

Development of strategic pitching skill items in professional baseball games

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Abstract:

Introduction: Strategic decision-making in pitching is a crucial factor in baseball performance, yet traditional metrics like earned run average and even advanced sabermetrics such as fielding independent pitching (FIP) and strikeout-to-walk ratio (K/BB) fail to directly measure how pitchers adapt their pitch selection in response to situational demands. Relatedly, although sports science has explored biomechanical and physiological aspects of pitching, little attention has been paid to the intentional structure of pitching strategy. This study addresses this critical gap by developing and validating a measurement model of strategic pitching skills based on pitch-by-pitch data. **Materials and Methods:** Using data from Nippon Professional Baseball (NPB), the study analyzed 28,222 plate appearances. A causal-effect analysis with the Delphi method was conducted with expert input to define two main domains of strategic pitching skill: pitch velocity skill and pitch location skill. Sub-skills included off-speed variation (velocity) and vertical, horizontal, and diagonal skills. A total of 20 items were initially created based on differences in pitch characteristics relative to the context (e.g., pitch count, previous pitch). Exploratory and confirmatory factor analyses were conducted to test the construct validity, followed by structural equation modeling (SEM) to examine criterion-related validity using FIP and K/BB as external indicators. **Results and Discussion:** After the exploratory analysis, 18 items remained, yielding a four-factor model that explained 70% of the variance. A confirmatory factor analysis further supported this model, and both horizontal and off-speed skills showed significant associations with improved performance, reflected in lower FIP (-0.51 and -0.39, respectively) and higher K/BB (0.76 for horizontal skill). These results confirm that the developed items are not only statistically valid but also practically meaningful. This model provides a novel framework for evaluating strategic pitching skills and has potential applications in individualized coaching, performance analysis, and AI-based scouting systems. **Conclusions:** This study developed and validated a set of strategic pitching skill items based on pitch-by-pitch data from NPB. The resulting model consists of two domains—pitch velocity skill and pitch location skill—comprising four sub-skills. Construct and criterion-related validity were confirmed, particularly for horizontal and off-speed skills. These skills offer practical value as measurable indicators for coaching, scouting, and player development.

Key Words: player development, construct validity, structural equation modeling, sabermetrics

Introduction

The evaluation of pitcher performance in baseball typically involves multiple indicators, including pitch velocity, control, and game-based statistics (Mercier et al., 2020). Sabermetrics, originally proposed by James (1977), has become a widely adopted framework for data-driven performance assessment in both Japanese and international baseball. Sabermetrics integrates empirical insights with statistical analysis to create sophisticated performance metrics such as fielding independent pitching (FIP) and strikeout-to-walk ratio (K/BB), which are considered more reliable than traditional measures like earned run average (Piette et al., 2010; Flanagan, 2014; Whiteside et al., 2016b). However, while these outcome-based metrics are effective for summarizing performance results, they do not capture the intentional processes and tactical reasoning behind pitch selection. Pitching is not simply a physical act; it is a dynamic, context-sensitive decision-making skill that evolves in real time based on batter characteristics and game situation (Tango et al., 2007; Flanagan, 2014). The strategic rationale underlying these decisions includes temporal elements such as speed changes and pitch timing and spatial elements such as pitch location and ball movement along vertical and horizontal axes (Whiteside et al., 2016a; Shinya et al., 2017; Glanzer et al., 2019).

In elite baseball environments, pitchers are expected to consistently make context-appropriate decisions while executing complex motor skills. Despite its centrality to pitcher performance, current evaluation systems lack a validated framework to assess the structure of such strategic skill. When relying solely on outcome-based

metrics, coaches are unable to systematically evaluate a pitcher's advanced strategic skills, and scouts or analysts similarly face difficulties in accurately identifying players with strong tactical aptitudes. This limitation also poses practical challenges for player development and training: For example, coaches aiming to improve a pitcher's sequencing logic or opponent-specific game planning currently lack objective tools to analyze or explain tactical decision-making. As a result, feedback on strategic elements often relies on intuition or experience rather than measurable indicators. This in turn limits coaches' ability to personalize instruction, track growth over time, or make data-informed adjustments to in-game strategies.

Recent sports science has advanced our understanding of the physiological and biomechanical aspects of pitching—accounting for factors such as fatigue, shoulder mobility, and postural control (Hato & Kinomura, 2021; Harper & Jones, 2023). However, this research has largely focused on injury risk and motor capacity, without addressing how pitchers strategically apply their physical abilities to outsmart or otherwise outplay their opponents. Thus, while pitching is increasingly understood as multifactorial, the strategic layer underpinning the pitching process remains undertheorized and unmeasured.

Additionally, previous research on pitching strategy has largely focused on the description of pitch sequences or batter outcomes (Gu & Hu, 2014; Katsumata et al., 2017), often using empirical data without modeling the cognitive or tactical structure underlying such behaviors. Biomechanical studies, meanwhile, provide essential insights into physical readiness but do not explain how pitchers choose or vary their tactics under different conditions.

In contrast, other sports such as soccer have already established frameworks for evaluating game performance through structural equation modeling (SEM) and tracking data (Suzuki & Nishijima, 2005; Matsuoka et al., 2020). These approaches allow researchers to model latent tactical competencies and assess their relationship to observable behaviors. Conversely, in baseball, only a few recent studies (Albert, 2010; Miyamoto & Ito, 2017; Lee et al., 2024) have begun to explore probabilistic or temporal patterns in pitch selection, and no validated measurement model currently exists to assess strategic pitching skills.

Therefore, the central problem addressed in this study is the absence of a validated framework for measuring the structure of strategic pitching skills in professional baseball, despite its critical role in performance outcomes.

Considering these gaps, this study has aimed to develop and validate a measurement model for strategic pitching skill using pitch-by-pitch data from Nippon Professional Baseball (NPB). Specifically, the study has sought to define observable indicators of strategic behavior and examine their structural validity using an exploratory factor analysis (EFA) and SEM. By identifying the latent dimensions of tactical pitching, a framework was constructed that can be applied across performance analytics, coaching, and talent evaluation.

In addition to its immediate use in coaching and scouting contexts, the proposed model also holds potential for integration into future technologies. For instance, combining this model with real-time tracking data could support the development of AI-based decision-support tools or automated scouting systems capable of detecting strategic trends at scale. As performance data becomes increasingly abundant and granular, structured frameworks like this one will become essential for interpreting not only what happened in a game but why it happened from a tactical perspective.

Material & Methods

Procedures

The study employed five procedures to analyze pitching data: (1) a causal-effect analysis applying the Delphi method to identify strategic pitching skill items, (2) processing of the dataset, (3) an exploratory factor analysis, (4) a confirmatory factor analysis for construct validity applying SEM, and (5) a criterion-related validity analysis of strategic pitching skills. This study was conducted with the approval of the Research Ethics Committee of the University of Tsukuba (Approval No. [30-29]).

Sample

The dataset used in this study comprised pitch-by-pitch data from the 2015 regular season of NPB, including games from both the Central and Pacific Leagues, with postseason games excluded. A total of 153,015 pitches were included, and the data was borrowed by the university from Data studium Inc. (Tokyo, Japan) under an academic-industrial alliance. For the analysis, the dataset was limited to pitches recorded during at bats that progressed to a two-strike count. The pitch-by-pitch data was then reconstructed into data per plate appearance, resulting in a total of 28,222 plate appearances, which served as the unit of analysis.

For criterion-related validity, factor scores of each strategic pitching skill were averaged by pitcher for the season, and their relationships with sabermetric indicators were tested using SEM. The indicators used were K/BB and FIP. The sample consisted of 119 pitchers who pitched at least 50 innings during the season. The rationale for selecting this threshold is discussed in Section 2.4.

Development of Measurement Items

To conceptualize the structure of strategic pitching skills and establish content validity, a characteristic factor analysis employing the Delphi method was conducted, with baseball experts providing input. The Delphi method aggregates expert opinions, while the causal-effect analysis is used to identify qualitative causal structures (Suzuki & Nishijima, 2002; Sizer et al, 2007). The panel of Japanese baseball experts was composed

of one graduate student specializing in baseball coaching, two Industrial Baseball Coaches baseball coaches, and one analyst. The graduate student possessed over five years of coaching experience. Both corporate baseball coaches had accumulated more than 10 years of combined experience as players and coaches at the corporate level and had achieved a national championship title. Individual interviews were conducted to explore the structure of pitching decision-making and strategic elements. Following the Delphi protocol, experts were interviewed independently and anonymously. Their responses were synthesized to identify common themes and differences, and feedback was provided iteratively to refine the conceptual structure. Based on the results, a causal structure diagram of the strategic pitching skill structure was created. Once consensus was reached, the finalized skill structure was used to generate 20 measurable strategic pitching skill items derived from the pitch-by-pitch dataset.

Criterion-Related Validity

For criterion validity, the external standards K/BB and FIP were selected. K/BB is a measure of a pitcher's dominance and control, with higher values indicating better performance. FIP, meanwhile, helps isolate a pitcher's performance from defensive factors by focusing solely on outcomes that are directly attributable to the pitcher (Tango et al., 2007). Previous research has shown both indicators to be stable predictors of pitching performance (Piette et al., 2010; Flanagan, 2014), with lower FIP and higher K/BB values indicating better performance.

Previous findings have underscored the importance of minimum sample sizes to support the reliability of advanced pitching indicators like K/BB and FIP. Specifically, past research has shown that these indicators yield more stable evaluations when calculated over at least 30 to 50 innings pitched, as this threshold helps minimize the influence of random variation and measurement error (Tango et al., 2007; McCracken, 2001; Saltzman et al., 2018). Accordingly, to enhance the precision and interpretability of the criterion-related validity analysis, this study limited the sample to pitchers who threw at least 50 innings during the season.

Statistical Analysis

An exploratory factor analysis was performed by applying maximum likelihood estimation. Factors with eigenvalues greater than 1.0 were extracted, followed by Promax rotations. Items with factor loadings below |0.35| were excluded from the analysis. For the construct validity, a confirmatory factor analysis was conducted applying SEM, based on the factor structure obtained from the exploratory analysis.

SEM parameters were estimated by the maximum likelihood method, with statistical significance established at $p < .05$. Model fit was evaluated using the following indices: a goodness of fit index (GFI), an adjusted GFI (AGFI), a normed fit index (NFI), a comparative fit index (CFI), a root mean square error of approximation (RMSEA), and the chi-square statistic (CMIN). Acceptable model fit was defined as a GFI, NFI, and CFI > 0.90 and an RMSEA < 0.08 (Tabachnick & Fidell, 2007; Bentler, 1990; Browne & Cudeck, 1993; Kline, 2016). IBM SPSS version 25 and AMOS version 25 were used for all statistical analyses.

Results

Composition of Strategic Pitching Skill Items

By applying a causal-effect analysis combined with the Delphi method, a conceptual structure of strategic pitching skills was developed (Figure 1).

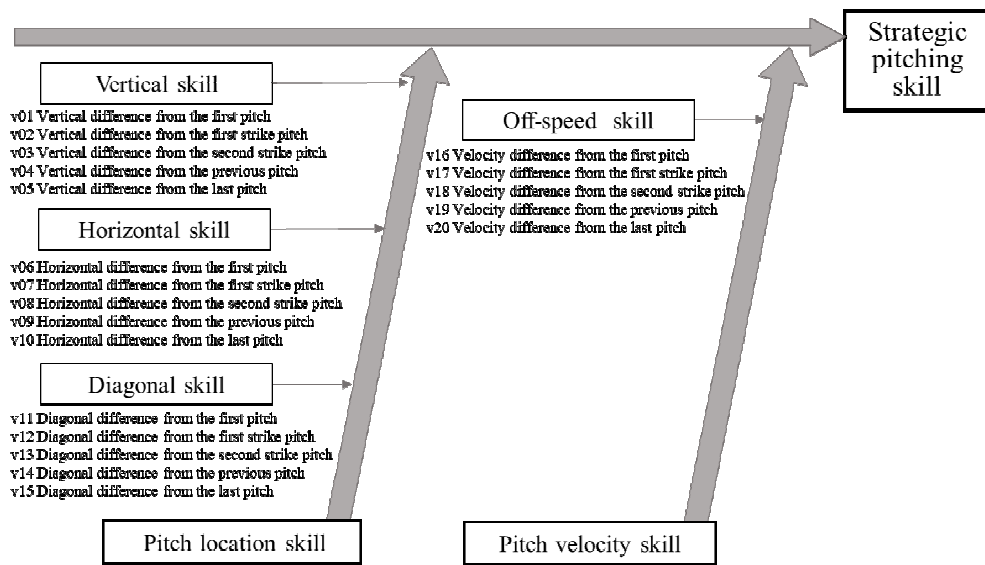


Fig.1. Causal Structure Diagram of Strategic Pitching Skill

Strategic pitching skills in baseball were broadly classified into pitch velocity skill and pitch location skill. Off-speed was categorized as a sub-skill under the pitch velocity skill. The pitch location skill consisted of three sub-skills: vertical skill, horizontal skill, and diagonal skill. Table 1 summarizes the measurement items and methods.

Based on this framework, a total of 20 strategic pitching skill items were generated from the pitch-by-pitch data. These items were operationalized as the differences in pitch characteristics relative to specific reference points: the first pitch two, the first strike three, the second strike, the final pitch of the at bat, and the immediately preceding pitch. Each sub-skill category included multiple items based on these differential criteria, allowing the model to reflect context-sensitive pitching decisions.

Table 1. Strategic Pitching Skill Items and Measurement Methods

skill	Lower skill	ID	Items	Description	Units
Pitch location skill	Vertical skill	v01	Vertical difference from the first pitch	Difference between the x-origin of the first pitch and the x-origin of this pitch	cm
		v02	Vertical difference from the first strike pitch	Difference between the x-origin of the first strike pitch and the x-origin of this pitch	cm
		v03	Vertical difference from the second strike pitch	Difference between the x-origin of the second strike pitch and the x-origin of this pitch	cm
		v04	Vertical difference from the previous pitch	Difference between the x-origin of the previous pitch and the x-origin of this pitch	cm
		v05	Vertical difference from the last pitch	Difference between the x-origin of the last pitch and the x-origin of this pitch	cm
	Horizontal skill	v06	Horizontal difference from the first pitch	Difference between the y-origin of the first pitch and the y-origin of this pitch	cm
		v07	Horizontal difference from the first strike pitch	Difference between the y-origin of the first strike pitch and the y-origin of this pitch	cm
		v08	Horizontal difference from the second strike pitch	Difference between the y-origin of the second strike pitch and the y-origin of this pitch	cm
		v09	Horizontal difference from the previous pitch	Difference between the y-origin of the previous pitch and the y-origin of this pitch	cm
		v10	Horizontal difference from the last pitch	Difference between the y-origin of the last pitch and the y-origin of this pitch	cm
	Diagonal skill	v11	Diagonal difference from the first pitch	Difference between the diagonal line of the first pitch and the diagonal line of this pitch	cm
		v12	Diagonal difference from the first strike pitch	Difference between diagonal line of the first strike pitch and the diagonal line of this pitch	cm
		v13	Diagonal difference from the second strike pitch	Difference between the diagonal line of the second strike pitch and the diagonal line of this pitch	cm
		v14	Diagonal difference from the previous pitch	Difference between diagonal line of the previous pitch and the diagonal line of this pitch	cm
		v15	Diagonal difference from the last pitch	Difference between the diagonal line of the last pitch and diagonal line of this pitch	cm
Pitch velocity skill	Off-speed skill	v16	Velocity difference from the first pitch	Difference between the velocity of the first pitch and the Velocity of this pitch	km/h
		v17	Velocity difference from the first strike pitch	Difference between the velocity of the first strike pitch and the Velocity of this pitch	km/h
		v18	Velocity difference from the second strike pitch	Difference between the velocity of the second strike pitch and the Velocity of this pitch	km/h
		v19	Velocity difference from the previous pitch	Difference between the velocity of the previous pitch and the Velocity of this pitch	km/h
		v20	Velocity difference from the last pitch	Difference between the velocity of the last pitch and the Velocity of this pitch	km/h

Construct Validity of Strategic Pitching Skill Items

To examine the factor structure of the developed strategic pitching skill items, an exploratory factor analysis was first conducted on the 20 candidate items. Two items related to diagonal skill—the differences relative to the second strike and the final pitch—showed factor loadings below 0.35 and were therefore excluded from further analysis. After removing these two items, Promax (oblique) rotation was applied to the remaining 18 items. The resulting factor pattern matrix revealed a four-factor solution that accounted for 70% of the total variance (Table 2) (Figure 2 presents the confirmatory factor structure of strategic pitching skills).

This finding supports the theoretical framework that these skills are conceptually distinct despite being components of a broader pitching strategy. To further verify the construct validity, a confirmatory factor analysis applying SEM was conducted based on the factor structure identified through the exploratory analysis. The model demonstrated a good fit to the data, with indices exceeding standard thresholds: GFI = 0.964, AGFI = 0.946, NFI = 0.968, CFI = 0.959, and RMSEA = 0.047. The chi-square value was $CMIN = 509.749$ ($df = 154$, $p < .001$), and the Akaike information criterion (AIC) was 623.749. All path coefficients from the latent variables to the observed ranged from 0.20 to 0.94 and were statistically significant, indicating that each item loaded appropriately on its respective factors. The correlation coefficients among the factors were statistically significant in the following pairs: 0.14 between vertical and horizontal skills, -0.05 between vertical and off-speed skills, and 0.07 between vertical and diagonal skills. Additionally, the coefficients were -0.23 between horizontal and off-speed skills and 0.13 between horizontal and diagonal skills. The correlation between off-speed and diagonal skills was -0.06 and not statistically significant.

Furthermore, the inter-factor correlations in the confirmatory model were consistent with the results of the exploratory analysis. The low correlations among the four latent constructs reinforced the discriminant validity of the model. These results confirmed that the proposed structure of strategic pitching skills was not only statistically sound but also conceptually distinct, allowing for a nuanced assessment of strategic pitching behavior.

Table 2. Factor Pattern Matrix of Strategic Pitching Skill Items After Promax Rotation

ID	Items	Horizontal skill	Vertical skill	Off-velocity skill	Diagonal skill	Communality
		F1	F2	F3	F4	H2
v07	Horizontal difference from the first strike pitch	0.92	0.00	0.00	0.01	0.85
v06	Horizontal difference from the first pitch	0.88	0.00	0.00	0.01	0.78
v09	Horizontal difference from the previous pitch	0.79	-0.01	0.00	0.00	0.62
v08	Horizontal difference from the second strike pitch	0.78	0.00	0.01	-0.01	0.61
v10	Horizontal difference from the last pitch	0.76	0.00	0.00	-0.01	0.56
v02	Vertical difference from the first strike pitch	-0.01	0.92	0.00	0.03	0.84
v01	Vertical difference from the first pitch	0.00	0.87	0.00	0.04	0.75
v04	Vertical difference from the previous pitch	0.00	0.79	-0.01	-0.02	0.62
v03	Vertical difference from the second strike pitch	0.00	0.79	-0.02	-0.04	0.62
v05	Vertical difference from the last pitch	0.01	0.73	-0.01	-0.04	0.54
v17	Velocity difference from the first strike pitch	0.00	0.04	0.92	0.00	0.86
v16	Velocity difference from the first pitch	0.00	0.03	0.90	0.01	0.81
v19	Velocity difference from the previous pitch	0.01	-0.08	0.69	0.01	0.48
v18	Velocity difference from the second strike pitch	0.00	-0.04	0.59	-0.01	0.34
v20	Velocity difference from the last pitch	-0.01	-0.05	0.58	-0.01	0.33
v11	Diagonal difference from the first pitch	-0.02	-0.01	0.00	0.80	0.64
v12	Diagonal difference from the first strike pitch	0.01	0.04	0.00	0.79	0.63
v14	Diagonal difference from the previous pitch	0.00	-0.07	-0.01	0.89	0.16
Factor contributing		3.42	3.88	2.81	1.43	11.03
Factor contributing rate		18.08%	18.76%	15.60%	7.03%	61.27%
Factor Correlation						
F2:Vertical skill			0.15			
F3:Off-Velocity skill			-0.06	-0.26		
F4:Diagonal skill			0.06	0.10	-0.06	

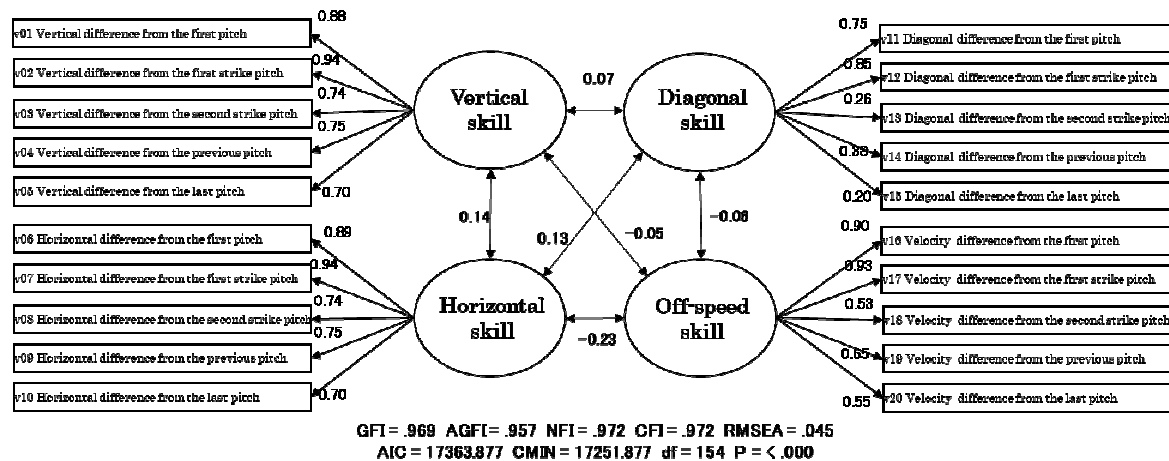


Fig. 2 Confirmatory Factor Structure of Strategic Pitching Skill

Criterion-Related Validity of Strategic Pitching Skill

To investigate the criterion-related validity of the strategic pitching skills, a structural equation model was developed applying factor scores for each skill and two sabermetric indicators: K/BB and FIP. Figure 3 illustrates the resulting causal relationships between the strategic pitching skills and the pitcher performance indicators.

The model fit indices demonstrated an excellent fit to the data (CFI = 0.909, NFI = 0.908, RMSEA = 0.037, AIC = 124.431, CMIN = 72.431, df = 1, p = .000). Although GFI and AGFI could not be computed due to missing values in a small number of pitchers' Sabermetric records, the overall model fit was deemed acceptable based on the other indices. The analysis revealed significant negative path coefficients between several strategic pitching skills and the FIP indicator. Specifically, the path coefficient from horizontal skill to FIP was -0.51, and

from off-speed skill to FIP was -0.39. Both coefficients were statistically significant. In addition, a significant positive path coefficient of 0.76 was observed between horizontal skill and K/BB.

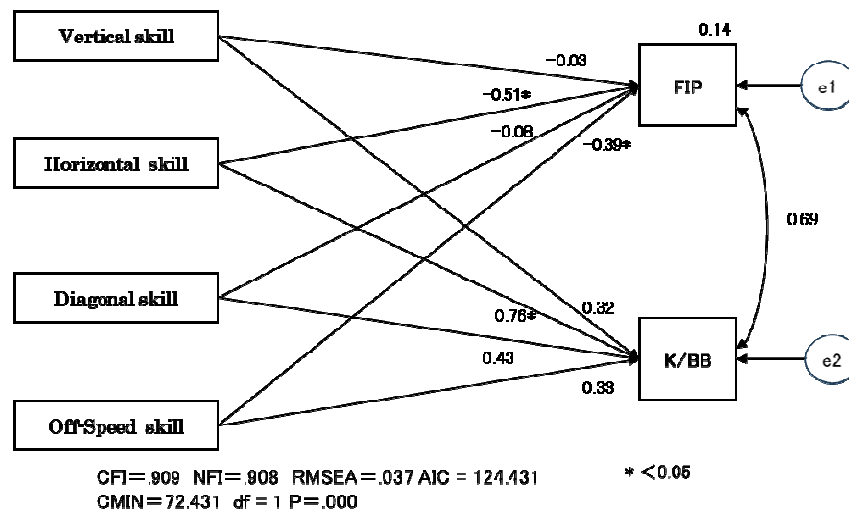


Fig.3. Criterion-Related Validity Between Strategic Pitching Skill Scores and Sabermetric Indicators

Discussion

The purpose of this study was to construct strategic pitching skill items using pitch-by-pitch data from NPB and to investigate their construct and criterion-related validity. To achieve this, a qualitative structure of strategic pitching skill was first derived by applying a causal-effect analysis combined with the Delphi method with input from baseball experts. A total of 20 strategic pitching skill items were subsequently established from actual pitch-by-pitch data. The validity of these items was evaluated using an exploratory factor analysis, a confirmatory factor analysis, and SEM. Few studies to date have attempted to structurally define strategic pitching skill using professional-level data. This study makes a novel contribution by revealing the structure of strategic pitching skill based on elite-level game data.

Composition of Strategic Pitching Skill Items

To develop strategic pitching skill items, the study applied a causal-effect analysis applying the Delphi method, extracting implicit knowledge from experienced experts. This approach aligned with findings from previous research in sports science, which has shown that combining the Delphi method with causal analysis is effective for identifying the structure of strategic skills (Suzuki & Nishijima, 2005; Matsuoka et al., 2021). In this study, the same methodology was applied to ensure content validity and logical consistency in defining the components of pitching strategy.

A set of twenty strategic pitching skill items was developed to represent core tactical behaviors in pitching. The final structure included two primary domains: pitch velocity skill and pitch location skill. Pitch velocity skill was defined by the sub-skill of off-speed skill, while pitch location skill comprised three sub-skills: vertical skill (high–low), horizontal skill (inside–outside), and diagonal skill (opposing corners). Previous studies have emphasized the strategic importance of pitch sequencing based on the strike count (Gray, 2002; Albert, 2010; Hashimoto & Nakata, 2022). For instance, Lee et al. (2024) quantified the impact of pitch count by applying the importance of moment index and showed that outcomes from early pitches, particularly the first pitch, significantly influence batter advantage and pitch selection. The second strike in particular makes it more likely for pitchers to choose a fastball, highlighting how the count greatly affects pitching strategy. This supports the notion that each pitch should be evaluated in its specific situational context. Because of these findings, each sub-skill was represented by items calculated as differences relative to pitch context, such as the difference from the first pitch or the difference from the previous pitch.

Strategic pitching in baseball can be categorized into temporal elements, represented by pitch velocity, and spatial elements, represented by pitch location. Combining variations in pitch velocity and pitch location is considered an effective strategy for disrupting a batter's perceptual and motor timing (Zelman, 2006; Whiteside et al., 2016a; Kusafuka et al., 2020). In an investigation into this topic, Zelman (2006) conducted a statistical analysis on the effects of pitch velocity, pitch movement, and pitch location on batting average. The study demonstrated that combining temporal variation, achieved through the use of fastballs and off-speed pitches, with spatial variation, achieved by targeting outside and low locations, enhances the effectiveness of suppressing a batter's response. These findings suggest that the skill of pitch velocity corresponds to a "temporal element," while the skill of pitch location corresponds to a "spatial element."

Pitch Velocity Skill

Off-speed skill was identified as a sub-skill of the pitch velocity skill. Off-speed refers to a strategy designed to deceive the velocity the batter anticipates and disrupt timing by throwing a slower pitch following a

fast pitch or vice versa (Zelman, 2006; Whiteside et al., 2016a). In relation to pitcher performance, off-speed skill has been suggested to be associated with metrics such as FIP and strikeout rate (Whiteside et al., 2016b; Martin, 2019). Biomechanical studies investigating the effects of varying pitch velocities on batting movements have observed that variations in pitch velocity lead to a greater disruption of timing and changes in batting mechanics (Takagi et al., 2010; Tago et al., 2017). These findings collectively suggest that the use of off-speed pitches represents an effective tactical element for suppressing batting performance.

Pitch Location Skill

Pitch location skill was structured into three distinct sub-skills: horizontal, vertical, and diagonal skill. Prior research has shown that manipulating pitch location is essential for suppressing batters (Gu & Hu, 2014; Cheshin et al., 2016; Shinya et al., 2017; Glanzer et al., 2019; Manzi et al., 2021). For example, vertical skill is used to interfere with batter gaze and timing, particularly when combining fastballs with sinking pitches like changeups (Whiteside et al., 2016a; Hashimoto et al., 2023). Gu and Hu (2014) emphasized the effectiveness of low pitches and proposed an optimal 4:6 ratio of high to low pitch usage. Horizontal skill, meanwhile, expands the perceived width of the strike zone and increases psychological pressure on the batter, particularly when high-velocity inside pitches are used to induce a sense of physical intimidation (Cheshin et al., 2016), an effect that enhances the effectiveness of subsequent pitches to the outer corner. Executing such location-based skills, however, requires stable mechanics. Glanzer et al. (2019), for instance, demonstrated that core and shoulder stability significantly affect location consistency. Manzi et al. (2021) further highlighted that control over trunk and hip mechanics is critical for accurate inside/outside pitching. Lastly, diagonal skill involves traversing the strike zone along an oblique path, requiring advanced control over one's bodily movements and release mechanics (Shinya et al., 2017). In terms of batting response, Katsumata et al. (2017) found that swing timing differs significantly when facing inside versus outside pitches, further underscoring the cognitive and motor impact of pitch location skill.

Overall, pitch location skill is not merely a technical choice but a strategic decision that exploits spatial disruption. Its effectiveness depends not only on pitch location but also on biomechanical control and repeatability.

Construct Validity of Strategic Pitching Skill Items

The construct validity of the strategic pitching skill items was examined through both an exploratory and a confirmatory factor analysis applying structural SEM. First, the exploratory factor analysis yielded four clearly interpretable factors corresponding to the four strategic pitching skill dimensions: vertical skill, horizontal skill, diagonal skill, and off-speed skill. The absolute values of the inter-factor correlations ranged from 0.05 between vertical and off-speed skills to 0.23 between horizontal and off-speed skills, indicating generally low associations among the factors. These low inter-factor correlations, which were observed in both the exploratory and confirmatory analyses, suggest that the identified skills represent distinct strategic constructs. This finding indicates that each skill captures an independent dimension of strategic pitching, validating the theoretical model proposed through expert analysis.

Secondly, to further verify the model, a confirmatory factor analysis was conducted applying SEM. The model demonstrated strong goodness-of-fit indicators across multiple indices. Specifically, the GFI and AGFI values exceeded 0.90, and CFI was greater than 0.95, while RMSEA remained below 0.08—thresholds considered indicative of a well-fitting model (Bentler, 1990; Browne & Cudeck, 1993; Tabachnick & Fidell, 2007; Kline, 2016). These results indicate that the model fit the observed data well and that the proposed structure was both valid and replicable. Each of the four strategic pitching skills was associated with a distinct and clearly defined set of measurement items, reflecting unique tactical components. The independent structure of the three pitch location skills—horizontal, vertical, and diagonal—further supports the multidimensional nature of spatial competence within strategic pitching (Shinya et al., 2017). Moreover, the relatively low inter-factor correlations observed in both the exploratory and confirmatory analyses suggest that each skill dimension represents a theoretically separable and practically relevant construct. These findings collectively reinforce the argument that strategic pitching skill can be decomposed into measurable, independent components that are grounded in both game theory and empirical observation (Whiteside et al., 2016a; Kusafuka et al., 2021).

Crucially, the model developed in this study is applicable in actual field settings. As the primary objective of this research was model construction, the detailed examination of the physical and technical methods required to execute pitch manipulation was not conducted. However, as intimated above, previous studies have reported that for pitchers to effectively manipulate pitch location, a high level of stability in pitching mechanics, motor control, and technical proficiency is required (Glanzer et al., 2019; Manzi et al., 2021; Shinya et al., 2017). Future research should investigate the relationship between the tactical skill model proposed in this study and biomechanical aspects such as motion stability and motor control. By utilizing big data from top-level Japanese baseball players, this study was able to clarify the conceptual structure of pitch manipulation strategies.

Criterion-Related Validity of Strategic Pitching Skill Items

This finding aligns with previous research demonstrating the effectiveness of strategic variability in reducing hitters' success and enhancing independent pitching outcomes. The criterion-related validity of the strategic pitching skills was examined by analyzing the causal relationships between the factor scores of each skill and the performance indicators derived from sabermetrics—specifically K/BB and FIP. A structural

equation model was constructed, and the resulting model demonstrated excellent fit based on standard indices (CFI = 0.909, NFI = 0.908, RMSEA = 0.037, AIC = 124.431, CMIN = 72.431, $df = 1$, $p = .000$). Although the GFI and AGFI values could not be calculated due to missing data in some pitchers' performance indicators, the overall model fit was judged to be satisfactory.

Significant path coefficients were observed, indicating that both horizontal skill and off-speed skill were significantly associated with lower FIP values. Specifically, the path coefficient from horizontal skill to FIP was -0.51 and from off-speed skill to FIP was -0.39. These results indicate that pitchers who strategically vary pitch location horizontally not only achieve lower FIP values but also exhibit improved strikeout-to-walk ratios, thereby reinforcing the practical utility of horizontal variation as an effective tactical pitching skill.

In the present study, horizontal skill showed significant associations with both FIP and K/BB. This finding indicates that the tactical ability to alternate pitch location between the inside and outside edges of the strike zone not only affects direct pitching outcomes—such as home runs allowed, walks, and strikeouts—but also influences performance metrics related to control. These results are consistent with prior research demonstrating that spatial variability in pitching can affect pitcher performance (Whiteside et al., 2016b). In addition, Kohara and Enomoto (2018) identified K/BB and FIP as valid indicators for distinguishing pitcher performance. Morris et al. (2017) further demonstrated that K/BB is a reliable metric for pitcher evaluation, showing that tactical skills contribute to reducing walks and improving command. They also noted that pitchers' use of spatial variation can disrupt a batter's plate discipline, which is ultimately reflected in their K/BB ratio.

The findings around off-speed skill were similar. Off-speed skill exhibited a significant negative association with FIP. This suggests that the use of velocity differentials as a tactical method to disrupt batter timing directly contributes to reducing home runs and walks while increasing strikeouts. This is in line with the findings of Whiteside et al. (2016b), who demonstrated that pitch velocity and release consistency are predictive of lower FIP values. Furthermore, Piette et al. (2010) reported that FIP is a highly reliable performance metric that is less affected by defensive factors and random variation.

Taken together, these results indicate that horizontal skill functions as a multifaceted tactical skill with significant relationships to both K/BB and FIP, while off-speed skill primarily contributes to pitching performance through its influence on FIP. These findings indicate that both skills can be considered essential elements in the framework of advanced pitching strategy.

Moreover, by structurally modeling pitchers' tactical skills and clarifying their relationships with performance indicators such as K/BB and FIP—which are designed to measure a pitcher's abilities—this study provides empirical support for the utility of tactical skills. These findings are expected to enhance the effectiveness of player development programs and scouting systems by enabling more accurate identification and cultivation of pitchers with strong strategic capabilities.

Limitations

The generalizability of the conclusions drawn from this study should be interpreted with caution, as the dataset was limited to elite-level Japanese professional baseball players. It remains uncertain whether these findings are applicable to amateur or developmental-level players. Moreover, the dataset did not include detailed biomechanical or physical information such as pitching motion or spin rate. Future research incorporating these elements may offer more comprehensive insights into strategic pitching behavior, particularly in these other contexts.

Conclusions

The purpose of this study was to construct a set of strategic pitching skill items from pitch-by-pitch data in NPB and to clarify the construction validity of strategic pitching skills. A qualitative framework of pitching strategy was derived, and a factor analysis and SEM were applied to evaluate both the construct and criterion-related validity of the developed items.

The following conclusions were obtained:

- 1) The structure of strategic pitching skills consisted of two primary domains—pitch velocity skill and pitch location skill—with a total of 20 skill items. The pitch velocity skill domain included the off-speed skill composed of five items. The pitch location skill domain consisted of three sub-skills: horizontal skill, vertical skill, and diagonal skill, comprising 15 items.
- 2) The strategic pitching skill items demonstrated strong construct validity for the four extracted skill domains of off-speed, horizontal skill, vertical skill, and diagonal skill.
- 3) Among these skills, horizontal skill and off-speed skill showed criterion-related validity based on their association with the sabermetric indicator FIP.

These findings not only provide theoretical insights into the structure and measurement of strategic pitching behavior but also offer practical implications for performance enhancement and player development. In particular, the extracted skills—namely horizontal skill (manipulation of pitch location across the strike zone) and off-speed skill (variation in pitch speed)—can serve as measurable indicators in coaching, scouting, and development programs. By incorporating these tactical indicators into practice, teams may be able to more effectively evaluate and develop pitchers with high strategic competence.

Definitions of Terms

1. Strategic pitching skill items: Strategic pitching skill items are defined as measurable, domain-specific tactical behaviors of pitchers—such as skill in pitch velocity, location, and sequence. These items were systematically constructed based on expert knowledge and game analysis, and their validity was confirmed using SEM. These items reflect latent strategic constructs that were analogous to other validated strategic skill scales in team sports (e.g., Suzuki & Nishijima, 2004; Elferink-Gemser et al., 2004; Ando et al., 2018; Matsuoka et al., 2020).
2. The first pitch: The term "the first pitch" refers to the initial pitch thrown by the pitcher to each batter.
3. The first strike: The term "the first strike" refers to the first strike thrown by the pitcher to each batter during an at bat.

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