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Original Research

A Comparison of Pitching Biomechanics and Sport Specialization in High School Pitchers

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Background

The prevalence of sport specialization in high school athletes continues to rise, particularly among baseball players. Previous research has focused on the incidence of injury among specialized and non-specialized athletes but has yet to examine the level of sport specialization and pitching biomechanics.

Hypotheses/Purpose

The purpose of this study was to investigate differences in pitching volume and biomechanics between low-, moderate-, and high-level specialized baseball pitchers. It was hypothesized that high-level specialized pitchers would have the most pitching volume within the current and previous years while low-level specialized pitchers would exhibit the least amount. The second hypothesis states that kinematics and kinetics commonly associated with performance and injury risk would differ between low-, moderate-, and high-level specialized pitchers.

Study Design

Case-Control Study

Methods

Thirty-six high school baseball pitchers completed a custom sport specialization questionnaire before participating in a three-dimensional pitching motion analysis. Sport specialization was based off current guidelines and categorized as low-, moderate-, and high-level specialized based upon self-reported outcomes. Pitchers then threw ≈10 fastballs from a mound engineered to professional specifications. Data averaged across fastballs was used for biomechanics variables. Key pitching biomechanical and pitching volume variables were compared between low-, moderate-, and high-level specialized pitchers.

Results

High-level specialized pitchers were older ($p = 0.003$), had larger body mass ($p = 0.05$) and BMI ($p = 0.045$), and threw faster ($p = 0.01$) compared to low-level specialized pitchers. Pitching volume and pitching biomechanics were similar across groups.

Conclusions

Pitching biomechanics were similar across groups, although high-level specialized pitchers threw with significantly higher throwing velocity compared to low-level pitchers. The low amount of pitching volume throughout the season may be responsible for the lack of additional observed differences. Further research should examine the relationship between pitching biomechanics, upper extremity strength and flexibility, and sport specialization.

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Level of Evidence

Level III

INTRODUCTION

Organized youth sports within the United States involve over 60 million youth athletes per year.[1] Participation across all age groups from six to eighteen years old has increased over the past two decades, resulting in a concomitant increase in sport specialization.[2–4] Sport specialization is defined as intentional and focused participation in a single sport for a majority of the year that restricts opportunities for engagement in other sports and activities.[5] Additionally, single and multisport athletes may be considered specialized if they meet some or all of the following criteria: a) participation in a single sport for greater than eight months of the year that includes regular organized practices, competitions, or other structured training, b) the athlete may have limited or ended involvement in other sports to enable focused participation in a single sport or have only ever been involved in one sport, c) focused participation in a single sport limits the opportunities or time available for other activities, such as involvement in other sports, academics, extracurricular activities, time with friends, and community engagement.[5] Furthermore, sport specialization can be categorized as high-, moderate-, and low-level specialized based on responses to "*Can you pick a main sport?*", "*Did you quit other sports to focus on a main sport?*", and "*Do you train >8 months in a year?*".[6] High-level specialists, those answering "yes" to at least two of the aforementioned questions, were previously shown to be more likely to experience an overuse injury compared to moderate- (answering "yes" to two questions) and low-level specialists (answering "yes" to ⩽ 1 questions).[6] Sport specialization is associated with performing the same mechanical motions repeatedly and often focusing on certain musculoskeletal areas while neglecting others in order to attempt to perform optimally in a sport.[7] Despite increasing evidence suggesting that sport specialization may contribute to overuse injuries in youth athletes, specialization prevalence continues to rise in the United States, particularly among baseball players.[8,9]

Specialization prevalence of multiple sports revealed that baseball athletes are more likely to specialize as well as endure the highest prevalence of overuse injuries.[10] Coinciding with recent trends, elbow injuries within youth baseball players significantly increased from 2006 to 2016, and 57% of all ulnar collateral ligament reconstructions now performed in youth pitchers.[11,12] Injury risk is increased when compounding repetition from practice and competition as repeated sport-specific mechanical motions can lead to traumatic injury or overuse injury, both of which are negative consequences of sport specialization.[10] While specialization is thought to enhance skills and abilities needed to achieve elite status, there is a consensus that participating in multiple sports throughout the year and unstructured play is important for developing a well-rounded athlete to mitigate the chronic stresses of pitching.[13]

Pitching volume has been shown to be a risk factor for upper extremity injury in youth baseball pitchers, as increased pitches per game, innings pitched per season, months pitched per year, and pitching for multiple teams are all associated with increased injury risk.[14,15] Repetitive stress on the musculoskeletal system can result in overuse injuries, to which youth athletes are considered highly susceptible due to musculoskeletal and physiological immaturity.[16] Pitchers between 9-14 years old who pitched more than eight months per year were shown to be five times more likely to undergo surgery compared to those pitching less than eight months. Additionally, youth pitchers who regularly throw with arm fatigue are 36 times more at risk to require surgery or end their baseball career due to injury.[15] Even with youth pitchers learning proper techniques, fatigue from competition can impair pitching biomechanics.[17–19]

Biomechanical assessments have been gaining popularity in order to assess performance and potential injury risk through analysis of kinematics (i.e., motions) and kinetics (i.e., forces and torques) within the pitching motion.[8,20] These assessments suggest a balance between increased performance brought on by increased throwing velocity and increased injury risk, as injuries are most likely to occur when high forces and torques are repeatedly applied to vulnerable tissue.[21] The large amount of kinetic forces produced throughout the body during the pitching motion cause the throwing arm to sustain a substantial amount of kinetic energy.[22] Understanding and implementing efficient pitching biomechanics can help to safely facilitate kinetic energy propagation from stride-foot contact (SFC) to ball release (BR), timepoints commonly used to denote the arm cocking, acceleration, and deceleration actions exhibited in the pitching motion.[23] Less-skilled pitchers demonstrate a decreased ability to safely propagate kinetic energy through to the baseball, leading to increased injury risk.[22,24] Pitching biomechanics that allow for fluid kinetic energy propagation may help mitigate the effects of increased pitching volume observed in specialized baseball pitchers.

Previous research has yet to examine the relationship between the level of sport specialization and pitching biomechanics. Therefore, the purpose of this study was to investigate differences in pitching volume and biomechanics between low-, moderate-, and high-level specialized baseball pitchers. It was hypothesized that high-level specialized pitchers would have the largest volume of pitching within the current and previous years with low-level specialized pitchers exhibiting the least amount of pitching volume. The second hypothesis states that pitching biomechanics variables commonly associated with performance and injury risk would differ between low-, moderate-, and high-level specialized pitchers.

MATERIALS AND METHODS

Data were retrospectively gathered from pitching biomechanics evaluations at the Wake Forest Pitching Lab, available as an open service to all interested pitchers. Pitching

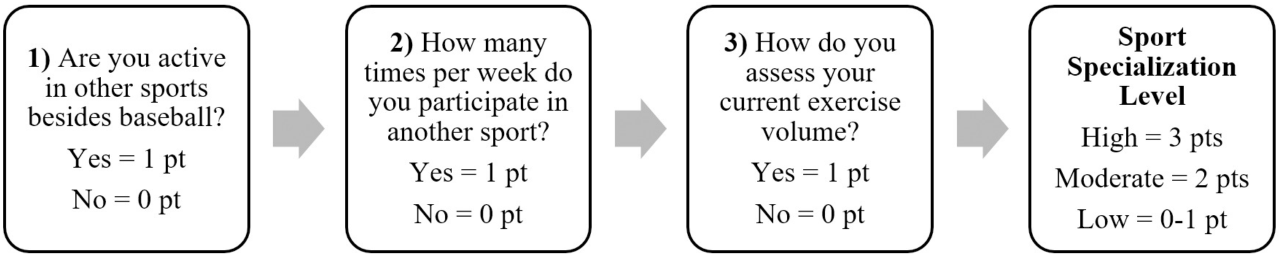

Figure 1. Process for determining sport specialization level

evaluations were specifically advertised to regional baseball teams. An evaluation included completion of several questionnaires, including the sport specialization questionnaire, and three-dimensional pitching motion analysis. Study inclusion criteria included high school pitchers between the ages of 13 – 18 for whom pitcher is their primary or secondary position. Participants were excluded from the study if pitching was not their primary or secondary position or if they presented with an injury at the time of the pitching assessment. This study was approved by Wake Forest University's Institutional Review Board.

Pitchers were first given a questionnaire to complete upon arriving at the lab. The questionnaire was adopted by the research team from a cricket health and well-being study[25] and was piloted and refined for use on baseball personnel including a group of current and former baseball players (n = 121), collegiate and professional baseball coaches (n = 5), and medical professionals (sport physician, physical therapists, and athletic trainers; n = 4) who specialize in treating baseball players.[26] The degree of to which an athlete was specialized was defined in conjunction with current published guidelines and categorized as low-, moderate-, or high-level specialization based upon the athlete's answer to three survey questions (Figure 1).[27] The first question required pitchers to answer *"Are you active in other sports besides baseball"* (i.e., exclusion of other sports) by listing all sports they're actively participating in. Pitchers were then asked, *"How many times per week do you participate in another sport"* (i.e., duration of training) and prompted to answer with *1 Day, 2 Days, 3 Days, 4 Days,* or *5+ Days*. Lastly, pitchers were asked *"How do you assess your current exercise volume"* (i.e., focused participation) on a seven-point scale, with 1 corresponding to *Extremely Low*, 4 representing *Quite High*, and 7 being *Extremely High*. A point was given if athletes were only active in baseball, participated in another sport less than four times per week, and if perceived exercise volume was below four on a seven-point scale.

The sum of these three questions was used to assign the degree of specialization with a score of "3" categorized as high-level specialization, "2" as moderate-level specialization, and "⩽ 1" as low-level specialization. The questionnaire also required each pitcher to self-report workload variables including, the number of games played in the current year, games pitched in the current year, innings pitched in the current year, and innings pitched in the previous year.

Biomechanical pitching data included kinematic and kinetic data examined from 3D motion capture reports generated as part of a pitching evaluation at the Wake Forest Pitching Lab dating from July 2019 to January 2020. Biomechanical data were collected using the full-body marker set required for PitchTrak[28] (Motion Analysis Corporation, Santa Rosa, CA), consisting of forty-one retro-reflective markers in conjunction with a twelve-camera motion analysis system (Qualisys AB, Göteborg, Sweden) sampling at 400 Hz. Each pitcher was given as much time as needed to complete their self-determined, regular pre-throwing warmup routine before stating their readiness to start throwing from the force-plate instrumented (AMTI, Watertown, MA) pitching mound (Porta-Pro Mounds Inc, Sauget, Illinois) sampling at 1,200 Hz. The pitching mound was engineered to meet major league specifications and was situated at a standard distance of 18.4 meters from the target. Pitchers threw roughly ten fastballs to which only fastball data were analyzed for this study. Ball velocity was recorded using a military-grade Doppler radar device (Trackman, Scottsdale, AZ).

Pitching biomechanics variables were taken from results averaged across all pitches. Kinematic outcomes included shoulder horizontal abduction angle at SFC, shoulder rotation angle at maximum shoulder external rotation (MER), lateral trunk tilt angle at MER, lead knee flexion angle at BR, forward trunk tilt angle at BR, and lateral trunk tilt angle at BR. Kinetic variables included maximum shoulder distraction force and maximum elbow valgus torque. Shoulder distraction force and elbow valgus torque were normalized by body weight (N) and body weight multiplied by height (Nm), respectively. Biomechanical variables were chosen due to their direct implications to injury risk or increased throwing velocity.[29] All variables were calculated with Visual3D (C-Motion, Inc. Germantown, MD).

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS Statistics v26; IBM Corp, Armonk, NY) at an a priori significance level of 0.05. Data were assessed with Shapiro-Wilk normality tests. An initial analysis of variance (ANOVA) was used to compare differences in age, height, mass, BMI, and throwing velocity between high-, moderate-, and low-level specialized pitchers. However, due to non-normal distributions, a Kruskal-Wallis test was used to assess differences in workload variables and biomechanics variables between the high-, moderate- and low-level groups. Variables that did not violate the assumption of normality were described as means

Table 1. Mean ± Standard deviation and inferential statistics of pitcher demographics

	Low (n = 11)	Moderate (n = 14)	High (n = 11)	95% CI	*F*	*P*-value	η^2
Age (y)	14.36 ± 0.92	15.21 ± 1.25	16.27 ± 1.1	14.83, 15.73	6.9	0.003*	0.29
Height (m)	1.82 ± 0.08	1.82 ± 0.1	1.85 ± 0.08	1.8, 1.86	0.21	0.735	-0.04
Mass (kg)	70.49 ± 7.93	75.4 ± 16.38	82.2 ± 8.98	71.67, 80.29	2.3	0.050*	0.12
BMI	21.29 ± 1.87	22.57 ± 3.52	24.18 ± 2.74	21.65, 23.69	2.92	0.045*	0.13
Velocity (m/s)	32.05 ± 1.92	34.4 ± 4.06	36.4 ± 2.26	33.14, 35.45	3.97	0.01*	0.27

Low = Low-level specialized, Moderate = Moderate-level specialized, High = High-level specialized, CI = Confidence interval, BMI = Body mass index
*Indicates Significant Difference (p < 0.05)

and standard deviations while non-normal variables were described as medians and interquartile range (IQR) values. To account for inflated Type I error rates incurred by performing multiple Kruskal-Wallis tests, Bonferroni corrections were applied to each H-test. Following the correction, pairwise comparisons with Bonferroni corrections were completed for H-tests that demonstrated significance following correction. Eta-squared effect sizes were calculated and interpreted as small = 0.01-0.06, moderate = 0.06-0.14, and large effects ⩾ 0.14.[30]

RESULTS

Thirty-six male high school pitchers (Age: 15.28 ± 1.32 years) were included in this study. Of the 36 pitchers, 11 (30.5%) were classified as low-level specialization, 14 (39%) as moderate-level, and 11 (30.5%) as high-level. Pitchers were 1.83 ± 0.08 meters in height and 75.98 ± 12.74 kilograms in weight, with a body mass index (BMI) of 22.67 ± 3.01 kg/m^2. Twenty-three pitchers were currently playing other sports, six pitchers noted spending four or more days per week participating in other sports, and 26 pitchers assessed their current exercise volume as five or more.

High-level specialized pitchers were significantly older (p = 0.003), had larger body mass (p = 0.05) and BMI (p = 0.045), and threw faster (p = 0.01) compared to low-level specialized pitchers (Table 1). No significant differences in pitcher demographics were observed between high- and moderate-level specialized pitchers as well as between moderate- and low-level specialized pitchers. No significant differences were found in games played in the current year, games pitched in the current year, innings pitched in the current year, or innings pitched in the previous year across groups (Table 2). Additionally, no significant differences were observed in pitching biomechanics variables across groups (Table 3).

DISCUSSION

The purpose of this study was to investigate differences in pitching volume and pitching biomechanics between low-, moderate-, and high-level specialized pitchers. Results from this study found that high-level specialized pitchers were significantly older and had significantly more weight and BMI as well as threw with significantly greater ball velocity compared to low-level specialized pitchers. All groups spent similar amounts of time participating in baseball-related activities as well as generated similar movements and torques throughout the pitching motion. Due to pitchers across groups generating similar movements and torques throughout the pitching motion, negative outcomes associated with sport specialization may not be a direct result of pitching biomechanics.

The lack of significant differences in pitching volume between groups may suggest that low-, moderate- and high-level specialized pitchers are spending the same amount of time participating in baseball per week, but low- and moderate-level pitchers spend additional time within other sports. Low-level specialized pitchers were the only group to note their weekly participation in other sports to be three days or more, with only six of fourteen moderate-level pitchers noting two days per week of non-baseball participation. The observed similar games and innings pitched suggest athletes across groups had seasons of similar length to which the number of innings pitched may further expose why no significant differences in pitching biomechanics were also observed. One study following youth pitchers over ten years found that athletes who pitched more than 100 innings in a year were 3.5 times more likely to sustain a serious injury.[31] Low-, moderate-, and high-level specialized pitchers within this study reported throwing an average of 34, 32, and 40 innings in the current year, respectively, as well as 48, 46, and 43 innings in the previous year, respectively. As muscle fatigue increases throughout the season, elbow joint stiffness decreases, leading to additional stress on the ulnar collateral ligament and a higher prevalence of injury.[32]

Changes in pitching performance have shown to decrease at a slower rate than changes in pitching biomechanics, suggesting kinematic compensations are made to limit fatigue.[33] Pelvic orientation, elbow height, and shoulder external rotation were the most sensitive kinematic parameters to inning, game, and season fatigue.[19] These biomechanical outcomes all have the possibility of producing greater torque at the shoulder and valgus stress at the elbow in fatigued pitchers.[34,35] Therefore, the amount of pitching volume exhibited within this study may suggest that differences in pitching biomechanics are further identified by pitchers with increased games played, games pitched, and innings pitched within a calendar year.

Pitching biomechanics were similar across groups and resembled pitching biomechanics typically seen in high school pitchers,[36–38] although high-level specialized pitch-

Table 2. Between-group comparisons of competitive exposure

	Low-Level Median (IQR)	Moderate-Level Median (IQR)	High-Level Median(IQR)	95% CI	*H*	*P*-value	η^2
Games played, current	36.0 (62.0)	29.0 (64.25)	48.5 (60.0)	27.6, 43.83	1.3	0.522	-0.02
Games pitched, current	7.0 (13.0)	2.5 (20.75)	13 (20.50)	8.8, 15.02	0.83	0.661	-0.04
Innings pitched, current	13.1 (42.5)	6.0 (50.0)	39.5 (64.0)	24.86, 45.98	0.84	0.656	-0.04
Innings pitched, prev.	46.0 (40.5)	30.0 (86.23)	40.17 (38.4)	35.11, 56.57	0.33	0.850	-0.06

IQR = Interquartile Range, CI = Confidence Interval

Table 3. Between-group comparisons of biomechanical outcomes

	Low-Level Median (IQR)	Moderate-Level Median (IQR)	High-Level Median (IQR)	95% CI	*H*	*P*-value	η^2
Stride Foot Contact							
Shoulder Horiz. Abd (°)	-34.83 (11.48)	-37.88 (30.3)	-24.01 (27.48)	-39.46, -28.94	2.43	0.297	0.01
Max. External Rotation							
Shoulder Rotation (°)	178.88 (2.66)	177.91 (4.84)	177.71 (3.33)	175.89, 178.03	4.98	0.083	0.1
Lat. Trunk Tilt (°)	23.28 (5.91)	27.44 (14.0)	18.28 (16.63)	17.63, 24.77	4.0	0.135	0.06
Ball Release							
Knee Flex. (°)	46.24 (11.71)	52.88 (18.45)	49.15 (17.74)	43.48, 53.27	3.63	0.162	0.05
For. Trunk Tilt (°)	40.69 (7.66)	34.51 (8.83)	40.51 (16.19)	34.94, 40.82	2.65	0.266	0.02
Lat. Trunk Tilt (°)	30.22 (8.96)	31.69 (14.41)	22.94 (14.32)	23.33, 30.77	2.92	0.233	0.03
Kinetics							
Shoulder Dist. (Nm, %BW)	1.13 (0.29)	1.31 (0.44)	1.46 (0.44)	1.18, 1.4	4.73	0.094	0.08
Elbow Valgus (Nm, %BW)	-0.03 (0.01)	-0.04 (0.02)	-0.04 (0.01)	-0.04, -0.03	4.51	0.105	0.08

IQR = Interquartile range, CI = Confidence Interval, Shoulder Horiz Abd = Shoulder horizontal abduction, Lat Trunk Tilt = Lateral trunk tilt, Knee flex = Knee flexion, For Trunk Tilt = Forward trunk tilt, Shoulder Dist = Maximum shoulder distraction force, Elbow valgus = Maximum elbow valgus torque

ers threw with significantly higher throwing velocity compared to low-level specialized pitchers. Differences in weight and BMI may explain why high-level specialized pitchers within this study threw faster than low-level specialized pitchers.[39] Due to the high-level group also being significantly older than the low-level group, it is possible that the observed difference in body mass may be attributed to maturation. Pitchers with more body mass are commonly shown to demonstrate higher throwing velocities than those who weighed less.[39,40] This is due to the ability of larger athletes to generate more strength and create larger forces. However, high- and moderate-level specialized pitchers did not experience greater loading within the shoulder and elbow, suggesting differences may be attributed to other potential factors. Throwing velocity has correlated with pitcher mass, throwing arm range of motion, upper extremity isometric strength, and upper extremity concentric strength.[39,41,42] In collegiate pitchers, isometric internal rotation, isometric external rotation, and concentric external rotation at 90°/s^{-1} and 180°/s^{-1} of the throwing-arm showed a strong positive correlation to throwing velocity.[41] Additionally, high school pitchers within a weighted baseball throwing program significantly increased their shoulder external rotation range of motion and throwing velocity compared to baseline obersvations.[42] Therefore, the difference found in throwing velocity between high- and low-level specialized pitchers may be further explained when examining strength and flexibility of the throwing arm.

This study acknowledges multiple limitations. First, sport specialization within this study was not determined in total congruence with the commonly referenced Jayanthi scale.[6] Until recently, the definition and categorization of sport specialization was not widely agreed upon. However, these results are the first to compare pitching biomechanics on any measure of specialization. Second, this study involved a wide range of when subjects reported for their pitching evaluation. Subjects reporting in the late summer months could potentially have more pitching volume throughout the year, especially in the specialized group. Third, data could have been skewed due to the subject's recall bias, specifically their ability to accurately recall the number of games played, games pitched, and innings pitched within both the current year and the previous year. Subjects were unlikely to precisely recall this data and instead provided an estimated recount to their best ability. Lastly, pitching biomechanics data collected within the lab setting decreases generalizability to the pitching biomechanics athletes might demonstrate during competition.

CONCLUSION

Low-, moderate-, and high-level specialized high school pitchers demonstrated similar pitching biomechanics across groups. The significant difference in throwing velocity between low-level and high-level specialized pitchers may be further explained by other components (such as upper extremity strength and range of motion) which were not measured as part of this study. Furthermore, the low amount of pitching volume throughout the season may be responsible for the lack of additional observed differences. Additional research efforts should examine the effect of a baseball pitcher's exposure to increased competitive workloads in a given year on pitching biomechanics as well as the relationship between upper extremity strength and range of motion and pitching biomechanics in specialized pitchers.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to report.

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