

# Age-Group Differences in Ball Velocity and Spin Rate Among Youth Baseball Players: A Cross-Sectional Study Using a Portable Tracking Device

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**Purpose:** To describe school-level differences in ball velocity and spin rate in youth baseball players assessed with a portable tracking device and to examine cross-sectional associations with body size. **Methods:** A total of 438 players were grouped as elementary ( $n = 29$ ), junior high ( $n = 154$ ), or senior high ( $n = 255$ ). Each performed 5 maximal-effort throws, and ball velocity (in kilometers per hour) and spin rate (in revolutions per minute) were measured with Rapsodo (mean of 5 trials). Testing differed by level (elementary: rubber ball, 16 m; junior/senior high: hardball, 18.44 m). Groups were compared using 1-way analysis of variance with Bonferroni-adjusted post hoc pairwise comparisons. Pearson correlations assessed associations between anthropometrics (height, body mass) and performance within each group. **Results:** Ball velocity and spin rate differed across levels ( $P < .001$ ). For ball velocity, correlations with height were  $r = .688$  (elementary),  $.763$  (junior high), and  $.124$  (senior high), and correlations with body mass were  $r = .391$ ,  $.690$ , and  $.218$ , respectively. For spin rate, correlations with height were  $r = -.383$ ,  $.541$ , and  $.106$ , and correlations with body mass were  $r = -.332$ ,  $.446$ , and  $.087$ , respectively. The velocity–spin correlation differed by level, showing a negative association in the elementary group ( $r = -.524$ ) but strong positive associations in the junior high ( $r = .776$ ) and senior high ( $r = .712$ ) groups. **Conclusions:** Under these field-based testing conditions, ball velocity and spin rate were higher in older school-level groups, and cross-sectional association patterns differed by level; longitudinal studies under standardized constraints are needed to characterize within-player changes over time.

**Keywords:** anthropometrics, throwing performance, age stratification, field-based measurement, adolescent athletes

The global popularity of baseball continues to increase, and recent advancements in sports science and motion capture technology have led to remarkable improvements in pitching performance. Ball velocity and spin rate are widely considered primary determinants of pitching performance in baseball.<sup>1,2</sup> These parameters not only influence the perceived quality of pitches, such as speed, movement, and deception, but also contribute to successful game outcomes.<sup>3,4</sup> Recent advancements in sports science and motion capture technology have enabled a more precise quantification of these metrics, facilitating targeted training and biomechanical analyses.


Although optimizing the velocity and spin is central to performance enhancement, these improvements may occur at the cost of increased mechanical stress on the throwing arm. The high-speed, large-range shoulder movements required to achieve optimal velocity place considerable loads on the joints and soft tissues, potentially contributing to the high incidence of injuries to the throwing-related shoulders and elbows in youth baseball players.<sup>5</sup> This underscores the importance of clinicians, coaches, and performance staff in balancing performance enhancement and injury prevention through appropriate monitoring and load management tailored to each athlete's profile.

Ball velocity has long been considered a key determinant of competitive success, as increased speed shortens a batter's response time.<sup>6</sup> Recently, the ball spin rate has gained attention as another critical performance factor owing to its aerodynamic effects.<sup>2,7</sup> Specifically, greater backspin induces a stronger upward Magnus

force, producing the well-known illusion of a “rising fastball” that makes pitches more difficult to hit.<sup>8,9</sup> Thus, pitches that combine high velocity and spin are considered the most effective in game situations.

From a biomechanical standpoint, ball velocity and spin rate originate from partially overlapping but distinct mechanisms.<sup>10–12</sup> Velocity generation relies heavily on whole-body coordination, efficient kinetic chain sequencing, and power transfer from the lower limbs through the trunk to the upper extremity.<sup>13,14</sup> In contrast, the spin rate is more sensitive to fine motor control at the end of the kinetic chain, including forearm angular velocity, finger force application, and wrist mechanics during ball release.<sup>15–17</sup> Although these biomechanical factors are essential for pitching performance, anthropometric characteristics, such as height and body mass, may further augment performance by increasing moment arms and mechanical leverage. For example, taller and heavier athletes may generate greater momentum and mechanical advantages, thereby enhancing velocity and spin. However, how such body size advantages manifest across different developmental stages remains unclear. Neuromuscular coordination and technical skills evolve throughout adolescence and may modulate the relationship between anthropometric factors and pitching performance. Particularly in youth baseball populations, including elementary, junior high, and senior high school players, the contribution of body size to velocity and spin rate generation at each competitive level remains unclear. Thus, the extent to which physical characteristics influence pitching performance in younger athletes and how this relationship changes as athletes mature should be examined.

Technological advances, such as the radar-based TrackMan and optical-based Hawk-Eye systems, have enabled comprehensive tracking of ball velocity and spin rate at the professional

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level.<sup>18,19</sup> However, these stadium-based systems are expensive and inaccessible to amateur and young players, leaving a critical data gap for developmental cohorts. Without age-stratified reference values, designing training or injury prevention programs tailored to the needs of young athletes is difficult. Portable tracking devices such as the Rapsodo system offer a potential solution. As an optical–radar hybrid, it allows the high-frequency collection of velocity and spin data in outdoor and nonprofessional settings.<sup>20</sup> These systems are increasingly used in high school and recreational baseball environments. However, information on the normative progression of ball velocity and spin rate measured using Rapsodo across different stages of player development is limited. Moreover, the extent to which the body size influences these parameters at various competition levels remains unclear.

Therefore, the present study aimed to (1) describe differences in ball velocity and spin rate across school-level groups (elementary, junior high, and senior high) measured using a portable tracking system and (2) determine the extent to which anthropometric characteristics (height and weight) are associated with these performance metrics across developmental stages. We hypothesized that (1) ball velocity and spin rate would progressively increase with competitive level, reflecting between-group differences in physical characteristics and throwing-related skills and (2) that body size would predict velocity more strongly than spin rate, especially in younger athletes.

## Methods

### Participants

A total of 438 male youth baseball players participated in this cross-sectional study and were stratified by school level: elementary ( $n = 29$ ), junior high ( $n = 154$ ), and senior high ( $n = 255$ ). Inclusion criteria were: (1) currently engaged in organized team-based baseball training and (2) no current restrictions on overhand throwing. Exclusion criteria were: (1) current shoulder or elbow pain, (2) history of upper-extremity surgery, or (3) inability to perform maximal-effort overhand throwing.

Body height was measured using a stadiometer (resolution: 0.1 cm, YS-201-S, YOSHIDA Co) and body mass using a digital scale (Model No. TBF-410, resolution: 0.1 kg, Body Fat Analyzer, Tanita Corporation) by trained staff following a standardized protocol. Participants completed a brief questionnaire on baseball playing history, including years of organized baseball experience (years) and age at initiation of organized baseball (years). Participants also self-reported their primary playing position, defined as the position played most frequently during the current season (pitcher/catcher/infielder/outfielder). Because younger players may perform multiple positions, primary position was recorded to describe the cohort and was not used as an inclusion criterion. Group age ranges and the distribution of primary positions are provided in Tables 1 and 2. An a priori sample size calculation was not performed because the study used a convenience sample based on field-testing opportunities; therefore, group sizes—particularly in the elementary school group—reflected recruitment feasibility and participant availability. The study was approved by the Institutional Review Board of Hankai Hospital (R-0004), and written informed consent/assent was obtained from all participants and their legal guardians.

### Experimental Procedures

All participants performed 5 maximal-effort overhand pitch-like throws intended to approximate a fastball-type release (hereafter

**Table 1 Distribution of Participants by Competitive Level, Ball Type, and Playing Position**

	Count (%)
Competitive level	
Elementary school	29 (6.62%)
Junior high school	154 (35.16%)
Senior high school	255 (58.22%)
Ball type	
Hardball	409 (93.38%)
Rubber ball	29 (6.62%)
Position	
Pitcher	117 (26.71%)
Catcher	45 (10.27%)
Infielder	157 (35.85%)
Outfielder	117 (26.71%)

referred to as “throwing trials”). Trials were performed from a regulation mound. Throwing distance was set according to age-specific regulations: 16.0 m for elementary players and 18.44 m for junior and senior high players.

Ball type followed the participants’ usual competition format in Japan. Elementary school players threw a Japanese J-type rubber ball (diameter  $\approx 69$  mm; mass  $\approx 129$  g), whereas junior and senior high players threw a standard hardball (diameter  $\approx 72.9$  mm; mass  $\approx 141.7$  g), consistent with league regulations. Accordingly, ball type and pitching distance differed by school level and were not experimentally controlled.

Ball velocity (in kilometers per hour) and spin rate (revolutions per minute) were measured using the Rapsodo Pitching 2.0 system (Rapsodo Inc). The device was set up and calibrated before each testing session according to the manufacturer’s instructions.<sup>20</sup> The mean of the 5 trials was used for analysis to improve within-session stability.

### Statistical Analysis

All analyses were performed using SPSS Statistics (version 29, IBM Corp). Statistical significance was set at  $\alpha = .05$  (2-sided). Normality was assessed using the Shapiro–Wilk test. Group differences in ball velocity and spin rate across school levels were examined using 1-way analysis of variance. Homogeneity of variance was evaluated using Levene’s test; when the assumption of equal variances was violated, Welch analysis of variance was used. When a significant main effect was identified, Bonferroni-adjusted post hoc pairwise comparisons were conducted to compare school-level groups.

To address the small sample size in the elementary-school group, post hoc power analyses were conducted using G\*Power (version 3.1.9.7) for key pairwise comparisons (elementary vs junior high; elementary vs senior high; and junior high vs senior high). To provide a conservative sensitivity-based estimate given unequal group sizes, power was estimated using a 2-tailed independent-samples  $t$  test with  $\alpha = .05$  and a fixed medium standardized effect size (Cohen  $d = 0.5$ ), based on the observed group sizes.

Within each school-level group, Pearson correlation coefficients were used to quantify associations between performance metrics (ball velocity, spin rate) and anthropometrics (height, body mass). Correlations are reported with 95% CIs calculated using

**Table 2 Anthropometric and Performance Characteristics by Competitive Level**

	Elementary school n = 29	Junior high school n = 154	Senior high school n = 255
Age, y	11.07 (1.10) <sup>a</sup> 8.00–12.00 <sup>b</sup>	13.55 (1.00) 12.00–15.00	15.52 (1.62) 15.00–18.00
Height, cm	147.29 (8.40) 134.00–164.00	162.46 (8.32) 140.00–188.00	171.09 (5.50) 155.00–190.00
Body weight, kg	39.57 (7.12) 30.00–55.00	54.79 (9.94) 34.90–90.00	64.70 (9.13) 47.10–96.50
BMI, kg·m <sup>-2</sup>	18.13 (2.39) 14.74–23.14	20.58 (2.41) 16.37–30.49	21.98 (2.95) 16.61–32.11
Baseball experience, y	2.20 (1.57) 0.50–5.00	5.85 (0.83) 1.00–11.00	7.03 (0.84) 0.33–14.00
Ball type			
Hardball	0 (0.00%)	154 (100.00%)	255 (100.00%)
Rubber ball	29 (100.00%)	0 (0.00%)	0 (0.00%)
Position			
Pitcher	14 (48.28%)	44 (28.57%)	60 (23.53%)
Catcher	4 (13.79%)	12 (7.79%)	29 (11.37%)
Infielder	6 (20.69%)	60 (38.96%)	91 (35.69%)
Outfielder	5 (17.24%)	38 (24.68%)	75 (29.41%)
Ball velocity, km·h <sup>-1</sup>	83.88 (8.52) 73.90–95.50	103.85 (10.98) 80.42–128.98	112.32 (9.11) 79.80–132.38
Spin rate, rpm	1044.37 (231.56) 707.40–1378.00	1640.30 (226.85) 996.00–2150.20	1775.01 (210.99) 1067.00–2365.00

<sup>a</sup>Mean (SD). <sup>b</sup>Range (min–max).

Fisher *z* transformation. Correlation magnitudes were interpreted based on the absolute value of *r* using prespecified thresholds: strong ( $|r| \geq .70$ ), moderate ( $|r| = .40-.69$ ), and weak ( $|r| = .10-.39$ ).

Within-session reliability for ball velocity and spin rate across the 5 trials was evaluated using ICC (1,5) and the standard error of measurement, based on a 1-way random-effects model. Reliability was assessed in a randomly selected subsample ( $n = 20$  per ball type) and calculated separately for each ball condition (hardball and rubber ball). ICC was interpreted as excellent ( $>.90$ ), good ( $.75-.90$ ), moderate ( $.50-.75$ ), or poor ( $<.50$ ) reliability.<sup>21</sup>

## Results

Results are presented in Tables 1–6 and Figures 1 and 2. A total of 438 male youth baseball players were included (elementary:  $n = 29$ ; junior high:  $n = 154$ ; senior high:  $n = 255$ ).

Within-session reliability of Rapsodo-derived outcomes across 5 consecutive trials was evaluated in a randomly selected subsample ( $n = 20$  per ball type). Reliability was excellent for the hardball condition (junior high players), with ICCs of .995 for ball velocity and .970 for spin rate; corresponding SEMs were 0.07 km·h<sup>-1</sup> and 5.48 rpm, respectively. In the rubber ball condition (elementary players), ICCs were .982 for ball velocity and .866 for spin rate, with SEMs of 0.72 km·h<sup>-1</sup> and 27.05 rpm, respectively.

Figure 1 displays ball velocity and spin rate across school levels. Both variables differed between groups (Tables 4 and 5;  $P < .001$ ). Bonferroni-adjusted post hoc pairwise comparisons indicated elementary < junior high < senior high for both ball velocity and spin

**Table 3 Descriptive Characteristics of All Participants (n = 438)**

	Mean (SD)	Range
Age, year	14.93 (1.83)	8.00–18.00
Height, cm	166.52 (9.39)	134.00–190.00
Body weight, kg	59.55 (11.65)	30.00–96.50
BMI, kg·m <sup>-2</sup>	21.29 (2.74)	14.74–32.11
Baseball experience, y	6.80 (2.31)	0.50–14.00
Ball velocity, km·h <sup>-1</sup>	107.38 (12.31)	73.90–132.38
Spin rate, rpm	1676.17 (284.94)	707.40–2365.00

rate. For ball velocity, Levene's test indicated unequal variances; therefore, Welch's ANOVA was applied, whereas standard one-way ANOVA was used for spin rate (Table 4). Post hoc power was estimated in G\*Power for the key pairwise comparisons using a fixed medium effect size (Cohen's  $d = 0.5$ ) and the observed group sizes. The estimated power was 0.69 for elementary versus junior high, 0.72 for elementary versus senior high, and 0.99 for junior high versus senior high, indicating lower statistical sensitivity for comparisons involving the elementary group.

Scatterplots for associations between performance outcomes and anthropometrics are shown in Figure 2 (with fitted lines and 95% confidence bands), and correlations are summarized in Table 6. For ball velocity, correlations with height were moderate in the elementary group ( $r = .688$ ; 95% CI, .414 to .841) and strong in the junior high group ( $r = .763$ ; 95% CI, .687 to .821), whereas

**Table 4 Group Comparisons of Ball Velocity and Spin Rate Among Competitive Levels**

	Elementary school <sup>a</sup> n = 29	Junior high school <sup>b</sup> n = 154	Senior high school <sup>c</sup> n = 255	F (df)	P	Effect size, $\eta^2$	Multiple comparisons
Ball velocity, km·h <sup>-1</sup>	83.88 (8.52)	103.85 (10.98)	112.32 (9.11)	138.923 (2, 84.087)	<.001	0.389	a < b < c
Spin rate, rpm	1044.37 (231.56)	1640.30 (226.85)	1775.01 (210.99)	143.10 (2, 429)	<.001	0.400	a < b < c

Note: Values are mean (SD). Group labels indicate school level (a = elementary school, b = junior high school, c = senior high school). In the “Multiple comparisons” column, “a < b < c” indicates that Bonferroni-adjusted post hoc pairwise comparisons showed significant differences between all groups (elementary < junior high < senior high).

**Table 5 Post Hoc Pairwise Comparisons of Ball Velocity and Spin Rate Among Competitive Levels (Bonferroni-Adjusted)**

	Mean difference (a – b)	95% CI	P	Effect size (d)
Ball velocity, km·h <sup>-1</sup>				
Elementary school <sup>a</sup> vs Junior high school <sup>b</sup>	-20.95	-25.64 to -16.25	<.001	2.03
Elementary school vs Senior high school	-29.53	-34.08 to -24.99	<.001	3.22
Junior high school vs Senior high school	-8.59	-10.95 to -6.22	<.001	0.84
Spin rate, rpm				
Elementary school vs Junior high school	-565.27	-669.48 to -461.05	<.001	2.60
Elementary school vs Senior high school	-700.56	-801.58 to -599.55	<.001	3.30
Junior high school vs Senior high school	-135.29	-188.07 to -82.52	<.001	0.62

Note: Values are mean differences (a–b). 95% CI represents 95% confidence interval of the mean difference. Effect size (d) represents Cohen d for pairwise comparisons.

**Table 6 Pearson’s Correlation Coefficients Between Performance Variables and Anthropometric Factors by Competitive Level**

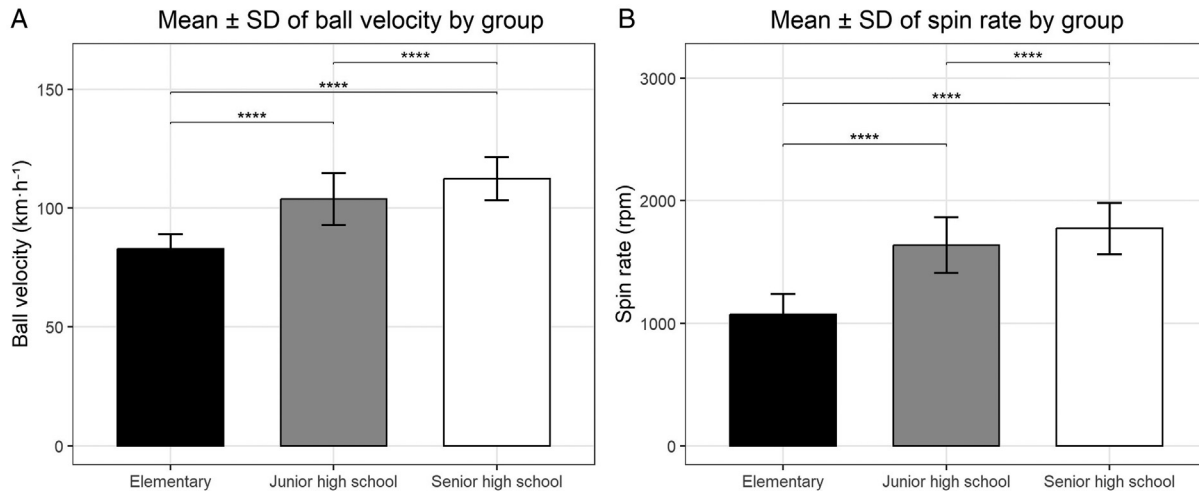
	Elementary school (n = 29)		Junior high school (n = 154)		Senior high school (n = 255)	
	Ball velocity	Spin rate	Ball velocity	Spin rate	Ball velocity	Spin rate
Height, cm	<b>.688**</b>	–.383*	<b>.763**</b>	<b>.541**</b>	<b>.124*</b>	.106
95% CI	.414 to .841	–.658 to –.005	.687 to .821	.417 to .643	.0003 to .243	–.019 to .227
Body weight, kg	<b>.391*</b>	–.332	<b>.690**</b>	<b>.446**</b>	<b>.218**</b>	.087
95% CI	.014 to .663	–.624 to .053	.596 to .764	.309 to .563	.097 to .333	–.039 to .209
BMI, kg·m <sup>-2</sup>	–.187	–.054	<b>.405**</b>	<b>.209**</b>	–.030	.030
95% CI	–.527 to .211	–.425 to .333	.262 to .528	.052 to .355	–.153 to .093	–.095 to .154
Ball velocity, km·h <sup>-1</sup>		<b>–.524**</b>		<b>.776**</b>		<b>.712**</b>
95% CI		–.740 to –.194		.704 to .831		.644 to .768

Note: 95% CI represents 95% confidence interval for Pearson’s r, calculated using Fisher’s z transformation. Bold values indicate statistically significant correlations. \*P < .05. \*\*P < .01.

the correlation in the senior high group was below the prespecified weak threshold ( $r = .124$ ; 95% CI, .0003 to .243). Correlations between ball velocity and body weight were weak in the elementary group ( $r = .391$ ; 95% CI, .014 to .663), moderate in the junior high group ( $r = .690$ ; 95% CI, .596 to .764), and weak in the senior high group ( $r = .218$ ; 95% CI, .097 to .333). Ball velocity was not associated with BMI in the elementary and senior high groups ( $r = -.187$ ; 95% CI,  $-.527$  to .211 and  $r = -.030$ ; 95% CI,  $-.153$  to .093, respectively), whereas a moderate positive correlation was observed in the junior high group ( $r = .405$ ; 95% CI, .262 to .528).

For spin rate, correlations with height were weak and negative in the elementary group ( $r = -.383$ ; 95% CI,  $-.658$  to  $-.005$ ) and moderate and positive in the junior high group ( $r = .541$ ; 95% CI,

.417 to .643), while the correlation in the senior high group was below the weak threshold ( $r = .106$ ; 95% CI,  $-.019$  to .227). Spin rate showed weak-to-negligible associations with body weight and BMI in the elementary and senior high groups (body weight:  $r = -.332$  and .087; BMI:  $r = -.054$  and .030), whereas the junior high group showed moderate correlations with body weight ( $r = .446$ ; 95% CI, .309 to .563) and a weak correlation with BMI ( $r = .209$ ; 95% CI, .052 to .355). The correlation between ball velocity and spin rate differed by school level: it was moderate and negative in the elementary group ( $r = -.524$ ; 95% CI,  $-.740$  to  $-.194$ ) and strong and positive in the junior high and senior high groups ( $r = .776$ ; 95% CI, .704 to .831 and  $r = .712$ ; 95% CI, .644 to .768, respectively).



**Figure 1** — (A) Mean (SD) of ball velocity (in kilometers per hour) by school level. (B) Mean (SD) of spin rate (in revolutions per minute) by school level. Bars represent mean (SD) for each group (elementary, black; junior high, gray; senior high, white). Horizontal brackets indicate significant Bonferroni-adjusted post hoc pairwise differences between groups (\* $P < .05$ , \*\* $P < .01$ , \*\*\* $P < .001$ , \*\*\*\* $P < .0001$ ; see Tables 4 and 5). Group sizes were elementary ( $n = 29$ ), junior high ( $n = 154$ ), and senior high ( $n = 255$ ).

## Discussion

In this cross-sectional study using a portable tracking system under field conditions, ball velocity and spin rate differed across school-level groups, and the magnitude and direction of associations among velocity, spin, and anthropometrics varied by level. Conversely, the velocity–spin relationship was negative in the elementary group but strongly positive in the junior and senior high groups (Table 6). Because the cohort included players with mixed primary positions and heterogeneous playing histories, and because testing constraints differed by level, the present findings should be interpreted strictly as cross-sectional comparisons between age-defined groups rather than as evidence of within-player developmental change. The observed between-group patterns may reflect cohort effects (eg, differences in playing history, training environment, coaching, or selection) rather than within-player change. Accordingly, this study focuses on describing age-group-specific performance characteristics and their associations with anthropometric variables, rather than inferring developmental trajectories.

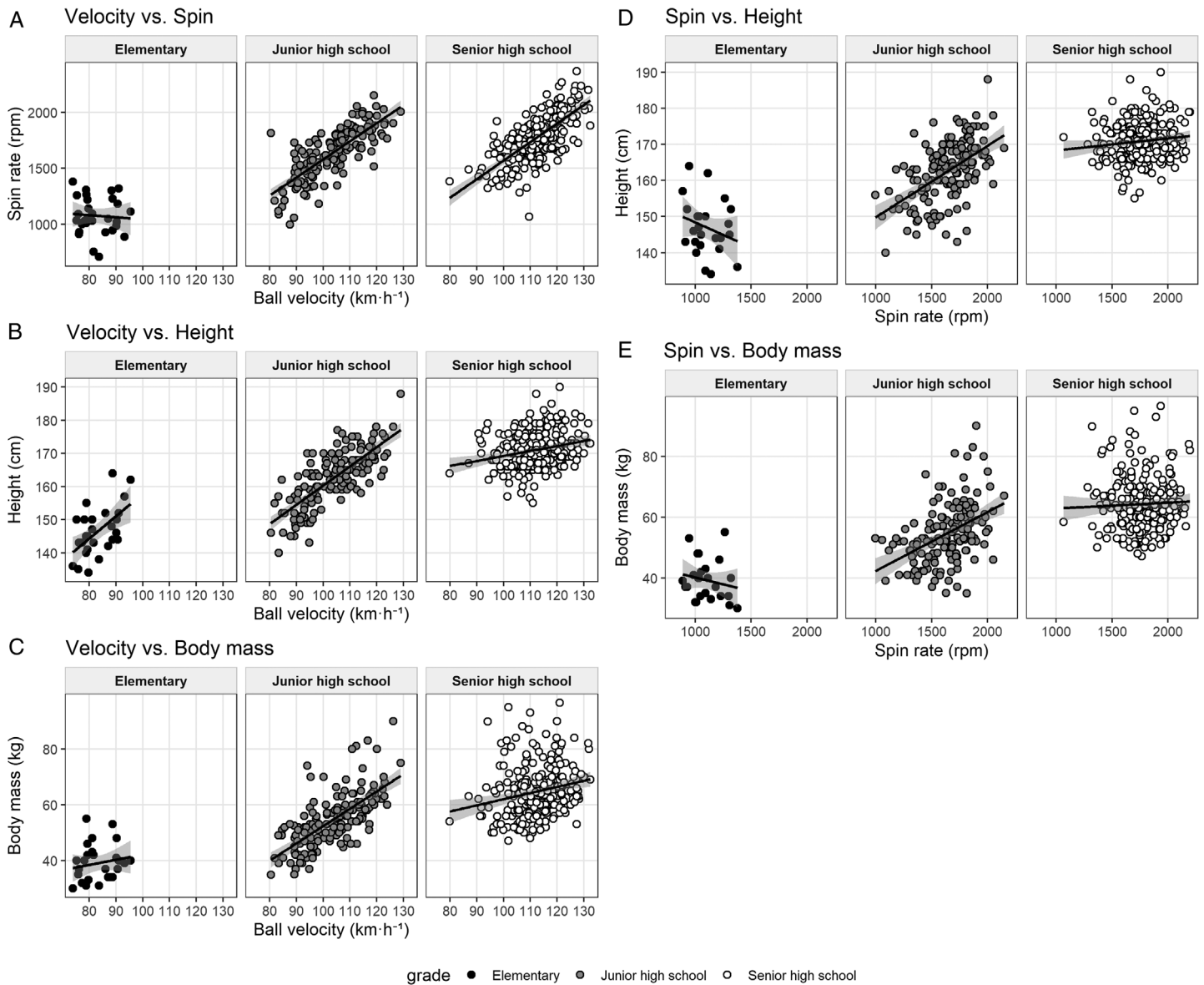
The portable tracking system (Rapsodo) demonstrated good-to-excellent within-session reliability for the measured outcomes. In a subsample who completed 5 consecutive throwing trials ( $n = 20$  per ball type), reliability in the hardball condition (junior high players) was excellent, with ICCs of .995 for ball velocity and .970 for spin rate and corresponding SEMs of  $0.07 \text{ km}\cdot\text{h}^{-1}$  and  $5.48 \text{ rpm}$ , respectively. In the rubber ball condition (elementary players), reliability was excellent for ball velocity (ICC = .982; standard error of measurement =  $0.72 \text{ km}\cdot\text{h}^{-1}$ ) and good for spin rate (ICC = .866; standard error of measurement =  $27.05 \text{ rpm}$ ). Collectively, these results support the use of Rapsodo for within-session assessments in applied settings, while also indicating that spin-rate estimates may be less precise in the elementary-school group throwing a rubber ball. Therefore, elementary-group spin-related associations should be interpreted cautiously and verified in future work using standardized equipment and testing constraints.

Nevertheless, the mean ball velocities observed in the older groups were broadly comparable to values previously reported in

older youth and high school samples (approximately  $103\text{--}113 \text{ km}\cdot\text{h}^{-1}$ )<sup>14,22,23</sup> (Supplementary Material S1 [available online]). Similarly, spin rates in the present cohort were lower than values commonly reported in collegiate and professional cohorts; for context, collegiate/professional fastballs are often reported around approximately 2080 to 2270 rpm<sup>11,17,24</sup> (Supplementary Material S2 [available online]). The alignment of these magnitudes with prior reports provides convergent evidence that the present measurements are plausible for youth populations assessed under field conditions.

The stronger associations between ball velocity and body size in the elementary and junior high groups may be consistent with the possibility that anthropometric variation contributes more to between-player differences in velocity at younger ages. However, these cross-sectional patterns do not establish that growth or maturation causes higher velocity, because age-group comparisons can also reflect differences in playing history and accumulated practice exposure, coaching and training environments, selection effects, and other unmeasured factors. Accordingly, the weaker velocity–anthropometric associations in the senior high group should be interpreted as descriptive and context-dependent rather than as evidence of a mechanistic “shift” in performance determinants.<sup>25</sup> Thus, the present results characterize how the relationship between throwing performance and body size differs across age-defined groups within a single testing context, without implying longitudinal developmental change. An additional descriptive observation was that BMI increased across school levels (Table 2), reflecting that body mass increased more than height on average. Because body composition was not directly assessed, differences in BMI across groups should be interpreted as descriptive and may reflect unmeasured differences in body composition and training exposure.<sup>26</sup>

The negative velocity–spin association in the elementary group is particularly notable and may reflect several nonmutually exclusive explanations. One possibility is a velocity–spin trade-off under less consistent release characteristics, where attempts to generate greater ball speed coincide with reduced ability to impart spin. A second, complementary hypothesis is that elementary-group players may exhibit less efficient kinetic-chain sequencing



**Figure 2** — Scatter plots showing relationships between performance and anthropometric variables by competitive level. (A) Velocity versus spin rate, (B) velocity versus height, (C) velocity versus body mass, (D) spin rate versus height, and (E) spin rate versus body mass. Points represent individual players. Solid lines indicate linear regression fits; shaded areas represent 95% CIs.

and a less stable release pattern (eg, greater variability in forearm/wrist orientation or release timing), which could reduce the consistency with which spin is transferred to the ball when throwing at higher intent.<sup>10,27</sup> In addition, level-specific testing constraints in the elementary group—specifically, differences in ball material and throwing distance relative to older groups—may influence grip–ball interaction and release behavior, thereby affecting how velocity and spin co-vary.<sup>15,28</sup> Because we did not measure biomechanical determinants of the release (eg, kinematics/kinetics, spin efficiency, or release orientation) or kinetic-chain variables, these explanations remain hypotheses that should be tested in future work. From a biomechanical perspective, the velocity–spin relationship can be influenced by how angular velocity is transferred through the kinetic chain and by release parameters (eg, wrist/forearm orientation and timing at ball release).<sup>29,30</sup> Although these mechanisms were not measured in the present study, they

provide a plausible framework for interpreting the observed level-specific patterns within this cross-sectional design without implying causality or longitudinal change.

From an applied perspective, portable tracking may be useful for describing age-group patterns and for monitoring changes within a consistent testing context (eg, same ball type, distance, setting, and instructions). However, practitioners should avoid interpreting cross-sectional between-group differences as within-player developmental change and should consider level-specific constraints, player role heterogeneity (eg, primary position and degree of specialization), and environmental context when comparing values across cohorts.

This study has some limitations. First, the elementary school cohort was smaller than the other groups, which limits precision for estimates in the youngest group. Post hoc power analyses for pairwise comparisons involving the elementary group (assuming

a medium effect size,  $d=0.5$ ) indicated estimated power below the conventional 0.80 threshold; therefore, analyses involving the elementary group had lower statistical sensitivity, and inferences for this subgroup should be interpreted cautiously. In addition, group sizes were determined by convenience sampling rather than a priori power analysis; therefore, estimates for the elementary group should be considered less precise. Post hoc power analyses using a conservative fixed effect size ( $d=0.5$ ) showed only moderate statistical power for comparisons involving the elementary group (power = 0.69–0.72), indicating an increased risk of Type II error in this subgroup. Consistent with this, the 95% CIs for correlations were wider in the elementary group than in the older groups (Table 6), reflecting greater uncertainty due to the smaller sample size. Second, the cross-sectional design precludes causal inference and does not allow characterization of within-player developmental trajectories. Third, and most importantly, testing constraints differed by school level (including ball type and throwing distance), and these factors were not experimentally controlled; therefore, between-group comparisons and velocity–spin relationships may be confounded by these level-specific conditions. Fourth, environmental conditions (eg, wind and temperature) were not standardized or systematically recorded, which may influence portable tracking outputs, particularly spin-related estimates. In addition, within-session reliability for spin rate was lower in the rubber ball condition than in the hardball condition, suggesting greater measurement variability for spin outcomes in the youngest group. Finally, the cohort included players with mixed primary playing positions and heterogeneous playing histories, which may also contribute to observed between-group patterns. Taken together, the results should be interpreted as descriptive age-group patterns under field-based testing conditions rather than as evidence of developmental change.

## Practical Applications

These findings provide practical context for coaches, practitioners, and sport scientists working with youth baseball players when using portable tracking in field settings. The present data describe cross-sectional differences between school-level groups in ball velocity and spin rate and highlight that the association between velocity and spin may differ by level. Portable tracking systems (eg, Rapsodo) can support field-based monitoring, particularly when testing procedures are kept consistent within a team or player over time. However, practitioners should avoid interpreting cross-sectional differences between cohorts as evidence of within-player change.

When interpreting tracking outputs, practitioners should consider that ball type, throwing distance, and environmental context may influence measurements and that spin-rate estimates may be less precise in younger players using a rubber ball. Accordingly, cross-sectional comparisons across cohorts should be made cautiously, and the greatest utility may be achieved by monitoring changes within a consistent testing context (eg, same ball type, distance, and setting) across repeated assessments.

## Conclusions

This study described cross-sectional differences between school-level groups in ball velocity and spin rate in youth baseball players assessed with a portable tracking device in a field setting. In this cross-sectional sample, both outcomes were higher in older groups, and associations among velocity, spin, and anthropometrics differed across groups, including a negative velocity–spin correlation

in the elementary group and strong positive correlations in the older groups (Table 6). These findings characterize age-group-specific performance patterns and their associations with body size under field-based testing conditions, and may support field-based monitoring when procedures are kept consistent; however, they should not be interpreted as evidence of within-player developmental trajectories. Between-group comparisons should be interpreted with caution given level-specific testing constraints (ball type and throwing distance), outdoor environmental variability, and heterogeneity in player roles. Because the elementary-school group was smaller, estimates in this subgroup were less precise (including wider correlation confidence intervals) and should be interpreted cautiously. Longitudinal studies under standardized conditions are warranted to characterize within-player changes over time.

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## References

1. Quinn M, Ge J, Ham J, et al. Effect of ulnar collateral ligament reconstruction on performance in major league baseball pitchers: a 2-year analysis of advanced pitching statistics, velocity, and spin rate. *Am J Sports Med.* 2025;53(6):1460–1468. doi:10.1177/03635465251326907
2. Jinji T, Sakurai S. Direction of spin axis and spin rate of the pitched baseball. *Sports Biomech.* 2006;5(2):197–214. doi:10.1080/14763140608522874
3. Hashimoto Y, Nagami T, Yoshitake S, Nakata H. The relationship between pitching parameters and release points of different pitch types in major league baseball players. *Front Sports Act Living.* 2023; 5:1113069. doi:10.3389/fspor.2023.1113069
4. Nagami T, Morohoshi J, Higuchi T, Nakata H, Naito S, Kanosue K. Spin on fastballs thrown by elite baseball pitchers. *Med Sci Sports Exerc.* 2011;43(12):2321–2327. doi:10.1249/MSS.0b013e318220e728
5. Chalmers PN, Sgroi T, Riff AJ, et al. Correlates with history of injury in youth and adolescent pitchers. *Arthroscopy.* 2015;31(7):1349–1357. doi:10.1016/j.arthro.2015.03.017
6. Kishita Y, Ueda H, Kashino M. Temporally coupled coordination of eye and body movements in baseball batting for a wide range of ball speeds. *Front Sports Act Living.* 2020;2:64. doi:10.3389/fspor.2020.00064
7. Nagami T, Higuchi T, Nakata H, Yanai T, Kanosue K. Relation between lift force and ball spin for different baseball pitches. *J Appl Biomech.* 2016;32(2):196–204. doi:10.1123/jab.2015-0068
8. Bahill AT, Karnavas WJ. The perceptual illusion of baseball's rising fastball and breaking curveball. *J Exp Psychol Hum Percept Perform.* 1993;19:3–14.
9. Higuchi T, Morohoshi J, Nagami T, Nakata H, Kanosue K. The effect of fastball backspin rate on baseball hitting accuracy. *J Appl Biomech.* 2013;29(3):279–284. doi:10.1123/jab.29.3.279
10. Stodden DF, Fleisig GS, McLean SP, Andrews JR. Relationship of biomechanical factors to baseball pitching velocity: within pitcher variation. *J Appl Biomech.* 2005;21(1):44–56. doi:10.1123/jab.21.1.44

11. Wong R, Laudner K, Amonette W, Vazquez J, Evans D, Meister K. Relationships between lower extremity power and fastball spin rate and ball velocity in professional baseball pitchers. *J Strength Cond Res.* 2023;37(4):823–828. doi:10.1519/JSC.000000000004330
12. Shibata S, Shimana T, Kado J, et al. Mechanism for control of ball spin rate by the upper limb in baseball pitching based on singular value decomposition. *J Biomech.* 2023;153:111603. doi:10.1016/j.jbiomech.2023.111603
13. Pryhoda MK, Sabick MB. Lower body energy generation, absorption, and transfer in youth baseball pitchers. *Front Sports Act Living.* 2022; 4:975107. doi:10.3389/fspor.2022.975107
14. Manzi JE, Yu JS, Sudah SY, et al. A systematic review of lower-body kinematic and strength factors associated with pitch velocity in adult baseball pitchers. *J Sport Rehabil.* 2023;32(4):440–448. doi:10.1123/jsr.2022-0059
15. Yamaguchi T, Suzuki S, Suzuki S, Nishi T, Fukuda T, Nasu D. Impact of slip distance between fingertips and ball on baseball pitching performance under different friction conditions. *Sci Rep.* 2025;15(1):9514. doi:10.1038/s41598-025-93632-y
16. Shibata S, Kaneko Y, Shimana T, et al. Estimation of tangential finger force and its relationship with the spin rate of pitched fastball. *Sports Biomech.* 2025;24(3):493–508. doi:10.1080/14763141.2022.2125823
17. Wong R, Laudner K, Evans D, Miller L, Blank T, Meister K. Relationships between clinically measured upper-extremity physical characteristics and ball spin rate in professional baseball pitchers. *J Strength Cond Res.* 2021;35(5):1331–1337. doi:10.1519/JSC.00000000003994
18. Nasu D, Kashino M. Impact of each release parameter on pitch location in baseball pitching. *J Sports Sci.* 2021;39(10):1186–1191. doi:10.1080/02640414.2020.1868679
19. Cant O, Kovalchik S, Cross R, Reid M. Validation of ball spin estimates in tennis from multi-camera tracking data. *J Sports Sci.* 2020;38(3):296–303. doi:10.1080/02640414.2019.1697189
20. Downs Talmage J, Friesen KB, Fava A, Everhart K, Oliver GD. Effects of increasing pitch count on pitch type ball metrics and release height in high school softball pitchers. *Sports Health.* 2024;16(4): 644–649. doi:10.1177/19417381231217668
21. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med.* 2016; 15(2):155–163. doi:10.1016/j.jem.2016.02.012
22. Kageyama M, Sugiyama T, Kanehisa H, Maeda A. Difference between adolescent and collegiate baseball pitchers in the kinematics and kinetics of the lower limbs and trunk during pitching motion. *J Sports Sci Med.* 2015;14(2):246–255.
23. Sgroi T, Chalmers PN, Riff AJ, et al. Predictors of throwing velocity in youth and adolescent pitchers. *J Shoulder Elbow Surg.* 2015;24(9): 1339–1345. doi:10.1016/j.jse.2015.02.015
24. Whiteside D, McGinnis RS, Deneweth JM, Zernicke RF, Goulet GC. Ball flight kinematics, release variability and in-season performance in elite baseball pitching. *Scand J Med Sci Sports.* 2016;26(3):256–265. doi:10.1111/sms.12443
25. Sakurai M, Szymanski DJ, Qiao M, Croftin RL. Combined counter-movement jump testing and motion analysis as the future of performance assessment for baseball pitchers: a narrative review. *J Strength Cond Res.* 2023;37(6):1327–1338. doi:10.1519/JSC.000000000004261
26. Loomba-Albrecht LA, Styne DM. Effect of puberty on body composition. *Curr Opin Endocrinol Diabetes Obes.* 2009;16(1):10–15. doi:10.1097/MED.0b013e328320d54c
27. Hirashima M, Ohtsuki T. Exploring the mechanism of skilled over-arm throwing. *Exerc Sport Sci Rev.* 2008;36(4):205–211. doi:10.1097/JES.0b013e31818781cf
28. Kinoshita H, Obata S, Nasu D, Kadota K, Matsuo T, Fleisig GS. Finger forces in fastball baseball pitching. *Hum Mov Sci.* 2017;54: 172–181. doi:10.1016/j.humov.2017.04.007
29. Diffendaffer AZ, Bagwell MS, Fleisig GS, et al. The clinician's guide to baseball pitching biomechanics. *Sports Health.* 2023;15(2):274–281. doi:10.1177/19417381221078537
30. Seroyer ST, Nho SJ, Bach BR, Bush-Joseph CA, Nicholson GP, Romeo AA. The kinetic chain in overhand pitching: its potential role for performance enhancement and injury prevention. *Sports Health.* 2010;2(2):135–146. doi:10.1177/1941738110362656