Original Article

A novel approach for baseball pitch analysis using a full body motion analysis suit: A case series study

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ABSTRACT

Biomechanical analysis of the baseball pitch has been used for many years to improve pitching accuracy. Common biomechanical analysis has relied on motion analysis cameras in a laboratory setting. The primary aim of this descriptive case series study was to utilize a novel method using a portable wearable 3D motion analysis suit to measure leg length/stride length ratio, foot placement, and pitch accuracy. Four National Collegiate Athletic Association (NCAA) Division III varsity baseball pitchers participated in this study. The XSens™ MVN motion analysis suit was worn by each participant to measure body kinematics and a high-speed camera was utilized to record pitching accuracy. The average leg length to stride length ratio results was determined to be 77%. This ratio could be utilized rather than the traditional stride length to body height due to the variations in leg length. The results from this motion analysis procedure with a wearable portable suit and a high-speed camera may help improve pitching accuracy by identifying optimal mechanics for each individual pitcher.
Keywords: Biomechanics; Accuracy; Performance; Throwing.

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INTRODUCTION

The baseball pitching motion is a complex full body skill involving both linear and angular action and involves movement patterns that are learned over time. The angular motion is accomplished by turning the hips and shoulders, enabling the pitcher to "wind-up" the back and shoulder muscles to greatly increase the arc through which his throwing arm travels. The "stride" is the forward step, initiating the linear action, which develops an integrated gradual increase of each body part, pulling the arm through its arc as the shoulders and hip unwind (Reiff et al.,1971). The amount and placement of the front foot during the pitcher' stride that a pitcher has is very important. Stride length has been measured by the distance between the front of the pitching rubber and the stride foot ankle joint centre at the time of front foot/stride foot landing. Therefore, the normalized stride length is how far the front foot lands in front of the rubber (Tocci et al., 2017).

Pitchers stride length has long been related to body height only. Many pitching coaches utilize this ratio to provide coaching cues. However, individual pitchers of the same body height may have differences in leg length which would affect their stride length. Identification of the various factors such as leg length, optimal stride length, foot position and centre of gravity positions related to accuracy could be used to improve a pitcher's performance. How players move their joint segments in a coordinated manner throughout the throwing action to achieve compensation among release parameters is not clear (Button et al., 2003).

Dynamic stability during the push off to landing phase is crucial for pitching performance. An analysis of individual pitchers to determine the dynamic stability, related to foot placement and centre of gravity displacement in all the x, y, z directions is needed. The body's centre of gravity movement/position during the pitching phase can affect the position of the lead foot position and pitching accuracy. An understanding of the biomechanics of an individual's pitching is valuable in the prevention, treatment and rehabilitation of injuries as well as sport performance (Flesig et al., 1995).

To become a skilled pitcher, one must be able to adapt and coordinate their body movements during the entire throwing procedure, especially during the acceleration and cocking phase of the pitch prior to ball release. Optimal baseball pitching mechanics are unique for each individual athlete in part based upon their anthropometrics. Thus, caution is needed when emphasizing video analysis of one person's mechanics and providing feedback based upon an "optimal" standardized pitching technique. An optimal technique for one pitcher may not be optimal for another person (Escamilla et al., 2002).

Over the past 10 years there have been several research studies that have utilized sensors involving gyroscopes, accelerometer, and/or magnetometers that have been worn on the upper extremity to identify torque and other upper extremity parameters related to baseball pitching (Camp et al., 2017); (Koda et al., 2010); (Makhni et al. 2018); (McGinnis et al. 2012); (Murray et al., 2017). Camera-less motion analysis using a wearable body suit that uses motion tracking with inertial motion sensors has been used in the past to provide an athlete to perform prescribed rehabilitation exercises correctly (Fitzgerald et al.,.2007). The Xsens™ wearable suit has also been successfully in analysing activities of daily living (Konrath et al., 2019). There is a recent trend that is supporting the use of wearable motion analysis suits for sport performance evaluation (Camomilla et al,. 2018).

There has been a plethora of research articles related to pitching mechanics but there is a dearth of literature related to the biomechanics and pitching accuracy. To date there are no known research papers that have analysed the baseball pitch using a wearable full body suit for motion analysis. The primary aims of this descriptive case series study was to successfully utilize a high technology wearable motion analysis suit and analyse leg length and stride length ratio, foot placement, and pitch accuracy.

METHODS

Participants

Four male varsity baseball pitchers (Ages 18-22 yrs.; Ht; 1.91-1.96 m; Wt:85.27-96.16 kg) all right hand dominant, from a NCAA Division III varsity baseball team were the participants. The participants were free from injury or reported pain and were able to throw from a mound without problems or symptoms. The experimental procedures were reviewed and approved by the University's Institutional Review Board and all the participants were provided with an informational session. The volunteer participants were recruited following an informational session provided to the baseball pitchers. All the participants signed a written informed consent form.

Measures

The measures that were utilized were pitch accuracy in cm, stride length in meters, centre of gravity displacement and front landing foot medial and lateral deviation in cm. Standardized length measurements were utilized for the pitching trials for the mound, target and position of home plate.

Procedures

The length of the pitching rubber to the back of home plate were ensured to be placed 18.44 m from each other. The participant threw from an indoor wooden pitching mound 25.54 cm in height with a gradual slope of 0.0254 cm per foot from a point 30.50 cm in front of the pitching rubber. All dimensions were based upon NCAA regulations (Paronto & Woodward, 2014).

The pitching target was placed behind Homeplate and measured 1.52 meters in height by x 1.40 meters in width (Muhl Tech Pitching Target, MulTech, Wharton, TX), see Figure 1. A strike zone target area was designated on the canvas backstop to simulate the strike zone for a batter. A level and tape measures were utilized to ensure proper placement of the pitching target. A plumb line and a level, and tape measures were utilized to measure and ensure proper measurements and to ensure level the strike zone, home plate and the pitching mound. The strike zone target area was subdivided into four equal quadrants of the strike zone. The quadrants were designated as Left Upper Quadrant (LUQ), Left Lower Quadrant (LLQ), Right Upper Quadrant (RUQ), and Right Lower Quadrant (RLQ). The pitching target area was 40.64 cm tall by 55.88 cm wide and each isolated quadrant area was 20.32 cm tall by 27.94 cm wide. A 7.6 cm diameter circular white target was placed in the centre of each quadrant, LUQ, LLQ, RUQ, RLQ.

The target consisted of a standard baseball L-screen with a target on the back to represent the strike zone over home plate for a right-handed batter (1.75 m). During the trials, only one of the quadrants was visible to the subject. The goal of the participants was to hit the centre of the target in each quadrant. The Designated Hitter™ - Pro Model dummy (The TAC Companies, LLC, National Harbor, MD) was used to provide a more realistic pitching environment. The dummy stood 1.75 m tall and was positioned as a right-handed hitter.

Each participant was instructed to throw as hard and accurate fastballs as they felt comfortable with the emphasis on accuracy from the stretch position of which the start position on the pitching rubber was consistent for every participant with every throw, middle of the pitching rubber. The participants reported that they threw 80-90% of maximal pitching speed. A standardized and recently calibrated Stalker Sport 2 Radar (Applied Concepts, Inc./Stalker Radar, Richardson, Texas) was used to assess baseball speed. The participant then threw 10 throws with the goal to hit the target in the centre of the RUQ, followed by 10 throws to the other three quadrants. A high-speed camera (240 Hz) was utilized to assess pitching accuracy.

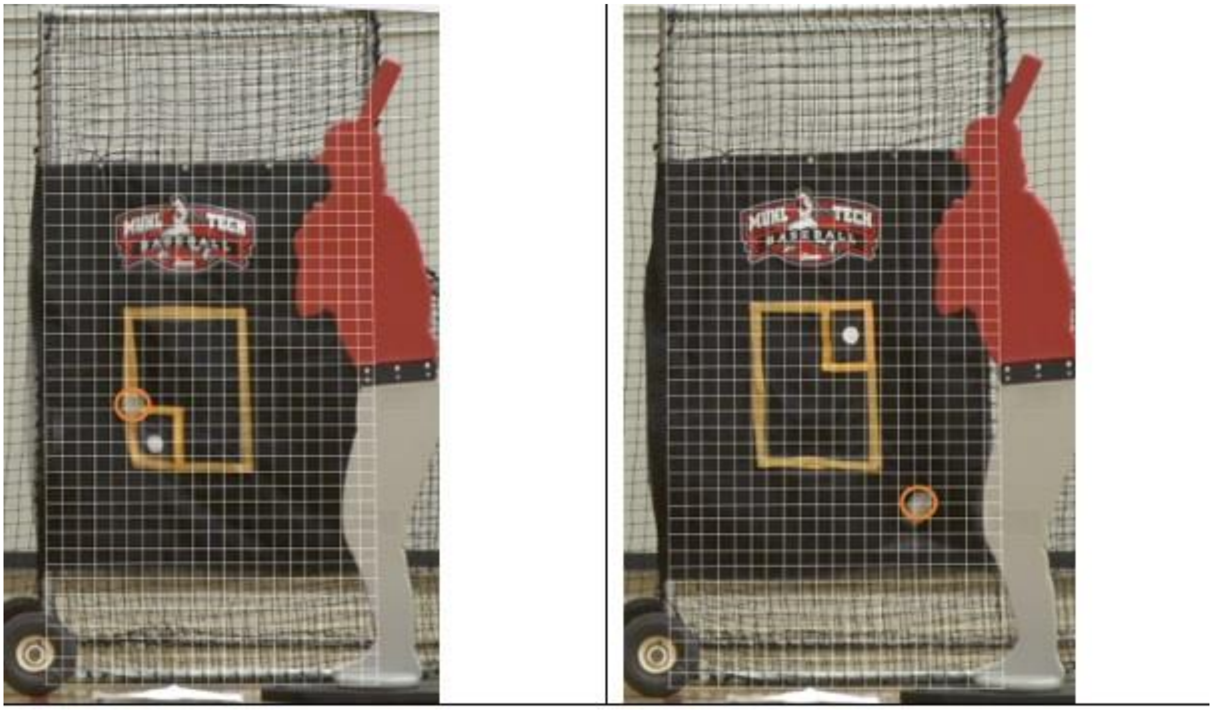

Figure 1. Example images of pitching accuracy measurements. Figure 1a (Left) Example of a strike while throwing at the lower Left Quadrant (LLQ). Figure 1b (Right) Example of a ball while throwing at the Right Upper Quadrant (RUQ). The baseball is outlined in for emphasis.

Each participant wore a Xsens suit that was sized appropriate to their body height. Each participant's anthropometric measurements for upper limb and torso length were measured with the standardized XSens measurement devices. Measurements were taken of the body height, shoe length, arm span, ankle height, hip height, hip width, knee height, shoulder width, shoulder height, and shoe sole height. Leg length was measured by the direct clinic method which uses a measurement between the anterior superior iliac spine and the tip of the lateral malleolus. This method has been shown to have been the most accurate of the five clinical methods to measure leg length (Woerman et al. 1984).

The motion tracking sensors within the suit allowed for the sensors to remain in the correct position throughout the participation in the study. The body motions of each subject were measured using an instrumented body suit (MVN Biomech Body Suit, Xsens Technologies, Enschede, Netherlands) containing 17 inertial measurement units. Subjects were then given a period to become accustomed to the Xsens suit, see Figure 2 and Figure 3. Prior to event recording, a complete and successful calibration phase was performed, following the Xsens calibration procedure. The data from each sensor were recorded at 120 Hz and processed using the Xsens MVN Studio-Pro software package. The Xsens sensors are translated to body segment kinematics using a biomechanical model which assume the subject's body includes body segments lined by joints. The Xsens system calculates the position, velocity, acceleration, orientation, angular velocity, and angular acceleration of each body segment. The biomechanical model consists of 23 segments, see Figure 2.

Figure 2. Participant wearing Motion Suit.

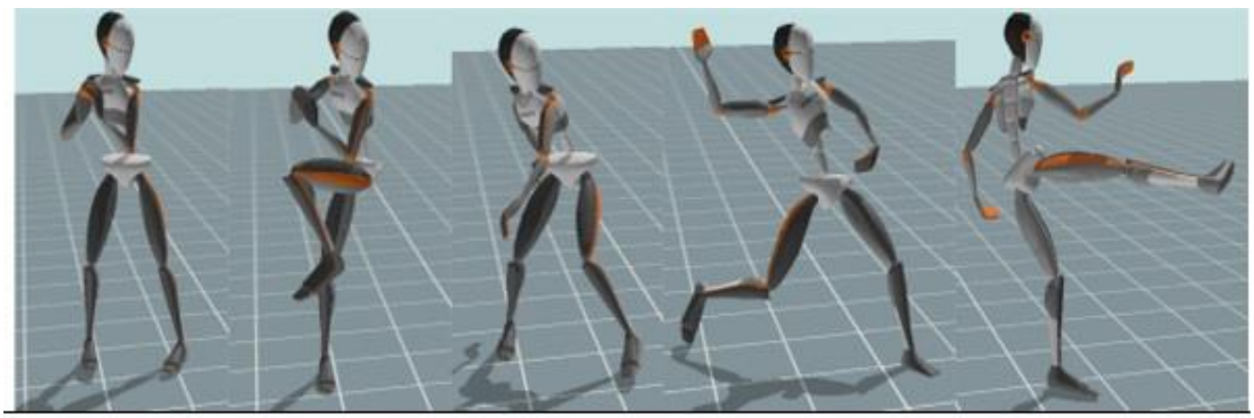

Figure 2. Xsens software visualization of the pitch from the stretch position to follow through.

For each test trial, the subject was instructed to throw consecutive target at one of the quadrants until 10 pitches struck the screen. For each test trial, real-time video was recorded at 29.97 frames per second at a resolution of 1920 x 1080 (Canon, EOS 7, Japan) and high-speed video was recorded at 240 frames per second at a resolution of 1920 x 1080 (Sony, NEX SF700, Japan). Pitching measured from the border of the quadrant by analysing the L-screen target to determine where each pitch struck the L-screen. Photogrammetry was used to place a 5.08 cm by 5.08 cm) grid over the L-screen to determine the location of each pitch.

Analysis
A descriptive analysis was performed due to the analysis being a case series and the need to analyse each individual pitcher separately as each baseball pitcher has his own unique optimal pitching profile in part due to anthropometric measurement differences for example leg length. See Table 1.

Table 1. Participant Demographics/Anthropometrics (Ht; Mass, Leg Length).

Characteristics	Participant #1 S2	Participant #2 (S3)	Participant #3 S4	Participant #4 S5
Height (m)	1.91	1.91	1.93	1.96
Lower Limb Length (m) (ASIS to lat malleolli)	0.97	0.98	1.00	1.08
Mass (kg)	85.27	91.17	88.90	96.16

RESULTS

Participant #2 had the best accuracy average in Left Lower Quadrant with an average error accuracy of 22.86 cm for all 10 throws (range 5.08 cm-58.42 cm) and the worst accuracy in Right Upper Quadrant with an average error of 45.72 cm (range 0-86.36 cm). Participant #3 had the best average accuracy of all 10 throws in Right Lower Quadrant with an average error accuracy of 17.78 cm (range 0-35.56 cm) and the worst accuracy over all 10 throws in Right Upper Quadrant with an average error of 25.40 cm (range 5.08-60.96 cm).Subject #4 had the best average accuracy10 throws in Left Lower Quadrant with an average error accuracy of 20.32 cm (range 0-55.88 cm) and the worst average error accuracy for 10 throws at 30.48 cm in Right Upper Quadrant (range 15.24-55.88 cm) see Table 2 and Table 3.

Table 2. Average Stride Length for all 40 pitches (front/centre of pitching rubber to lead front leg (ankle joint centre) @ foot plant vs Body Height and Leg Length vs Body Height.

Characteristic	Participant #1	Participant #2	Participant #3	Participant #4
Stride Length (m)	1.30 m	1.24 m	1.31 m	1.34 m
Stride Length vs Body Height (%)	70%	65%	67%	68%
Leg Length vs Body Height (%)	51%	51%	52%	55%
Leg Length vs Stride Length (%)	74%	79%	76%	80%

Table 3. Lead Foot Plant placement relative to midline (positive value toward third base) with Best 3 pitches for Ball Accuracy (Resultant distance from centre of target (cm) for Quadrant.

Characteristic	Participant #1 S2	Participant #2 (S3)	Participant #3 (S4)	Participant #4 S5
Accuracy 1 (cm) Resultant	RUQ 0.0 cm hit target	LUQ 0.0 cm hit target	0.0 cm LUQ	0.0 cm RUQ
Left Foot Placement vs Midline	10 cm closed	11 cm closed	19 cm closed	23 cm closed
Ball Velocity 1(mph) and km/hour	(32.63 m/sec)	(31.74 m/sec)	(33.08 m/sec)	(36.21m/sec)
Accuracy 2	RLQ 0.0 cm hit target	LUQ 0.0 cm hit target	0.0 cm LUQ	0.0 cm RUQ
Left foot (Front) placement vs midline	7.7 cm closed	11 cm closed	19 cm closed	23 cm closed
Ball Velocity 2 Accuracy 3	(31.74 m/sec) RLQ 5.08 cm	(32.19m/sec) 0.0 cm RLQ	(33.08 m/sec) 0.0 cm RLQ	(35.32 m/sec) 0.0 cm RLQ
Front Foot Placement vs Midline	7.7 cm closed	11 cm closed	19 cm closed	23 cm closed
Ball Velocity 3	(32.19 m/sec)	(31.74 m/sec)	(32.19m/sec)	(35.76 m/sec)

Table 4. Front foot placement relative to midline (maximal deviation from start to foot plant) for the least accurate 3 pitches (Resultant distance from centre of target (cm) overall with respective quadrants.

Characteristic	Participant #1 S2 Missed low and outside all pitches	Participant #2 (S3) 1,2 Low and out worst then just low 3rd	Participant #3 S4 1 high inside 2 low out 3 low	Participant #4 S5 All missed low and outside
Accuracy 1 (cm) Resultant	86.36 cm RUQ	63.5 cm RUQ	76.2 cm RLQ	78.74 cm LUQ
Front foot deviation from midline	-1.1 cm open	6 cm closed	26 cm closed	23 cm closed
Ball Velocity 1(mph) and km/hour	(33.08 m/sec)	(30.85 mph)	(32.63 m/sec)	(35.32 m/sec)
Accuracy 2	83.82 cm RUQ	60.96 cm RUQ	55.88 cm RLQ	63.5 cm RLQ
Front Foot deviation from midline at foot plant from landing	14.4 cm closed	13 cm closed	19 cm closed	21 cm closed
Ball Velocity 2	(32.63 m/sec)	(31.29 m/sec)	(33.98 m/sec)	(36.21m/sec)
Accuracy 3	73.66 cm RUQ	50.80 (LLQ)	55.88 cm LLQ	58.42 cm RLQ
Front foot deviation from midline at foot plant	4.2 cm closed	9 cm closed	21 cm closed	28 cm closed
Ball Velocity 3	(32.63 m/sec)	(31.29 m/sec)	(33.08 m/sec)	(35.32 m/sec)

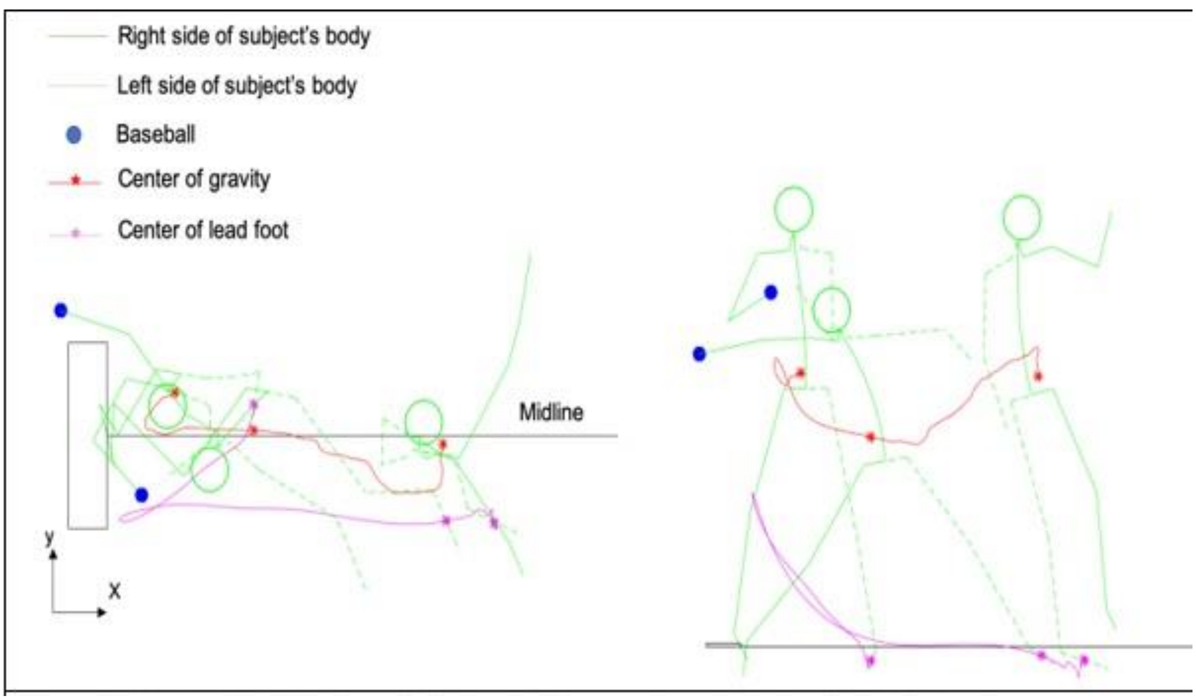

Figure 4. Axial and sagittal view of Pitcher Stride Length and centre of gravity tracings.

Participant #5 had the best average accuracy for the 10 throws in Left Lower Quadrant with a best average error accuracy for 10 throws of 17.78 cm (range 0-50.8 cm) and the worst accuracy for 10 throws in Left Upper Quadrant with an average error of 27.94 cm (range 5.08 cm-58.42 cm). Participant 2, 3, 4 all had the same front foot distance landing from the midline at foot flat for all 3 of the most accurate pitches. Only 1 pitch from the least accurate pitches from all four subjects matched the distance related to the subjects most accurate 3 pitches, participant #4 23 cm closed position. Upon further review of that pitch, participant #4 stride length was 1.42 m compared to the overall stride length average 1.34 m and the average stride length of all three most accurate pitches being 1.33 m.

Leg Length vs Stride length average range for all four participants were from 74-80%. The average was 77% however, Stride Length vs Body height average range for all four participants was 65-70%. The range of leg length relative to body height was 51-55%. This range demonstrates that pitchers do have leg length differences that will affect their stride length. See Table 4 and Figure 4.

DISCUSSION

Stepping too far across the body with the striding foot, results in a closed rather than open position before release. If an athlete strides too far in the lateral direction, then it could result in a restricted hip and shoulder turn during the delivery which may affect control and an impairing a proper follow through position. This fault can result in injury to the throwing arm. The classic finishing position is to have the pitcher’s body square to the hitter and the hands ready in a fielding position (Reiff, 1971).

In this study it was determined that all subjects landed in a closed position for all their most accurate pitches. Subject #1 best pitch accuracy revealed a 10 cm closed position compared to the least accurate open –1 cm position. Participant #2 had the best pitch accuracy with a 10 cm closed position versus a 6 cm closed position for the least accurate pitch. Participant #3 had the best accurate pitch with a 19 cm closed position versus a 26 cm closed position for the least accurate pitch. Subject #4 had a 23 cm closed position for both the best and least accurate pitch suggesting other biomechanical factors were related to accuracy for this individual pitcher.

Leg length to body height ratios have been previously documented as 53% by Drillis R. & Contini, 1966. Variations in leg length are present with individuals with similar body heights. In the current study the range of leg length to body height ratio was 51-55%. In a study by Edwards et al 1963, 47 baseball pitchers from five Midwestern universities were involved to analyse stride length and position on the pitching rubber had on control in baseball pitching. Each subject threw from one of three positions on the rubber (left side, centre, right side) and one of three strides (under-stride, normal stride, over-stride). It was determined that changing the length of stride or position on the pitching rubber or any combination would not necessarily help correct pitching consistently high, low, inside or outside the strike zone while throwing fastballs (Edwards,1963) .Fast ball pitching from the stretch position compared to the wind up was determined have no significant differences between kinetic, kinematic and temporal variables (Dun et al., 2008).

The stride length was determined by measuring the distance from the front of the rubber to the joint centre of the lead leg during foot plant (Van Trigt et al,. 2018). The results of our study determined an average stride length relative to body height to was 68%. This contrasts with prior published studies which revealed 77% stride length to body height (Dun et al., 2007), 82% stride length vs body height (Elliott et al. 1986), 75% (Dillman et al., 1993),;70-90% ,80% (Van Trigt et al., 2018). and 79% for youth baseball pitchers (Tocci et al., 2017).

Coach Bill Thurston a widely recognized expert in baseball pitching mechanics recommended an 80% stride length to body height ratio (Thurston, 1984). Errors in pitching mechanics may be related to errors in pitching errors maybe related to errors in ball release timing (Shinya et al., 2017). Professional baseball pitchers have been shown to be significantly more accurate in the lateral direction with pitch accuracy compared to high school pitchers (Kawamura et al,. 2017). Eighty two percent stride length vs body height was reported for American professional pitchers and 86% for Japanese professional pitchers (Oi et al. 2019). However, in college aged Caucasian American men had 18% longer calf region compared to college aged Japanese males (Nakanashi and Nethery, 1999).

However, it has been shown that elite Cuban baseball pitchers were predominantly mesoendomorphic, however, mean somatotype values varied between pitchers with different performance levels with the better performing players (>= .600 Wpct) being more mesomorphic that the lower performing pitchers (< .600 Wpct). Relative leg length (RLL) was equal to leg length x 100/height with pitchers presenting with 24.89 + 1.14 Mean and standard deviation [30]. Due to the differences in lower leg length in individuals with the same body height, leg length relative to stride length maybe a better value to identify and assess for baseball pitchers.

CONCLUSION

This novel research procedure has provided preliminary findings that supports the need for future use of biomechanical analysis of the baseball pitch using a motion analysis suit and throwing type activities related to accuracy. Improving the consistency of optimal timing, coordination and body orientation is paramount in successful throwing. Also, the effects of practice on movement distance and final optimal position reproduction is related to equilibrium point control of movements (Jaric et al., 1994). A study by Edwards, involving 43 university baseball pitchers determined that varying the position on the pitching rubber (Left side, Centre, Right Side) and using three strides (Under stride, Normal Stride, or Over stride) did not help correct pitching consistently high, low, inside or outside the strike zone (Edwards, 1963). As performers progress in their skill development they should become more independent and rely on internal sources of information. At advanced stages of performance, the athlete should use specialized feedback from external sources that are specific to the needs of the performer (Lievermann et al., 2002).

Pitching coaches can be provided with clear, concise and effective information to provide the pitchers based upon the results of the biomechanical analysis that can be performed at the teams own indoor or outdoor facility. The findings of this study can provide the individual athlete with objective data on which quadrant was his worst and best accurate and which centre of gravity path was best related to accuracy. This may save valuable time in practice to understand which quadrants an individual needs work on and after corrections provided a follow up biomechanical evaluation along with accuracy assessment can help provide objective assessment.

Measuring leg length for each pitcher is important in determining optimal stride length as individual’s leg length varies relative to body height and may a significant factor have related to optimal stride length. The findings of this study provide a basis that future studies are needed with an increased number of subjects and levels of skill and with a pre and post analysis. As in the past, it has been shown that 44% of flaws were corrected utilizing two biomechanical analysis (Fleisig et al. 2018). Understanding each individual’s unique anthropometrics, centre of gravity, stride length, stride deviation and pitching accuracy through this novel biomechanical approach may help improve sport performance and decrease the chance of injury by determining the best optimal technique and possibly improve pitching performance and decrease the movement variability.

AUTHOR CONTRIBUTIONS

Paul K. Canavan: Contributed to the design of methods, procedures, data collection, analysis and manuscript development. Bethany Sunderman: Contributed to data analysis. Nicholas Yang: Contributed to the design of methods, procedures, data collection, analysis and manuscript development.

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DISCLOSURE STATEMENT

The Authors declare that there is no conflict of interest related to this manuscript.

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