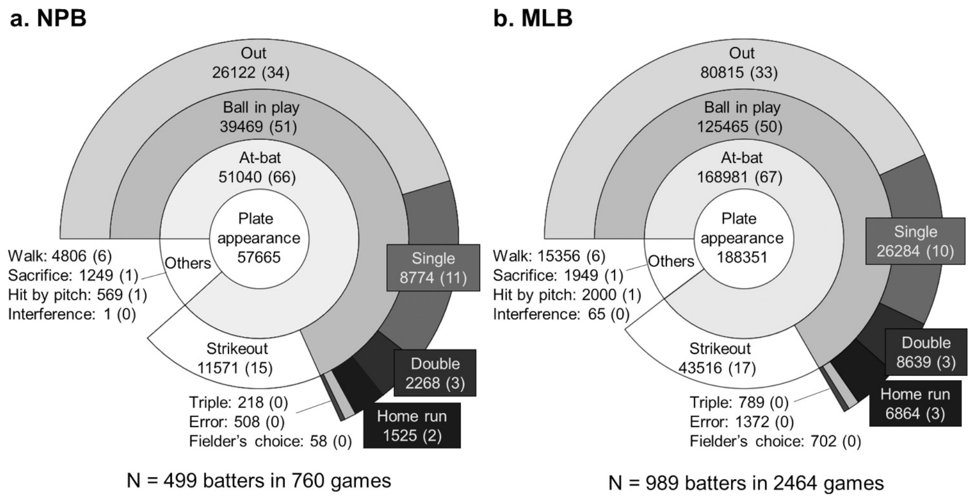

Figure 1. Number of at-bats out of all plate appearances (inner circle), number of balls in play out of all at-bats (middle ring) and number of batting results out of all balls in play (outer circle). The numbers in parentheses indicate the median number for each batting event per game. A total of 57,665 plate appearances by 499 batters in 760 games were recorded by the radar system in NPB, which account for 87% of all top-league official games in 2019.

game [9 – 14] for NPB and 10 [8 – 13] for MLB, $p < .001$, $r = 0.10$), whereas the numbers of home runs were higher in MLB than in NPB (3 home runs/game [1 – 4] for MLB and 2 [1 – 3] for NPB, $p < .001$, $r = 0.20$).

The data distributions of the ball kinematic characteristics for each batting result in NPB and MLB are shown in (Figure 2). The median speed, launch angle, and flight distance of all batted balls were, respectively, 139 km/h (IQR: 122 – 152 km/h), 10° (−9° to 29°), and 44 m (5 – 85 m) in NPB. Although significant differences were found in all these variables between NPB and MLB ($p < .001$), the effect sizes were small ($r = 0.14$, 0.04, and 0.05 for ball speed, launch angle, and flight distance, respectively). The median ball speed for each batting result was consistently and significantly lower in NPB than in MLB ($p < .001$, $r = 0.14$, 0.12, 0.21, and 0.31 for outs, singles, doubles/triples, and home runs, respectively). In particular, the speed of home runs was 7 km/h lower in NPB (160 km/h [IQR: 156 – 165 km/h]) than in MLB (167 km/h [162 – 172 km/h]). Significant differences were found in flight distance of the home runs (121 m [114 – 126 m] in NPB vs. 122 m [116 – 127 m] in MLB, $p < .001$, $r = 0.07$) and launch angle (28° [25°–32°] in NPB vs. 28° [24°–32°] in MLB, $p = .002$, $r = 0.03$), but the effect sizes were very small.

The results of the paired t-test showed that IPBA in NPB was significantly higher for fly balls than for grounders in the speed ranges of <130 km/h and >150 km/h (range of Cohen's $d = 1.08 – 5.75$), but not in the ranges of 130 – 150 km/h ($d = 0.09 – 0.47$, (Figure 3(a-i)). The resulting IPBA over the entire speed range was found to be significantly higher for fly balls than for grounders in the NPB games (0.267 ± 0.010 for grounders vs. 0.381 ± 0.018 for fly balls, $p < .001$, $d = 5.20$). IPSP was significantly higher for fly balls than for grounders over all speed range ($d = 1.17 – 7.18$, (Figure (3a)). The

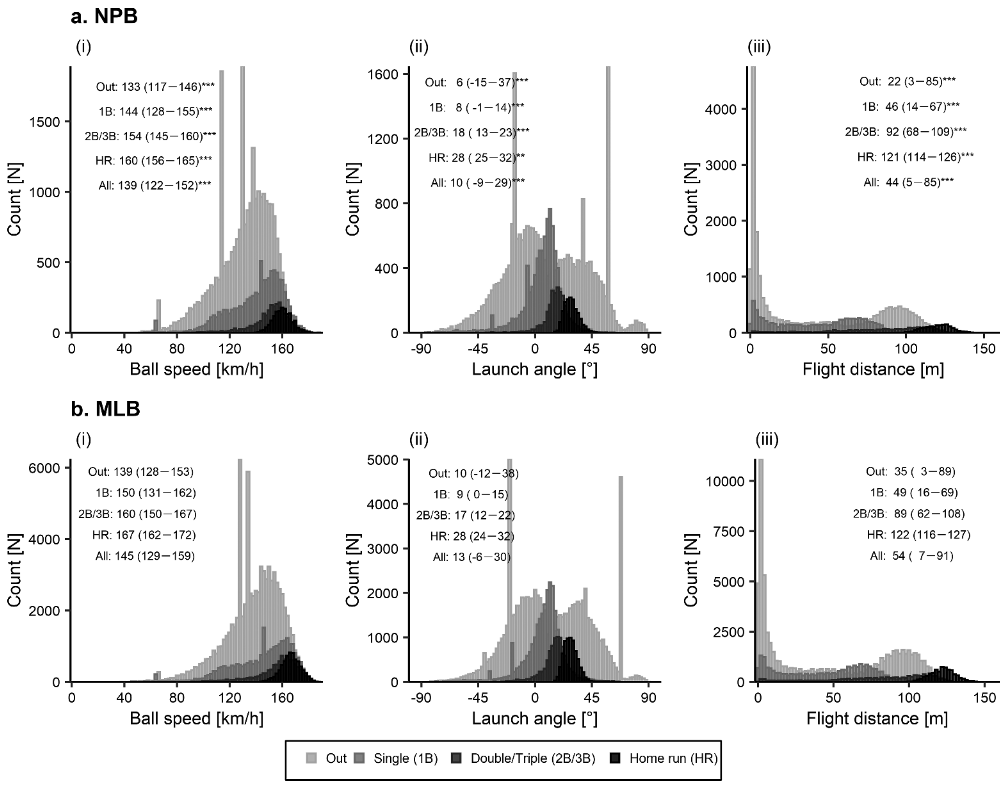

Figure 2. Distributions of (i) batted ball speed, (ii) launch angle, and (iii) flight distance for outs, singles, doubles/triples, and home runs in (a) NPB and (b) MLB. Values are shown as the median (interquartile range). Significant differences in kinematic variables between NPB and MLB: ***p < .001, **p < .010, *p < .050. The extremely large counts in the particular range on the distribution of the batted ball speed and launch angle could be caused mostly due to the "non-null solution", which had been used in the MLB for 2015–2019 seasons (Tango, 2017). We applied the same method to the NPB data, allowing us to compare the kinematic characteristics of the batted balls between the two leagues.

resulting IPSP over the entire speed range was found to be significantly higher for fly balls than for grounders (0.285 ± 0.010 bases/BIP for grounders vs. 0.730 ± 0.079 bases/BIP for fly balls, p < .001, d = 5.40). Similar trends were found in MLB (Figure 3(b)).

The number of each batting result for given combinations of batted ball speed and launch angle in NPB is shown in (Figure 4). Most batted balls were hit at 10°–20° with a speed of 150 – 160 km/h. The majority of singles (62.1%) were launched within the range of 0°–20° and many doubles/triples (60.1%) were launched either at 10°–20° with a speed of 140 – 170 km/h or at 20°–30° with a speed of 140 – 160 km/h. Most home runs (86.8%) were launched at 20°–40° with a speed of 150 km/h or higher. Batted balls launched at 20°–40° with a speed in the intermediate range (120 – 150 km/h) resulted in a much lower IPBA (range: 0.01 – 0.41) than those in the low and high-speed ranges. IPBA was consistently high (>0.65) for batted balls launched at 10°–20° with a speed of >110 km/h (Figure 5(a)). The so-called "barrel zone", defined as the speed and launch angle of batted balls leading to a minimum 0.500 IPBA and 1.500 IPSP (MLB Advanced

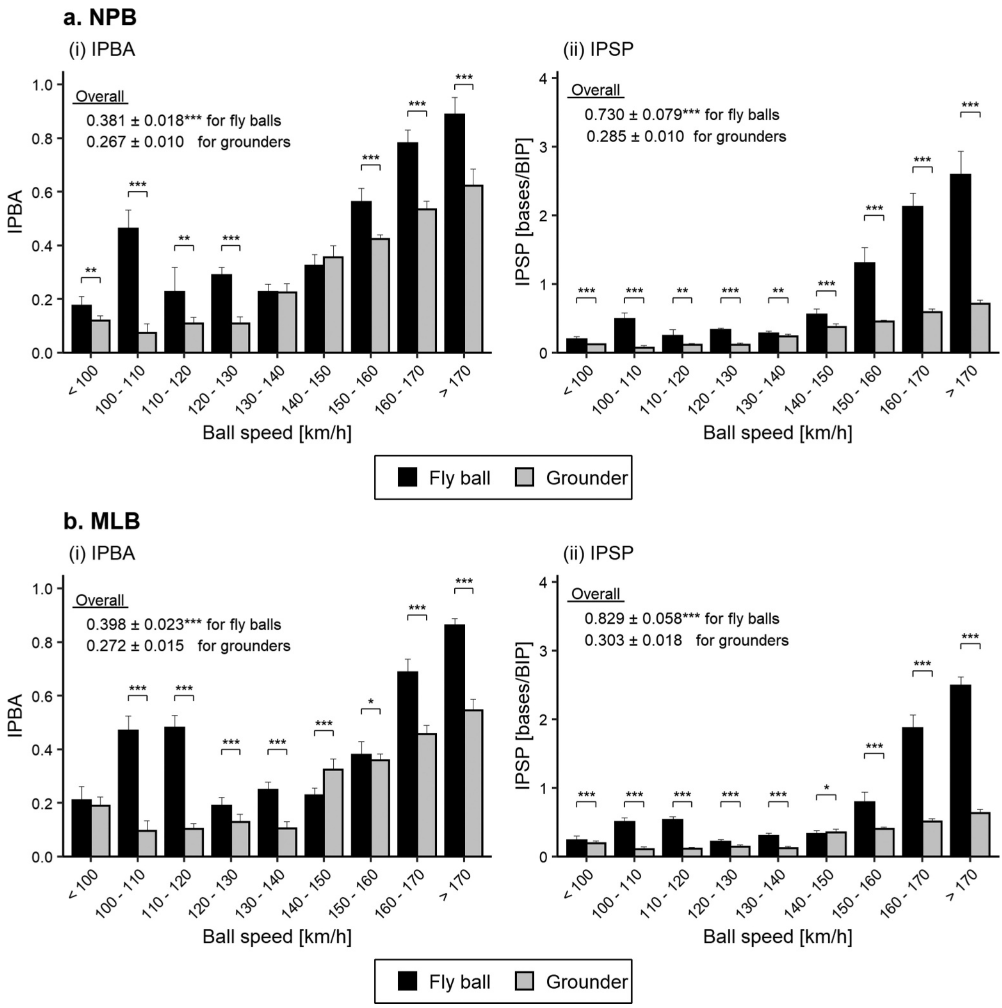

Figure 3. IPBA and IPSP by ball speed range in (a) NPB and (b) MLB. Significant differences in batting statistics between grounders and fly balls: ***$p < .001$, **$p < .010$, *$p < .050$.

Media, n.d.-a), was found to consist of the following zones in NPB: 20°–30° at 150 – 160 km/h, 20°–40° at 160 – 170 km/h, and >10° at >170 km/h. The barrel zone in MLB was found to be batted balls launched at 20°–40° with a speed of 160 – 170 km/h and 10°–40° at >170 km/h (Figure 5(b)).

4. Discussion

The aims of this study were to describe the kinematic characteristics of batted balls in official NPB games and to compare IPBA and IPSP between grounders and fly balls across various ranges of ball speed. The results showed that typical characteristics of a smallball strategy were present in NPB: fewer strikeouts, more sacrifice bunts, more singles, and less home runs. Those results agree with the assumption that offensive

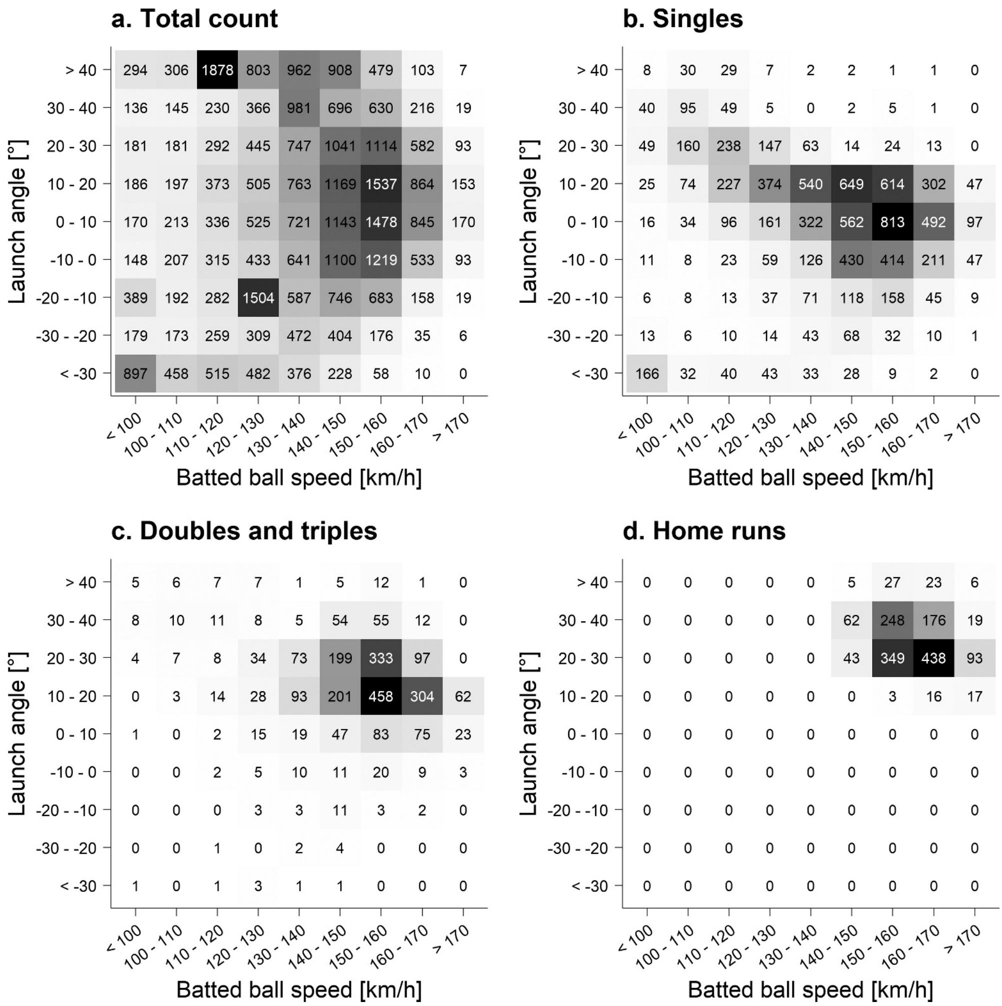

Figure 4. Frequency distributions over the ranges of ball speed and launch angle in NPB.

strategies and average batted ball speed in NPB are different from those in MLB. Nevertheless, compared with hitting grounders, hitting fly balls resulted in higher IPBA and IPSP; thus, our hypothesis that hitting fly balls does not result in better batting statistics than hitting grounders was rejected. These observations suggest that the pro-flyball principle is applicable to NPB. Balls launched around 10°–20° resulted in better IPBA with a speed of 120 – 150 km/h, which coincided well with the typical speed range in NPB games (IQR: 122 – 152 km/h). Notably, the barrel zone, which is >0.500 IPBA and >1.500 IPSP, was found at >150 km/h in NPB, while it was found only at >160 km/h in MLB. This indicates that the barrel zone is found in the lower speed range in NPB than in MLB.

The results of our analysis showed that 32.3% of in-play balls resulted in base hits in NPB. In general, the ratio of the number of base hits to total plate appearances, commonly referred to as batting average, is considered excellent if it exceeds .300 in official games. The result of our analysis indicates that hitting balls into fair territory even

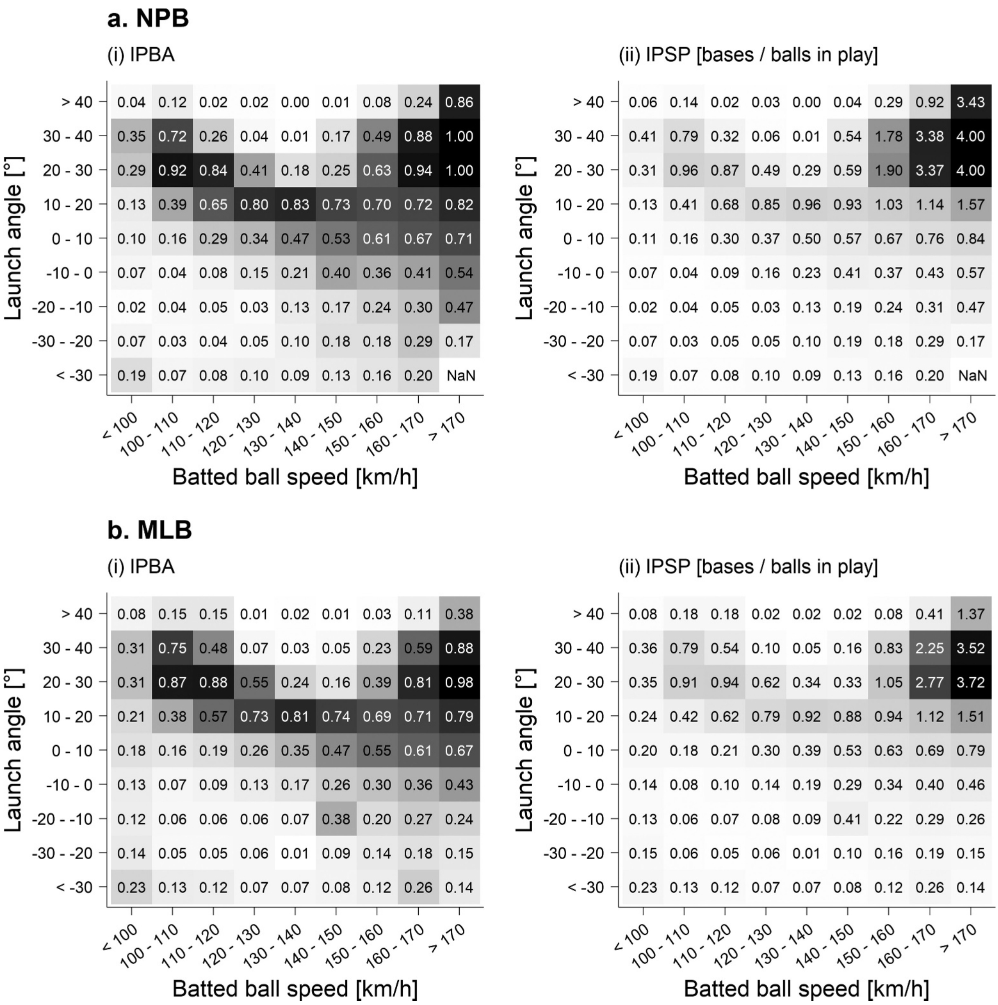

Figure 5. Batting statistics by ball speed and launch angle in (a) NPB and (b) MLB. Colours indicate the value of the batting statistics.

with the typical distribution of the ball speed can contribute to achieving such an excellent batting average with avoiding the strikeouts. To improve batting average, players generally set goals in batting techniques: to hit the ball at a high speed and/or launch it intentionally towards a space between infielders at every plate appearance. The results of this study suggest an additional goal for players to strive for: hitting the ball into the fair territory by any means.

Our results demonstrated that fly balls resulted in better batting statistics than grounders in NPB, similarly to MLB. This finding does not agree with the conventional expectation that hitting grounders would lead to better batting statistics than fly balls for teams or leagues adopting a smallball strategy (Mori, 1977; Shibata, 1989). A possible reason for this disagreement is that fewer errors occur at the professional level. In fact, there were less than 1 error per game in NPB, although more errors occurred in the fielding of grounders compared with fly balls (461 out of 508 errors occurred when fielding grounders). Hitting grounders, therefore, is not likely to lead to a remarkable advantage over fly balls in NPB. Furthermore, strong fielding by defensive players could be another reason for our finding. Compared with lower levels, professional players can be expected to have a wider defensive zone in which they can field grounders and get the batter out. To intentionally hit a grounder into a space between the defensive zones of fielders, the batter must make contact at a certain point on the ball while controlling the bat angle in both the horizontal and vertical directions (Shimura et al., 2018). This suggests that getting base hits by hitting grounders into gaps in the defence with high probability might not be an easy task for the players who are trained to intentionally hit the ball in various directions. For these reasons, hitting grounders does not seem to be an effective offensive strategy for improving batting statistics.

The comparisons of IPBA between the fly balls and grounders with the given speed range showed that the advantage of fly balls was not observed in the intermediate range of ball speeds. $IPBA_{FB}$ was lower in the intermediate range (110 – 150 km/h) than in the low-speed range (100 – 110 km/h) and the high-speed range (>150 km/h). In contrast, $IPBA_{GB}$ was higher for grounders in higher speed ranges than in lower speed ranges. This characteristic of fly balls was also reported in MLB and was called the "donut hole" (Nicolella, 2015). Fly balls in the donut hole can be easily caught by outfielders whereas the fly balls in the lower speed range tend to fall in front of outfielders, leading to singles off of so-called bloopers, and fly balls hit in the high-speed range tend to fly over outfielders. Therefore, an ideal launch angle for improving batting statistics can be expected to vary over the entire speed range.

The speed- and angle-specific IPBAs show that a launch angle of 10°–20° appears to be ideal for improving batting average based on our finding that IPBA was above 0.650 for all speed ranges except <110 km/h. This result agrees with the finding of the simulation study (Bahill, 2019) showing that launching a ball at 10°–15° upward will result in base hits. This might be attributable to the fact that the batted balls launched in this range can travel through various distances within a short flight time, thus decreasing the likelihood that the fly balls will be caught by fielders; in other words, the batted balls in the range of launch angles are likely to land between fielders' defensive zones for singles, doubles, or triples. To examine this speculation, the relation between the locations where batted balls landed and the corresponding batting results was plotted for four ranges of launch angle (Figure 6). As the figure illustrates, batted balls resulted in base hits when they landed between infielders, between an infielder and outfielder, and between outfielders. The landing area that results in singles, doubles, or triples was substantially wider for the batted balls launched at low angles than high angles. When a batted ball is launched at a low angle, the chance that a fielder catches the ball before landing is low. In contrast, when a batted ball is launched at a high angle, it takes a longer time to fall and there is a likelihood that a fielder can catch the ball. For batted balls launched at 30°–40°, there is hardly any chance that the ball lands between outfielders. These observations support the speculation that launching the batted balls in the range of 10°–20° is advantageous for reducing the likelihood of the batted ball being caught by fielders. Furthermore, fly balls launched at 10°–20° resulted in higher IPBA, particularly in the range of 120 – 150 km/h. This speed range coincided well with the interquartile range of ball speed in NPB (122 – 152 km/h). Fly balls launched in this range are commonly referred to as line drives; thus, to achieve better IPBA, NPB players whose batted ball speed is typical should

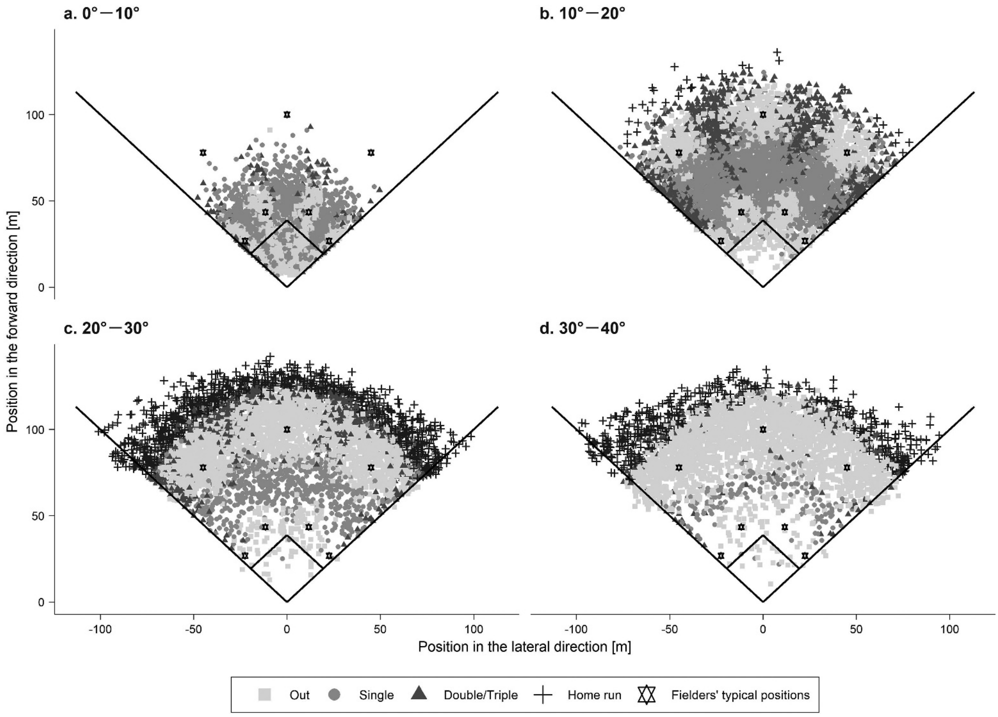

Figure 6. Locations where batted balls landed for four launch angle ranges. The marker type and its colour indicate the batting result as well as typical position for each fielder.

aim to hit line drives, rather than high fly balls based on accepting the "fly-ball revolution" literally. Hitting low line drives has been conventionally set as a target for batters in the United States (Lindbergh & Sawchik, 2019). The results of the present study suggest that the same target is applicable to NPB batters whose batted ball speed is typical. Only batters whose batted ball speed is above typical should adopt the pro-flyball principle and aim for projecting balls in the range of 20°–30° for achieving both higher IPBA and IPSP.

The speed- and angle-specific IPBAs and IPSPs show that the barrel zone was found to consist of several zones in NPB games: 150 − 160 km/h at 20°–30°, 160 − 170 km/h at 20° −40°, and >170 km/h at 10°–20°. On the other hand, a barrel zone was found only at >160 km/h in MLB. The observed difference in barrel zones is partly attributable to the fact there are more home runs in the range of 20°–30° with a speed of 150 − 160 km/h in NPB (31.3% of all balls projected in the range) than in MLB (13.5%). Ballpark size might account for the higher percentages of home runs with these launch conditions of the batted balls, as the distances from the home plate to the foul pole at both side and the deep centre field are shorter in NPB (99 ± 2 m and 121 ± 1 m) than in MLB (101 ± 2 m and 123 ± 3 m; Monagan, 2014; Nippon Professional Baseball Organization, n.d.). Interestingly, however, the flight distances of home runs were found to be similar between the two leagues (median: 121 m [IQR: 114 − 126 m] in NPB vs. 122 m [116 − 127 m] in MLB). In addition, we compared the flight distance of the home runs in NPB with the speed- and angle-matched home runs in MLB (n = 729). The result showed that the flight distance of home runs was 4 ± 6 m shorter in MLB games than the NPB games with the given speed, launch angle, and landing area of the fair territory (opposite, centre, or same fields with a 30°-interval). The difference in ballpark size cannot explain these observations. We suppose that the rate of backspin of the batted ball might provide a physical explanation for the observed difference in the barrel zones between the two leagues. A simulation study reported that a bat swing characterised as a "chop-down swing" (a type of swing in which the vertical component of the bat velocity is directed downward at impact) resulted in the batted balls to have greater rates of backspin than an upward swing did for a given set of impact conditions (same speed of the pitched ball, same swing speed, the same impact location; Shimura et al., 2012). In Japan, a downward swing has been taught as a standard technique over several decades and adopted by many baseball players (Matsui, 2012; Toyoda, 1996). Thus, the backspin rate of home runs might be greater in NPB than in MLB and the increased rate of backspin might have generated greater lift acting on the ball during flight, resulting in the increase in the flight distance for a given speed and launch angle of the batted ball (Nathan, 2007; Rex, 1985). Further studies are needed to examine whether the spin rate of batted balls affects the characteristics of the barrel zones.

The primary limitation of this study is that the "non-null solution" caused the extremely large counts in the particular range of launch angle and batted ball speed and distorted the true distributions of the launch angle and batted ball speed of the fly-balls and grounders. The distorted distribution might have led us to a wrong conclusion about the applicability of the pro-flyball principle. To examine the validity of the main finding, we re-did the analyses assuming the worst-case scenario, that is, all 3190 outs of the cases to which the non-null solution was applied were assumed to be fly balls. The result showed that IPBA was significantly higher for fly balls than for grounders (0.357 ± 0.020 for fly balls vs. 0.286 ± 0.012 for grounders, $p < .001$, $d = 2.63$). Also, IPSP was significantly higher for fly balls than for grounders (0.684 ± 0.081 for fly balls vs. 0.306 ± 0.011 for grounders, $p < .001$, $d = 4.33$), indicating that the use of the non-null solution did not alter the main finding. In addition, IPBA in the range of 10°–20° was not affected by the non-null solution as 99.7% (5711 cases) of all batted balls found in this range were tracked by the radar system successfully. The remaining 0.3% (18 cases) consisted of 4 outs, 11 singles, and 3 doubles and the IPBA of these cases was as high as the IPBA with a speed of 120 − 150 km/h, the typical speed range in NPB games. Therefore, we are confident in suggesting to NPB players whose batted ball speed are typical that they should aim to hit line drives to achieve better IPBA.

This study evaluated whether the advantage of hitting fly balls over grounders exists in the top-league games of professional baseball in Japan. Although the offensive strategies and average batted ball speed in NPB were different from those in MLB, hitting fly balls resulted in better batting statistics than hitting grounders. This might be attributable to the fact that launching grounders into gaps in skilled defensive players with high probability might not be an easy task even for the players who are trained to intentionally hit the ball in various directions in NPB. Coaching books have suggested that the defensive ability or rough condition on the ground may alter the advantage of hitting fly balls over grounders (Johnson, 2011; Shibata, 1989). Further research into different age groups, such as players in high school or college baseball, may elucidate the effective offensive strategy for each population.

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Availability of data

All deidentified, anonymous data are available on request from the corresponding author.

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Appendix

Table.A1 List of the values used as the best estimates of missing variables.

Ball trajectory	Batting result	Number of the cases where the kinematic data was complete	Number of the cases where the kinematic data was missing	Ball speed [km/h]	Launch angle [°]
Bunt	Out	20	212	65.9	−18
Bunt	Single	22	82	63.6	−34
Bunt	Error	5	32	57.2	−58
Bunt	Fielder's choice	1	16	52.8	−69
Grounder	Out	12,491	1128	129.5	−15
Grounder	Single	3773	192	144.1	−5
Grounder	Double	210	3	147.8	−2
Grounder	Triple	7	0	-	-
Grounder	Error	388	39	131.6	−15
Grounder	Fielder's choice	32	5	121.5	−22
Line drive	Out	1933	4	145.8	14
Line drive	Single	3785	11	144.3	13
Line drive	Double	1249	3	154.7	15
Line drive	Triple	98	0	-	-
Line drive	Home run	54	0	-	-
Line drive	Error	11	0	-	-
Fly ball	Out	7005	410	138.3	37
Fly ball	Single	875	9	115.6	28
Fly ball	Double	794	7	146.7	26
Fly ball	Triple	113	0	-	-
Fly ball	Home run	1468	3	160.1	29
Fly ball	Error	17	7	136.8	34
Pop-up	Out	1482	1436	114.8	58
Pop-up	Single	21	3	103.7	33
Pop-up	Double	2	0	-	-
Pop-up	Error	4	5	124.0	66
Undefined	-	2	-	-	-
Total		35,862	3607		

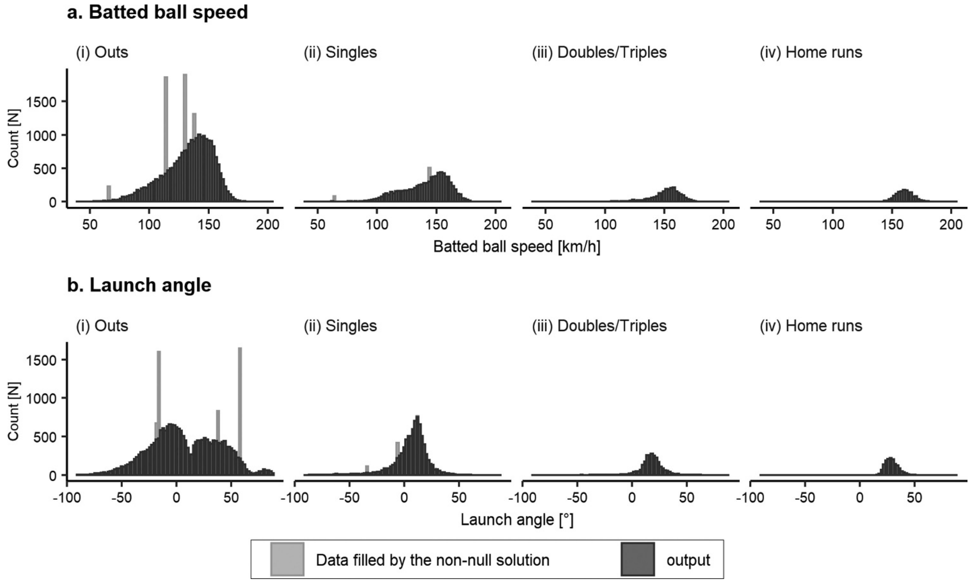

Figure A1. Original distributions of (a) batted ball speed and (b) launch angle for outs, singles, doubles/triples, and home runs in NPB and data filled by the "non-null solution" (Tango, 2017).