Investigations of the Throwing Biomechanics Index in Collegiate Baseball Pitchers

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Keywords: Motion Analysis, Shoulder, Elbow, Injury.

Abstract: In the field of sports biomechanics the aim is to improve performance and reduce injury. In this study we create a novel throwing biomechanics index by using logistic regression to identify the most important and significant variables that influence injury. Fifteen biomechanics (kinematic and kinetic) variables were identified using logistic regression and the standards of the throwing biomechanics index were determined based on the healthy and high performing group (ball speed > 80 mph). Z-scores were used to determine the index value for each pitcher. Division 1 and 2 collegiate baseball pitchers participated in this study that were grouped based on their injuries before and after the study compared to the healthy group. The healthy group had the highest throwing biomechanics index and further analysis will provide more insights on both injury and performance. The throwing biomechanics index found significant relationships with the pitcher's height (p=.0165), mass (p=.0003), age (p=.0099), forearm length (p=.0001), internal flexibility (p=.0015), external ROM (p=.0002), and external flexibility (p=.0142). There is great value in quantifying a throwing biomechanics index for both understanding the injury mechanisms and for improved performance.

1 INTRODUCTION

Proper throwing mechanics in baseball pitching are important to improve performance and reduce injuries. Baseball pitching is very demanding on the shoulder; the shoulder internally rotates at about 7,000 degrees per second and the force applied is greater than 800 Newtons (Zheng et al., 1999). Throwing arm injuries are common because the repetitive and high stress motions for pitchers of all ages, from youth to professional (A Popchak et al., 2015; Sutter et al., 2018). This prompts the goal to further understand the mechanism throwing arm injuries (shoulder and elbow) to enhance preventative protocols, improve performance, and promote better rehabilitation practices. This work extends beyond baseball to other sports and all shoulder and elbow injuries.

The ability to identify the ideal pitching mechanics is beneficial to the sport. Thompson et al found that increasing both shoulder rotation angle and shoulder angular velocity has shown to increase ball speed and performance in youth baseball pitching (Thompson et al., 2018). Further, a previous study showed that the increase in ball speed and shoulder external rotation angle was related to increased shoulder range of motion (Seroyer et al., 2010). Baseball pitching is a complex movement that puts a lot of stress on the throwing arm (both the elbow and shoulder). A previous study found that higher shoulder joint loading (forces and torques) in competitive baseball players leads to more injury incidences (Oyama, 2012). Further, in a study analysing pitching mechanics, emphasized that poor pitching mechanics can compound the repetitive stress placed on the soft tissues of the shoulder and elbow and has been implicated as a potential risk of injury (Calabrese, 2013). It is well understood that high joint loading with repetitive motions can lead to potential injury. Ultimately there are many factors that influence the incidence of injury, including the following: joint loading, flexibility, experience of pitcher, and pitching mechanics (A. Popchak et al., 2015). This shows the importance of understanding of the optimal position of the throwing-arm during baseball pitching is critical in improving performance and reducing injuries.

Both throwing arm motions and joint loadings have been a popular topic in literature; however, it is unclear which variables are most important and

Stokes, H., Eaton, K. and Zheng, N.
Investigations of the Throwing Biomechanics Index in Collegiate Baseball Pitchers.
DOI: 10.5220/0012255100003587
In *Proceedings of the 11th International Conference on Sport Sciences Research and Technology Support (icSPORTS 2023)*, pages 227-232
ISBN: 978-989-758-673-6; ISSN: 2184-3201

influential in impacting both injury and performance. The purpose of this study is to propose an index that summarizes all throwing biomechanics variables into one score that are related to injuries in collegiate baseball pitchers. Further understanding could be advantageous for optimizing throwing mechanics, monitoring shoulder health, and reducing injuries.

2 METHODOLOGY

The study included 177 National Collegiate Athletic Association baseball pitchers: Division I (n = 117) and Division II (n = 60) (mean ± SD: age, 20 ± 1 years; height, 186 ± 7 cm; weight, 85 ± 9 kg). The study protocol was approved by an institutional review board at the University of North Carolina at Charlotte, and all pitchers gave informed consent. All pitchers were healthy at the time of testing, or they were excluded from the study.

2.1 Pitcher Injury Information

The injury questionnaire was used to record the pitcher's team, class, height, weight, history of injury or surgery, and experience (Table 1). Self-reported injury questionnaires were filled out by pitchers during biomechanical testing and at follow-up (Stokes et al., 2021). Any injury or surgery before biomechanical testing were referred to as having injury history. Any injury or surgery after biomechanical testing noted in a follow-up injury questionnaire are referred to as having follow-up injury. Further, eight subjects had both an injury or surgery before and after. All injuries and surgeries were on the elbow or shoulder of the pitcher.

Table 1: Pitcher injury group count information.

	Injury Before	Injury After	Injury Before & After	Healthy*
n	38	25	8	31

*Healthy pitchers who were also high performing (ball speed > 80 mph).

2.2 Shoulder Exam

A custom wireless device was developed for testing purposes and this methodology has been previously published (Stokes et al., 2021; Zheng & Eaton, 2012). It utilizes a force sensor and an orientation sensor that is powered by a rechargeable 9-volt battery. Ten trials were collected from each pitcher including 5 trials on external rotation and 5 trials on internal rotation. A 15 second pause was taken between trials. The trials were averaged and gave the resulting variables of internal range of motion (ROM), internal flexibility, external ROM, and external flexibility.

2.3 Motion Capture

Sixteen reflective markers were attached to major joints for motion capture and biomechanical analysis based on a previously reported studies (Stokes et al., 2021; Zheng et al., 2004). These markers were attached bilaterally to the distal end of the midtoe, lateral malleolus, lateral femoral epicondyle, greater trochanter, lateral tip of the acromion, and lateral humeral epicondyle on both sides. Additionally, on the throwing arm, 2 reflective markers were placed medially and laterally on the wrist and 1 on the back side of the distal end of the middle metacarpal.

Pitchers were allowed to warm up in any way they needed primarily by stretching and throwing. The pitchers threw balls from an artificial portable mound that was 60 feet 6 inches from home base. Motion data were collected at 240 Hz using a 10-camera motion capture system (VICON). Ball speed was measured using a radar gun, and a rope frame determined the strike zone for each of the 10 fastball pitches. Pitchers rested as needed between pitches.

2.4 Baseball Pitching Biomechanics

The 3 fastest strike pitches were digitized, analyzed, and averaged to represent each pitcher. The whole pitching motion was divided into 6 phases: windup, stride, arm cocking, arm acceleration, arm deceleration, and follow-through (Figure 1) (Dillman et al., 1993). For the end of the stride phase, the lead foot contact was used for normalization and labeled 0%. For the end of arm acceleration, the ball release was used for normalization and labeled 100%. Data from –50% to 200% covering, at a minimum, the stride to arm deceleration phase were analyzed.

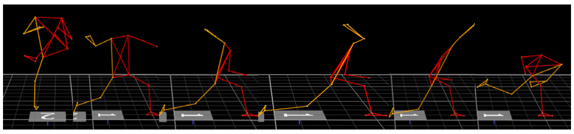

Figure 1: The digitized output of the six baseball pitching phases (wind-up, stride, arm cocking, arm acceleration, arm deceleration, and follow through).

A custom program (MATLAB; MathWorks) was created to calculate the throwing arm motion and loading during the baseball pitching (Fleisig et al., 1995; Fleisig et al., 1999; Zheng, 2003; Zheng et al., 1999). The throwing arm motions were identified at three key times (foot contact, at maximum shoulder external rotation (i.e., the end of arm cocking phase), and ball release). A few maximum angular velocities were also identified. The throwing arm motions at foot contact were shoulder abduction angle, shoulder horizontal adduction angle, shoulder external rotation angle, and elbow angle. The throwing arm motions at maximum external rotation were initial elbow extension angle, maximum shoulder horizontal adduction angle, and maximum shoulder external rotation angle. The throwing arm motions at ball release were shoulder abduction angle and elbow angle. The maximum angular velocities were the maximum elbow extension angular velocity, maximum shoulder internal rotation velocity, and maximum shoulder linear velocity. The peak throwing arm joint loadings are the forces and torques of both shoulder and elbow. The peak throwing arm joint loadings for the shoulder were posterior force, distal force, inferior force, adduction torque, internal rotation torque, and horizontal adduction torque. The peak throwing arm joint loadings for the elbow were anterior force, medial force, superior force, varus torque, and extension torque.

2.5 Throwing Biomechanics Index

A multinomial logistic regression was performed using SPSS to determine which factors were most influential and related to injury. There were 15 significant variables that include: stride length at foot contact, foot angle, knee angle at foot contact, maximum hip angular velocity, trunk forward angle, maximum spine lateral bend angular velocity, maximum external rotation angle, elbow angle at foot contact, maximum elbow angular velocity, peak anterior/posterior shoulder force, peak superior/inferior shoulder force, peak medial/lateral shoulder force, peak internal/external shoulder torque, resultant elbow force, and valgus/varus elbow torque. In this initial investigation all variables are weighted the same of 1 index point so a perfect score for the throwing biomechanics index is 15.

The standards of the throwing biomechanics were determined based on the healthy and high performing group (ball speed > 80 mph). For each variable the mean and standard deviation was taken of the healthy and high performing group. From there each pitcher was compared to the mean of the healthy and high performing group for each variable. The z-score for each variable was used to calculate the probability to give a continuous value compared to the healthy and high performing group which we defined as the index value for each variable. For the kinematic variables a two tailed approach was used because the mean of the healthy and high performing group was the ideal value. For the kinetic variables a one tailed approach was used because the lower the force or torque the better and the risk is found in the higher values.

A bar graph was used to visually compare the throwing biomechanics index across the three injury and the healthy and high performing groups. A table shows the mean and standard deviations for the three injury and the healthy and high performing groups. One-way ANOVA with post-hoc tests and Pearson correlation tests were performed to compare the throwing biomechanics index using SPSS. The alpha value was set at 0.05.

3 RESULTS

The results show the healthy and high performing group had the highest throwing biomechanics index compared to the other groups (Figure 2). The injury before group's throwing biomechanics index is 7.19 ± 1.75, the injury after group's throwing biomechanics index is 7.59 ± 1.31, the injury before & after group is 7.57 ± 1.24, and the healthy group was 7.69 ± 1.67 (Table 2). When comparing across the three injury groups and the healthy and high performing group's index score there was no statistically significant difference.

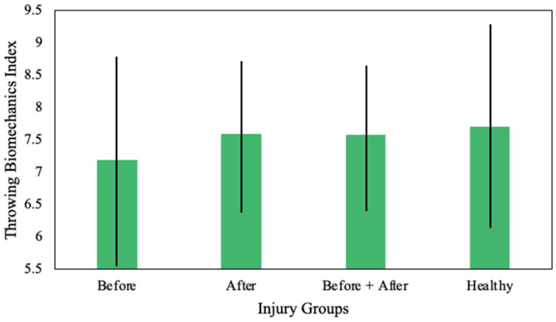

Figure 2: The throwing biomechanics index for the before, after, before + after injury groups and the healthy and high performing group.

Table 2: The mean and standard deviation for the index score for the before, after, before + after injury groups and the healthy and high performing group.

	Injury Groups			
	Before	After	Before + After	Healthy
Mean	7.19	7.59	7.57	7.69
Standard Deviation	1.75	1.31	1.24	1.67

Further analysis investigated the individual index scores for all fifteen variables that were used to create the index (Table 3). When comparing across the three injury groups and the healthy and high performing group's index score for each of the fifteen variables there was no statistically significant difference. The healthy and high performing group has the largest mean for six of the fifteen variables.

Table 3: The mean and standard deviation for the individual index scores (maximum of 1) for all fifteen variables that were used to create the index for the before, after, before + after injury groups and the healthy and high performing group.

	Injury Groups			
	Before	After	Before + After	Healthy
Stride length at foot contact	0.49±0.3	0.40±0.3	0.28±0.2	0.52±0.3
Foot angle	0.45±0.4	0.42±0.3	0.42±0.3	0.47±0.3
Knee angle at foot contact	0.58±0.3	0.58±0.2	0.68±0.2	0.47±0.3
Max hip angular velocity	0.47±0.3	0.57±0.3	0.59±0.3	0.62±0.3
Trunk forward angle	0.39±0.3	0.43±0.3	0.45±0.3	0.50±0.3
Max spine lateral bend angular velocity	0.47±0.3	0.52±0.3	0.58±0.3	0.50±0.3
Max external rotation angle	0.44±0.3	0.44±0.3	0.44±0.3	0.52±0.3
Elbow angle at foot contact	0.40±0.3	0.50±0.3	0.25±0.2	0.46±0.3
Max elbow angular velocity	0.41±0.3	0.51±0.3	0.40±0.3	0.55±0.3
Anterior/ posterior shoulder force	0.43±0.3	0.44±0.3	0.68±0.1	0.50±0.3
Superior/ inferior shoulder force	0.54±0.3	0.61±0.2	0.47±0.3	0.51±0.3
Medial/lateral shoulder force	0.57±0.3	0.49±0.3	0.72±0.3	0.51±0.3
Internal/external shoulder torque	0.55±0.3	0.61±0.2	0.43±0.3	0.52±0.3
Resultant elbow force	0.49±0.3	0.46±0.3	0.65±0.2	0.50±0.3
Valgus/varus elbow torque	0.52±0.3	0.59±0.2	0.52±0.2	0.52±0.3

The results show that many of the pitcher demographic and shoulder exam variables are related to the throwing biomechanics index (Table 4). The height, mass, age, forearm length, and external flexibility all have a moderately strong negative statistically significant correlation with the throwing biomechanics index. Showing that the larger throwing biomechanics index was related to smaller variables and the smaller throwing biomechanics index was related to the larger variables. The internal flexibility and external ROM all have a moderately strong positive statistically significant correlation with the throwing biomechanics index. Showing that the smaller throwing biomechanics index was related to smaller variables and the larger throwing biomechanics index was related to the larger variables.

Table 4: The Pearson correlation values for the pitcher demographic and shoulder exam variables and the throwing biomechanics index, where p< .05 is bolded.

		R	p
Demographics	**Height**	**-0.2368**	**.0165**
	Mass	**-0.3490**	**.0003**
	BMI	-0.1604	.1073
	Age	**-0.2542**	**.0099**
	Forearm Length	**-0.3747**	**.0001**
	Upper Arm Length	-0.0148	.8826
	Years Played	-0.1024	.3058
Shoulder Exam	Internal ROM	-0.1627	.1023
	Internal Flexibility	**0.3105**	**.0015**
	External ROM	**0.3642**	**.0002**
	External Flexibility	**-0.2422**	**.0142**

4 DISCUSSIONS

The kinematic and kinetics variables have significant relationships with the injury groups in collegiate baseball pitchers. When combined the significant variables to create a throwing biomechanics index there were trends but there were no statistically significant differences between the for the before, after, before + after injury groups and the healthy and high performing group. This methodology helps create an index that is useful in being able to evaluate the athletes. Findings of this study indicated that throwing arm injuries are complicated and often due to overuse and faulty mechanics of throwing. Tracking changes of a throwing athlete with throwing biomechanics index may provide insight into implications of throwing mechanics and injuries.

Further diving into the relationship of the throwing biomechanics index with other variables such as the demographic variables, performance variable, and shoulder exam variables showed statistically significant relationships. For the relationship between the throwing biomechanics index and the pitcher demographic variables there was a statistically significant relationship between height, mass, age, and forearm length. For the relationship between the throwing biomechanics index and the pitcher shoulder exam variables there was a statistically significant relationship between internal flexibility, external ROM, and external flexibility. For all the other variables there was not statistically significant relationship with the throwing biomechanics index. Kinetic variables are dependent on height and weight so seeing those connections is obvious with the throwing biomechanics index; however, the dominant arm internal SRF, dominant arm external ROA, non-dominant arm external ROA, and dominant arm external SRF must be related to the throwing biomechanics kinematics components, which means this single index is a well reflection of collegiate throwing biomechanics.

This novel methodology leaves room for further research. The value in the index is that it gives a quantitative way to summarize all the throwing biomechanics variables. Many papers have investigated specific or certain types of variables but very few have investigated a way to quantify a summary variable. The index is useful in monitoring rehabilitation protocols as well as monitoring the athlete’s injury risk. The higher the index the closer the athlete is to both healthy and high performing as we quantify by the ball speed. The results we see show that those athlete’s that had the injury after and the injury before + after have very similar index scores, while the injury before group had the lowest index score. It is interesting to consider that the those who had injuries before may be using different mechanics after their rehabilitation period and this could be impacting the overall index score. This could follow the idea of those athlete’s that are more injured have a lower index and those who are healthy have a higher index and more investigations will help give a clear picture of what is going on. It is important to note that there were eight subjects in the before and after injury group so some variation may come from the sample size. Variables seen throughout the kinetic chain spurs on more investigations of how even the wind up may influence pitcher’s potential injury and performance potentials.

There are several limitations of this work as initial exploration. Majority of them will be revised with further and future work. One challenge is the sample size, to fully test and evaluate our methodology it would be advantageous to have more cases of pitcher’s who have had injuries before, injuries after, and both injuries before and after. The inherit challenge when working with athlete’s is the fact that every athlete is different and there are exceptions. Further case studies may help fully understand the injury mechanisms. Another consideration is with testing a larger sample size it would help identify and confirm the validity of the index. Understanding optimal mechanics, we could adjust the index more specifically if we can determine thresholds of healthy and high performing players for all these variables. This index is intended to evaluate both injury mechanisms and performance so real game data would be useful to compare the throwing biomechanics index to quantifiable performance parameters.

Future work would include using a larger sample size and further looking into all the variables. This study could then be extended beyond collegiate baseball pitchers to those of youth, high school, and professional baseball pitchers. This index could then further be investigated or expanded to all throwing athletes for example American football quarterbacks, track and field javelin throwers, and many others. Connecting the throwing biomechanics index to demographics, shoulder rotational properties, and other clinical tests to increase the knowledge in this field. There is great value in quantifying a throwing biomechanics index for both understanding the injury mechanisms and for improved performance.

ACKNOWLEDGEMENTS

This study is funded by a Clinical Research Grant from Major League Baseball.

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