Impact of each release parameter on pitch location in baseball pitching

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ABSTRACT
This study investigated the amount of impact of each release parameter – pitch speed, release position, release projection angle and spin rate and axis – on pitch location during four-seam fastball pitching. Data from 26 pitchers, including professionals, semi-professionals and collegiate pitchers, were obtained by using simplified radar ball-tracking system called TrackMan Baseball. The results of a multiple linear regression analysis indicate that the release projection angle had the largest effect on the pitch locations and the spin rate had the smallest effect among significant predictor variables in both vertical and horizontal planes. The amounts of change in pitch location affected by 1-SD changes in release projection angles in vertical and horizontal planes (0.73° and 0.69°, respectively) were both about half of home-plate width (19.8 cm and 18.2 cm); those affected by 1-SD changes in the spin rate (67.7 rpm) were both about 1/10 of the size of a baseball (0.83 cm and 0.75 cm). The results of this study are concrete indicators for coaches and players when they use a ball-tracking system and interpret the measured data.

Introduction
To overcome an opposing batter, it is advantageous for baseball pitchers to throw high-velocity pitches and various breaking pitches, but it is also important that they throw them accurately to intended locations. What factors influence pitch accuracy? Recently, various parameters can be easily assessed with the evolution of ball-tracking technology. For effective use of the measured data, it is necessary to understand the influence of each parameter on the location of pitch and ball trajectory.

The location of pitched ball at home plate, the pitch location, is basically determined by the states of the ball just after its release, such as its position, velocity and projection angle. In addition, a ball in air is affected by three forces: gravity, drag (air resistance) and Magnus force (Bahill, 2019a). The force of gravity pulls the ball downward, and the drag force operates in the opposite direction of the ball’s movement in relation to its velocity, air mass density and radius. Magnus force is generated by a spinning object, and it is affected by the spin rate and two directions of spin axis, namely the azimuth and elevation angles. In the current study, among the parameters that affect pitch location, we focused on the parameters a pitcher can control, which we call release parameters. In the vertical plane, the height of pitch location is affected by the combination of seven release parameters: release height, release position relative to the pitching rubber (extension), release velocity, vertical projection angle, spin rate and azimuth and elevation angles of the spin axis. In the same way, the horizontal pitch location is affected by seven parameters in the horizontal plane.

Previous studies on accuracy in baseball pitching have investigated the size and shape of error in pitch location (Kawamura et al., 2017; Shinya et al., 2017) and the relationship between the variability in pitch location and pitching kinematics during four-seam fastball pitching (Glanzer et al., 2019). However, these studies did not investigate the release parameters. One study investigated some of the release parameters during several types of pitching but did not consider the relationship with pitch location (Whiteside et al., 2016). Many other basic throwing studies have investigated the relationship between release parameters and pitch location, and all of them commonly reported that the release speed and/or projection angle are more important than the release positions for consistency of pitch location (Cross, 2018; Dupuy et al., 2000; Kudo et al., 2000). These studies were conducted by using simple underarm or overarm ball-throwing tasks and assumed that both the ball spin and air resistance were negligible. In baseball pitching, however, the effect of ball spin on pitch location cannot be ignored.

On the other hand, many experimental and simulation studies have examined the influence of ball spin on ball movement in air (Alaways & Hubbard, 2001; Bahill & Baldwin, 2007; Jinji & Sakurai, 2006; Nagami et al., 2016, 2011; Nathan, 2008). They focused on the aerodynamics of a spinning ball and its rotational speed and spin axis for several types of pitches but were not interested in the extent of the influence of each release parameter on pitch location, including release speed, projection angle and position. Actually, the extent of their influence could be evaluated by using the flight models proposed in these studies and conducting a sensitivity analysis.
However, in addition to the physical model, pitch location would be affected by the actual variability of the release parameters associated with biomechanical and motor control constraints. Using actual data will allow us to know the relationship between the distribution of pitch location and the variability of each release parameter in situ.

In this study, we investigated the impact of each release parameter on pitch location by using experimental data obtained during four-seam fastball pitching by a simplified measuring system called TrackMan Baseball (TrackMan, Vedbaek, Denmark). In general, it is considered that players and coaches have difficulty intuitively understanding statistical results presented in scientific papers (for instance, coefficients in a multiple regression analysis). For this reason, we discuss the results with concrete values of how many centimetres pitch location changed depending on the average variability of each parameter.

**Methods**

**Participants**

Twenty-six pitchers participated in the experiment, including six professional pitchers, four former professional pitchers, ten semi-professional pitchers and six collegiate pitchers. All pitchers were right-handed and injury free at the time of data collection. The professional and former professional pitchers belonged to the Nippon Professional Baseball Organization (NPB). All semi-professional pitchers belonged to the Japan Amateur Baseball Association, which is the second highest-level baseball league after the NPB in Japan. All collegiate pitchers belonged to a top-level university baseball league. The mean ± standard deviations (SDs) in the height, weight and age of all pitchers were 181.1 ± 5.9 cm, 82.4 ± 9.3 kg and 27.0 ± 8.0 yrs. All the participants provided written informed consent prior to the experiments. This study was approved by the Ethics and Safety Committees of NTT Communication Science Laboratories and was conducted in accordance with the Declaration of Helsinki.

**Procedure and data acquisition**

All pitchers threw from an indoor pitching mound in our laboratory. The location of the pitching rubber relative to home plate was in accordance with general baseball regulations (0.25-m vertical displacement; 18.44-m horizontal displacement). Baseballs used in the experiment were official baseballs in each league (Mizuno Corp., Osaka, Japan). After sufficient warming-up, pitchers were asked to throw four-seam fastballs aiming at a 10-cm-square target located at a 50-cm height, 100 cm behind the front of home plate and 25 cm left from the centre of home plate from the pitcher’s view, i.e., “low and outside” for a right-handed batter. They were asked to throw more than 20 pitches with the same strength and accuracy as they would in a real game. Each pitcher threw between 20 and 33 pitches.

The ball movement after its release was measured by TrackMan Baseball. TrackMan Baseball is a 3D Doppler radar system, which is currently used by a majority of Major League and NPB teams who have installed TrackMan systems in their stadiums (Heather Marsten, 2016). The system was a fixed and was installed and calibrated by technicians from Trackman Inc. according to their criterion. Ten parameters output by TrackMan were used in the current study. The names and definitions of these parameters (described below) were taken from the Trackman’s website (Woods, 2018), but the units were converted to the metric system.

- PlateLocHeight [cm]: The height of the ball relative to home plate as the pitch crosses the front of the plate.
- PlateLocSide [cm]: Distance from the centre of the plate to the pitch as it crosses the front of the plate. Positive numbers are pitches to the right of centre from the pitcher’s perspective (inside to a right-handed batter).
- RelHeight [cm]: Height above home plate at which the pitcher releases the ball.
- RelSide [cm]: Distance from the centre of the rubber at which the pitcher releases the ball. Balls thrown from the right side of the mound from the pitcher’s perspective have a positive number.
- Extension [cm]: The distance from which the pitcher releases the ball relative to the pitching rubber.
- RelSpeed [km · h]: Speed of pitch when it leaves the pitcher’s hand.
- VertRelAngle [:]: Initial vertical (up-down) direction of the ball when it leaves the pitcher’s hand. A positive number means the ball is released upward.
- HorzRelAngle [:]: Initial horizontal (left-right) direction of the ball when it leaves the pitcher’s hand. A positive number means the ball is released to the right from the pitcher’s perspective.
- SpinRate [rpm]: How fast the ball is spinning as it leaves the pitcher’s hand reported as the number of times the pitched ball would spin per minute (“revolutions per minute”).
- SpinAxis [:]: Elevation angle between spin axis and horizontal axis in the vertical plane. A pitch with a spin axis of 180° has perfectly vertical deflection.

Although the azimuth of the spin axis – the angle between the spin axis and axis directed from the pitching rubber to home plate in the horizontal plane – would affect the pitch locations, the TrackMan system cannot obtain it. We discuss the extent of the influence of the azimuth on the pitch locations in the discussion section.

**Data analysis and statistics**

We first calculated the within-player mean and variability of all release parameters and averaged them as weighted mean ± SD between pitchers considering the number of trials for each pitcher. The within-player variability was calculated as the square root of the weighted mean of variance.

To assess the effect of changes in release parameters on pitch locations, we adopted a multiple linear regression analysis in the vertical and horizontal plane separately. We conducted the analysis in the following steps: First, deviations in each parameter – the differences between the value in each
trial and individual mean – were calculated for all pitchers. The deviations were then pooled by a parameter across all pitchers (N = 709). Lastly, a multiple regression analysis was conducted for the pooled data. This allowed us to investigate the effect of within-player changes in the release parameters on pitch locations for baseball pitching.

In the vertical plane, the dependent variable was PlateLocHeight, and independent variables were RelHeight, Extension, RelSpeed, VertRelAngle, SpinRate and SpinAxis. In the horizontal plane, the dependent variable was PlateLocSide, and independent variables were RelSide, Extension, RelSpeed, HorzRelAngle, SpinRate and SpinAxis. Both unstandardized and standardized coefficients from the regression analysis were used to interpret each predictor variable’s contribution to the model. Each coefficient was tested by the t-statistic (p < 0.05). Some independent variables were correlated (Supplemental Tables 1 and 2). However, because the variance inflation factor (VIF), an index of multicollinearity among the dependent variables, was sufficiently lower than 10 (Supplemental Table 3), we considered that the data did not have a multicollinearity problem (Samprit & Hadi, 2012). For the statistical analyses, we used the Statistics and Machine Learning Toolbox in MATLAB 2017b (MathWorks Inc., Natick, MA, USA).

Moreover, we investigated the required sample size for these multiple regressions (Abt et al., 2020). The power analysis was conducted by using G*Power version 3.1 with the “Linear multiple regression: Fixed model, R² deviation from zero” procedure (Erdfelder et al., 2009). Given six predictor variables, the result of an a priori analysis with 0.35 large effect size revealed that we need a sample size of N = 67 to achieve 0.95 power in a test based on α = 0.05; therefore, our sample size was quite satisfactory.

In addition, we evaluated the amount of predicted change in pitch locations affected by a 1-SD change in each release parameter, calculated from the unstandardized coefficients obtained from a multiple linear regression and from the within-player variability. Generally, standardized coefficients obtained from a multiple linear regression are interpreted as 1-SD changes in the dependent variable associated with 1-SD changes in the independent variable. However, we conducted the analysis for the pooled data, so their interpretation would be different from that derived using the within-player variability. Because we wanted to know the impact of the average variability of each release parameter on the pitch location, we used the within-player variability, not the standardized coefficients. The standardized coefficients were used only to assess the contribution of each release parameter to the model.

Results
The within-player mean and variability of all parameters of interest are listed in Table 1. The details of the multiple linear regression model in the vertical and horizontal planes are shown in Tables 2 and 3. The amounts of predicted change in pitch locations affected by a 1-SD change in each release parameter are shown in Table 4.

In the vertical plane, the multiple regression revealed a significant prediction equation (F(6,702) = 6217.6, p < 0.001) that explained 98.1% of the variance in PlateLocHeight, and the coefficients for all independent variables were significant (Table 2). Among them, VertRelAngle had the largest effect on PlateLocHeight, and SpinAxis had the smallest effect.

In the horizontal plane, the multiple regression revealed a significant prediction equation (F(6,702) = 7765.5, p < 0.001) that explained 98.5% of the variance in PlateLocSide, and the coefficients for RelSide, HorzRelAngle, SpinRate and SpinAxis were significant. Among significant predictor variables, VertRelAngle had the largest effect on PlateLocSide, and SpinRate had the smallest effect.

Discussion
The current study used experimental data obtained during four-seam fastball pitching to evaluate the extent of the influence of each release parameter on pitch location. First, we compared our data (RelSpeed, SpinRate and SpinAxis) with three previous studies which used detailed video footage methods (Jinji & Sakurai, 2006; Nagami et al., 2011; Whiteside et al., 2016). The mean RelSpeed in our study (six professionals, four ex-professionals, ten semi-professionals and six collegiate pitchers in Japan; 132.3 km · h⁻¹) was midway between the mean fastball speed in Nagami’s (11 collegiate and 11 professional pitchers in Japan; 135.7 km · h⁻¹) and Whiteside’s studies (nine pitchers in NCAA Division I; 137.9 km · h⁻¹) and that in Jinji’s study (nine collegiate pitchers

### Table 1. Within-player mean and variability of all parameters (N = 26, between-player weighted mean ± SD).

| Parameter       | Mean   | Variability |
|-----------------|--------|-------------|
| PlateLocHeight  | 82.33 ± 11.55 | 20.73 ± 5.15 |
| PlateLocSide    | −14.41 ± 9.04  | 18.90 ± 4.56 |
| RelSpeed [km · h] | 132.31 ± 7.26 | 1.93 ± 0.78 |
| RelHeight [cm]  | 173.71 ± 13.74 | 2.50 ± 0.70 |
| RelSide [cm]    | 47.74 ± 18.20  | 2.98 ± 1.09 |
| Extension [cm]  | 183.45 ± 11.40 | 4.49 ± 1.24 |
| VertRelAngle [°] | −1.18 ± 1.09  | 0.73 ± 0.19 |
| HorzRelAngle [°] | −3.41 ± 0.85  | 0.69 ± 0.21 |
| SpinRate [rpm]  | 1982.50 ± 204.63 | 67.65 ± 17.78 |
| SpinAxis [°]    | 215.52 ± 9.78  | 5.32 ± 1.89 |

### Table 2. Results of multiple linear regression in VERTICAL plane.

| Parameter       | Unstandardized coefficients | SE    | t-Stat | Standardized coefficients | p value |
|-----------------|-----------------------------|-------|--------|---------------------------|---------|
| RelSpeed [km · h] | 1.369                       | 0.066 | 20.82  | 0.127                     | < 0.001 |
| RelHeight [cm]   | 1.264                       | 0.052 | 24.16  | 0.152                     | < 0.001 |
| Extension [cm]   | 0.236                       | 0.028 | 8.34   | 0.051                     | < 0.001 |
| VertRelAngle [°] | 27.073                      | 0.149 | 181.17 | 0.956                     | < 0.001 |
| SpinRate [rpm]   | 0.012                       | 0.002 | 7.07   | 0.040                     | < 0.001 |
| SpinAxis [°]     | −0.388                      | 0.022 | −18.06 | −0.100                    | < 0.001 |
Table 3. Results of multiple linear regression in HORIZONTAL plane.

|                  | Unstandardized coefficients | SE  | t-Stat | Standardized coefficients | p value |
|------------------|----------------------------|-----|--------|---------------------------|---------|
| RelSpeed [km · h] | -0.090                     | 0.053 | -1.70 | -0.009                    | 0.089   |
| RelSide [cm]     | 1.051                      | 0.031 | 33.71 | 0.166                     | < 0.001 |
| Extension [cm]   | 0.030                      | 0.022 | 1.36  | 0.007                     | 0.174   |
| HorzRelAngle [°] | 26.394                     | 0.131 | 201.45| 0.963                     | < 0.001 |
| SpinRate [rpm]   | 0.011                      | 0.001 | 7.80  | 0.040                     | < 0.001 |
| SpinAxis [°]     | 0.833                      | 0.018 | 47.30 | 0.234                     | < 0.001 |

Table 4. Predicted changes in pitch location affected by 1-SD changes in release parameters. 1-SDs were the within-player variability indicated in Table 1.

|                  | PlateLocHeight [cm] | PlateLocSide [cm] |
|------------------|--------------------|-------------------|
| RelSpeed          | 2.64               | -0.17             |
| RelHeight         | 3.16               | -                 |
| RelSide           | -                  | 3.13              |
| Extension         | 1.06               | 0.13              |
| VertRelAngle      | 19.82              | -                 |
| HorzRelAngle      | -                  | 18.21             |
| SpinRate          | 0.83               | 0.75              |
| SpinAxis          | -2.06              | 4.43              |

in Japan; 122.4 km · h). Our study involved a wide range of pitchers, which was reflected in the wide range of RelSpeed (from 112.7 to 143.5 km · h). The mean SpinRate in our study (1982.5 rpm) was also midway between the mean spin rate in Nagami’s (2058 rpm) and Whiteside’s studies (2082 rpm) and Jinji’s study (1884 rpm). These results support Nagami’s result that the pitch speed and spin rate are well correlated (Nagami et al., 2011). SpinAxis in our study (215.5°) was similar to the elevation angle of the spin axis in Nagami’s (212°) and Jinji’s studies (206.4°), but larger than it in Whiteside’s study (193.5°). Jinji et al. reported that the elevation angle of the spin axis is strongly correlated with the right/left sideways motion of the hand just before ball release (Jinji et al., 2011). Japanese pitchers may tilt their hands sideways more than the American pitchers in the Whiteside’s study. Taken together, the data obtained with the Trackman system accurately reflected the levels of our pitchers and seem to be comparable to data from video analyses in previous studies. In the following, we discuss the consistency of pitch location and the impact of small changes in ball trajectory on batter performance.

In baseball pitching, consistency of pitch location is an important factor in avoiding “walks”, “hit by pitches” or “wild pitches” and pitching with the intended strategy. In the present study, the release angle had a decisive effect on pitch location in both planes. The amount of change in PlateLocHeight and PlateLocSide affected by 1SD changes in VertRelAngle and HorzRelAngle (0.73° and 0.69°, respectively) were both about half of home-plate width (Table 4). In comparison, the impacts of other parameters on pitch locations were quite small. In particular, the amount of change in pitch locations affected by 1SD changes in SpinRate (67.7 rpm) was about 1/10 of the size of a baseball in both planes. Therefore, to improve the consistency of pitch location, pitchers should reduce the variability in the release projection angle for both planes. This is evident from the strong correlation between within-player variability in release angles and consistency of pitch locations (Figure 1).

The release parameters depend on the hand trajectory of the throwing arm and the timing of ball release. In a series of studies conducted with a basic ball-throwing task, Hore et al. claimed that inconsistency in the height of pitch location did not primarily result from differences in hand trajectory height but from errors in release timing (Hore, Watts, Tweed et al., 1996; 1996; Hore & Watts, 2011). On the other hand, in real baseball pitching, it has been reported that the variability in shoulder movement early in the pitching motion (Glanzer et al.,

Figure 1. Variability relationship between release projection angles and pitch locations in vertical and horizontal planes. These are between-player relationships of within-player SDs of release angles and pitch locations. Pearson’s correlation coefficient (r) is indicated in each panel.
and variabilities in kinematics and kinetics tend to be greatest in younger pitchers and decrease as pitchers mature (Fleisig et al., 2009). It is unclear whether release timing or hand trajectory would be more critical in reducing the variability in release projection angle, but it may be important to reduce variability in both at the early stage of learning.

In the current study, to evaluate the extent to which each parameter influences pitch location, we assumed that the release parameters are independent of each other. However, it should be noted that some release parameters are biomechanically related. For example, since pitch speed and spin rate have a positive correlation, pitches having the same pitch speed should be compared when evaluating the spin rate. Another example is the possibility of a compensatory relationship, namely a negative correlation, between release parameters. Many basic throwing studies have found that the compensatory relationship improves the consistency of pitch location (Dupuy et al., 2000; Kudo et al., 2000; Nasu et al., 2014). Although the effect of release projection angle on pitch location was dominant, it is likely that other release parameters compensated for the variability in release angle. Exploring whether such a compensation relationship exists in baseball pitching remains as future work.

To be sure, the influence of the spin rate and axis on pitch location was much smaller than that of release projection angle. However, small changes in pitch trajectory effectively work to reduce a batter’s hitting accuracy. Higuchi et al. examined batters’ accuracy in hitting fastballs with different backspin rates at a constant pitch velocity and found that a 1-rps (60 rpm) increase in the spin rate of a launched fastball would augment the vertical impact deviation by 1.42 mm (Higuchi et al., 2013). This means that a small change in the trajectory by controlling the spin rate can lead to a batter’s mispredicting it even with the same type of pitch. The simulated vertical sweet spot of a bat, an area that leads to hit success with high probability, was reported to be 5 mm (Bahill, 2019b). Therefore, a 106-rpm (2.51/42 × 60 = 105.6) change in the spin rate with constant pitch velocity would reduce a batter’s hitting accuracy. In the current study, it was 1.56 times the mean individual variability of SpinRate.

It appears to be difficult to change the SpinRate by 100 rpm while maintaining the same pitch speed. Note that our results indicate that the impact of SpinRate on pitch location was smaller than that of SpinAxis, which is consistent with previous studies (Jinji & Sakurai, 2006; Nagami et al., 2011). The amount of SpinAxis’s impact on pitch location was twice as large as SpinRate’s in the vertical plane and was four times larger in the horizontal plane (Table 4). In general, coaches and players tend to pay attention to an easy-to-understand amount of spin rate, but they should know the importance of its axis. The relationship between spin axis and kinematics has not been fully investigated yet, but the accumulation of such knowledge will enable effective training and pitching strategies.

We could not consider the effect of the azimuth of the spin axis on pitch location in the current study. Because the Magnus force acts perpendicular to the direction of pitch flight and to the direction of the spin axis, the closer these two axes are (i.e., the smaller the azimuth angle), the smaller this force. Nagami et al. reported that the mean azimuth angle during four-seam fastball pitching was 20° and that the effective spin parameter, which was calculated using angular velocity with the exception of the azimuth angle component, could accurately explain pitch deflection (Nagami et al., 2016). This means that the spin rate’s impact on pitch location would increase or decrease according to the azimuth angle of the spin axis. Therefore, when using a system that cannot measure this angle, such as TrackMan Baseball, coaches and players need to interpret the measurement data in consideration of this limit.

In summary, the current study clarified the impact of each release parameter on pitch location and indicated specific amounts of their impact. We found that the release projection angle had a dominant impact in both the vertical and horizontal planes. In addition, we discussed the small change in ball trajectory caused by changes in the spin rate and axis. When using a ball-tracking system, coaches and pitchers should explore how changes in pitching motion would change the release parameters and should be aware of how these changes would affect pitch location and batter’s performance.

Disclosure statement

The authors declare no potential conflict of interest.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, DN, upon reasonable request.

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