RELATIONSHIP BETWEEN PITCH VELOCITY AND PHYSICAL FITNESS IN ELITE BASEBALL PITCHERS

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Abstract:

The purpose of this study was to determine the key physical conditions needed for a pitcher by studying the relationship between pitch velocity and a set of selected physical fitness variables.

Seventeen baseball coaches and experts were recruited to recommend and select key variables determining pitchers' physical fitness. After a three-round inquiry, 16 variables were identified. Internal consistency reliability (Cronbach's α reliability) was 0.826 and the content validity ratio was 1. A total of 27 male elite baseball pitchers (22.97±4.01 years old), who came from Chinese professional teams, were tested by the 16 variables selected and their pitch velocity was determined after warm-up. The correlations between pitch velocity and the other 15 variables were computed. The coefficient of the correlation among pitch velocity and max distance long toss, jump lunge with load, and shoulder internal rotation was 0.628 ($p<.05$), 0.369 ($p<.05$), and -0.312($p<.05$), respectively. A follow-up regression analysis found that three variables explained 42.9% of the pitch velocity variance. The pitch velocity was moderately related to their max distance long toss and somewhat correlated with jump lunge with load and shoulder internal rotation.

Keywords: *pitching speed, strength and conditioning, fitness assessment*

Introduction

Pitchers are the soul and core of a baseball team, and they often play a key role in a baseball game. About 65 to 85% of a winning team's success is attributed to pitchers (Reiff, 1971). Pitch velocity (PV) is very important for success in pitching. There are some factors influencing PV, such as wind speed, muscle strength, psychology, umpire bias in judgment, weather, and so on (Parsons, Sulaeman, Yates, & Hamermesh, 2011). From the performance perspective, PV has traditionally been accepted as a criterion to assess quality of a pitcher (Werner, Suri, Guido, Meister, & Jones, 2008). And it is important that pitchers generate the throwing force at the same release point (Perkin, 2014).

The biomechanics underlying the skill of pitching performance has been the focus of numerous studies, aiding pitchers in understanding their needs and how to enhance their skills (Fortenbaugh, Fleisig, & Andrews, 2009). Baseball pitchers, exposed to high stress on their throwing elbow and shoulder because of repetitive pitching, would frequently get injured (Olsen, Fleisig, Dun, Loftice, & Andrews, 2006). Baseball pitchers lose pitching strength during the game and suffer from pain in their throwing elbow and shoulder after it (Fleisig, et al., 1996). Fatigue also reduces the pitcher's PV (Escamilla, et al., 2007). Therefore, improving their strength is very important.

Furthermore, it was proved that strength was associated with ball velocity although the contribution of particular muscle groups was not exactly clear (Bartlett, Storey, & Simons, 1989). Pugh, Kovaleski, Heitman, and Pearsall (2001) reported that arm and grip strength correlated with PV ($p\leq.05$) for the experienced group, whereas arm strength correlated with PV for the inexperienced group ($p\leq.05$). Lower body strength is as important as upper body strength because pitching process is a kinetic chain in which strength is transferred from the lower to the upper body (Matsuo, Escamilla, Fleisig, Barrentine, & Andrews, 2001; Seroyer, et al., 2020; Stodden, Fleisig, McLean, & Andrews, 2005; Werner, et al., 2008). A similar result was obtained by MacWilliams, Choi, Perezous, Chao, and McFarland (1998), who found that maximum linear wrist velocity correlated highly with the maximal push-off force of the throwing leg in the direction of the pitch. McEvoy and Newton (1998) considered that ballistic resistance training can improve baseball pitching. However, the results obtained by Magnusson, Gleim, and Nicholas

(1994) showed that there was significant weakness in the supraspinatus, the external rotators, and the abductors in the professional baseball pitchers.

It was widely accepted that pitchers should be trained by conventional weight training (Bailery, 1988) and plyometric training (Burgener, 1989), which were helpful to improve PV, however, what are the best methods still remains unclear. Byram et al. (2010) tested the pitchers on the weakness of external rotation and supraspinatus strength in preseason because that weakness increased the risk of injury. Magnusson et al. (1994) identified that three glenohumeral muscles: supraspinatus, external rotators, and abductors, required in pitching motion, were weak in professional baseball pitchers. Thus, internal rotation strength was stronger than external rotation (Ellenbecker & Mattalino, 1997).

Undoubtedly, PV is associated with pitchers' physical fitness (PF). And it is very important to select specific and effective training methods to improve PV. While previous research has focused on the methods of the specific PF, little attention has been given to the relationship and prediction between PV and PF. Generating consistent maximum ball velocity is an important factor for a baseball pitcher's success.

However, there are very few sport-specific studies examining the relationship between field tests or exercises and pitching velocity. This lack of knowing a correlation between PF and PV is complex due to which some coaches use methods that are only subjectively believed to improve ball speed.

The purpose of this paper was to determine the key PF components needed for a pitcher by studying the relationship between PV and a set of selected PF variables, which, in turn, should help coaches design more effective training programmes to improve pitchers' PF. The results and information derived from this study may be helpful for coaches, physical therapists, and athletic trainers who directly interact with baseball players.

Methods

In the study, a survey in the form of a questionnaire was utilized. When a baseball tournament in China was held, 17 baseball coaches and experts were recruited to recommend and select key variables that determine pitcher's PF. After a three-round inquiry, 16 variables were identified. Internal consistency reliability (Cronbach's α reliability) was 0.826 and the content validity ratio (CVR) was 1 (CVR = [Ne-N/2] / [N/2], in which the Ne was the number of panelists indicating "fairly essential" and N was the total number of panelists (Lawshe, 1975). The sample size (Pocock, 1983) was based on the formula: $n=Z^2 P (1-P)/d^2$ (Z=1.96, 95% confidence interval [CI]; P=prevalence; d=precision) (Daniel, 1999). A total of 27 male elite baseball pitchers (age: 22.97±4.01 years; PV: 132.38±5.77km/h; training experience: 11.52±3.24 years), who came from Chinese professional teams, were tested by the 16 variables selected and their pitch velocity was measured. The variables included PV (km/h), 10m sprint (s)(10S), 5-different-direction sprints (s) (DDS), reaction time (s) (RT), max distance long toss (m) (MDLT), standing long jump (m) (SLJ), standing triple jump (m) (STJ), jump lunge with load (s) (JLWL), medicine ball side throw (m) (MBST), twisting crunch (num) (TC), shoulder internal rotation (num) (SIR), modified plank (point) (MP), double unders (num) (DU), stork balance stand test (s) (SBST), deep squat test (point) (DS), and forward split (cm) (FS). After an adequate warm-up including 5-minute jogging, 5-minute related dynamic stretching exercises and 5-minute specific warm-up (throwing, jumping, lifting, sprinting, deep squat, and lunge), 27 male baseball pitchers were tested, and assessed during three days according to test rules (NSCA, 2008). Pitchers had a 5-min between-variables rest. Before the study, all athletes were informed of the study purpose, risks, and benefits and they agreed to participate. All procedures were in compliance with the 1975 Declaration of Helsinki as revised in 2000.

Pitch velocity (PV). PV was assessed between the pitcher's mound and home plate (18.44m). The tester with a radar gun stood behind the home plate and was protected by net. The pitch velocity was measured when the baseball passed through the home plate. After an adequate general warm-up and specific related stretching exercises, they started to throw with maximum effort with approximately a 60-second rest between each repetition. Then, only the three best throws that passed the strike zone were recorded, and their mean was computed.

10m sprint (10S). Sprint performance over 10m was recorded by a stopwatch (Made in China). The tester promptly triggered the hand-release switch the instant the pitchers left the starting line, and stopped it when they crossed the terminal line. After an adequate general warm-up and specific related stretching exercises, the pitchers were permitted to do several specific runs. They ran twice with maximum effort with a 60-second rest between runs. The time was recorded, and mean was computed.

Five different direction sprints (DDS). After an adequate warm-up and specific related stretching exercises, the pitchers started from the defensive position O, sprinted to A and with the glove touched logo A, then quickly returned to O. Next, they started from the defensive position O, sprinted to B, C, D and E like A and B, as shown in Figure 1. The pitcher was permitted to try once. The tester used the stopwatch (Made in China) to record the time from start to finish. The pitchers were

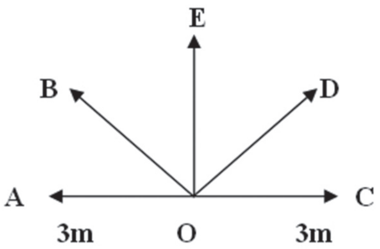

Figure 1. Different direction sprints.

permitted to attend twice with maximum effort with a 120-second rest between runs. The time was recorded, and mean was computed.

Reaction time (RT). The tester used the software called Fastball Reaction Time to measure reaction time. The pitcher was permitted to try once before he was measured. The reaction time was measured ten times, and mean was computed.

Max distance long toss (MDLT). After an adequate warm-up and specific related stretching exercises, the pitcher stood on the home plate and threw three times a flat-ground throwing as far as possible with approximately a 60-second rest between each repetition. Participants were instructed to throw hard on a horizontal line. The tester recorded the best maximum distance among the three throws.

Standing long jump (SLJ). After an adequate warm-up and the specific related stretching exercises, the pitcher stood behind the jump line and jumped three times as far as possible with approximately a 60-second rest between each repetition. The tester recorded the farthest distance among the three jumps.

Standing triple jump (STJ). After an adequate warm-up and the specific jump, the pitcher stood behind the jump line and jumped three times as far as possible in three strides with approximately a 60-second rest between each repetition. The tester recorded the farthest distance among the three jumps.

Jump lunge with load (JLWL). After an adequate general warm-up and the specific related stretching exercises, the pitcher stood with the feet shoulder-width apart and loaded a 20kg barbell. He started to take a big step forward with his right leg in a lunge position as soon as he had heard the signal. He shifted weight forward on this leg then jumped up quickly switching the position of his feet and legs while mid-air so his right leg moved backwards and his left leg moved forwards. This movement pattern is repeated during 30s. The pitcher had a 5-minute rest between two tests. The highest number of correct lunges was recorded.

Medicine ball side throw (MBST). After an adequate warm-up and the specific related stretching exercises, the pitcher held a 3kg medicine ball with two hands and threw it laterally three times with maximum effort with approximately a 60-second rest between each repetition. The tester recorded the farthest distance.

Twisting crunch (TC). After an adequate warm-up and the specific related stretching exercises, the pitchers lay on his back on the mat with the knees flexed at 90 degrees. When pitchers heard the start signal, they immediately raised the upper body off the mat and used the right elbow to touch the left knee joint, after touching the left knee, lower down the upper body and raise it again to touch the right knee. The tester recorded the time and frequency.

Shoulder internal rotation (SIR). After an adequate warm-up and the specific related stretching exercises, pitchers should stand with their shoulders externally rotated and elbows bent at 90°. Keeping the shoulder away from the body, they rotated it forward, keeping the elbows bent at 90°. Return the elastic band to the starting position. Pitchers used a 5LB elastic band with internal rotation at 90° thus simulating pitching shoulder motion. Pitchers should perform as many moves as possible in 10 seconds with approximately a 120-second rest between each repetition. The tester recorded a higher number of moves (frequency) within 10 seconds between two repetitions.

Modified plank (MP). After an adequate warm-up and the specific related stretching exercises, the pitcher did seven kinds of plank. First, the pitcher did a normal plank for 15 seconds. The next part of the test starts immediately after the 15-second plank. In the second step, the pitcher extended his left arm forward keeping it parallel to the ground and holding this position for 15 seconds then returned it to the starting position. In the third step, the pitcher extended the alternating arm and held the position then returned it to the starting position. In the fourth step, the pitcher extended the left leg and kept it parallel to the ground while holding this position for 15 seconds then returned it to the starting position. In the fifth step, the pitcher did the same with his right leg, and then returned it to start. In the sixth step, the pitcher extended the left arm and the right leg and kept it parallel to the ground for 15 seconds. In the last step, the pitcher executed the same with his right arm and left leg, holding them straight out for 15 seconds. The pitcher got one point after he accurately completed one kind of the described movement. The pitcher should stop this test immediately if his body cannot stay in the same plane and if he cannot keep his limbs straight and balanced at any point during the test. If the pitcher fell over or lost his balance at any point during the test, stop. Record the highest score achieved by the pitcher after the test.

Double unders (DU). After an adequate general warm-up and the specific related stretching exercises, the pitchers started to jump rope for 30 seconds — the rope should pass beneath his feet twice while he is in the air. The tester recorded the frequency.

Stork balance stand test (SBST). After an adequate general warm-up and the specific related stretching exercises, the pitchers lifted the right foot near the left knee joint. As soon as they heard "start", they lifted the left heel off the ground and stood on the balls of the left foot. The tester recorded the time until their left heel touched the ground, or the right foot left the position.

Deep squat (DS). After an adequate general warm-up and the specific related stretching exercises, the pitcher assumed parallel stance with the feet shoulder-width. The feet should be in the sagittal plane with no lateral outturn of the toes. He lifted a baseball bat on the top of the head and slowly lowered himself into the deepest possible squat position, the heels on the floor, head and chest facing forward and the bat maximally pressed overhead. The knees should be aligned over the feet with no valgus collapse. After the tester observed them from the front and side, he gave a score from one to three by FMS (Functional Movement Screen). Three points is the highest score.

Forward split (FS). After an adequate general warm-up and the specific related stretching exercises, the pitchers slowly started to forward split the legs with maximum effort. The tester measured the distance three times between bifurcation and the ground. The shortest distance was recorded.

All the data was presented as mean±SD. The effects were analyzed by SPSS18.0, and the correlations between PV and other 15 variables were computed. Furthermore, the regression analysis was used between PV and the other variables. A criterion of .05 level was used to decide statistical significance, and a level of r was used to decide statistical correlation.

Results

As can be seen in Table 1, 16 variables of the pitchers' PF were measured. We computed the mean (M) and standard deviation (SD).

As revealed in Table 1, there was a moderately high correlation between PV and MDLT (r=0.628, P<.05), a moderate correlation between PV and JLWL (r = 0.369, P<.05), and a low correlation between PV and SIR (r = -0.312, P<.05). There was almost no relationship between PV and other variables.

As can be seen in Table 2, the R square was .429. MDLT, JLWL, and SIR explained 42.9% of the PV variance. The ANOVA demonstrated that the regression was significant and meaningful (F=9.948, p<.001) (Table 3). As provided in Table 4, there was a regression analysis. PV can be computed by a formula that is a= 92.628+.409 (MDLT).

Table 1. Correlations between PV and 15 selected variables

ID	Variables	Construct	M±SD	*SD*	*r*
1	PV (km/h)	Speed	132.381	5.772	
2	10S(s)	Quickness	1.774	.069	.069
3	DDS (s)	Quickness	11.213	.688	.125
4	RT (s)	Reaction speed	.208	.020	-.076
5	MDLT (m)	Arm strength	97.786	7.707	.628*
6	SLJ (m)	Lower extremity power	2.671	.095	.141
7	STJ (m)	Lower extremity power	8.538	.294	.171
8	JLWL (s)	Body fast strength	40.119	3.749	.369*
9	MBST (m)	Core power	14.107	1.102	-.106
10	TC (num)	Core strength	31.548	2.769	-.062
11	SIR (num)	Upper extremity fast strength	33.714	1.701	-.312*
12	MP (point)	Core stability	6.262	.701	.174
13	DU (num)	Coordination	58.357	5.170	-.188
14	SBST (s)	Balance	25.691	10.547	-.103
15	DST (point)	Functional movement	2.500	.552	-.008
16	FS (cm)	Core flexibility	14.452	6.740	.075

Note. s=seconds, m = meters, num = number; *p<.05)

Table 2. R Square

Model		R	R square	Adjusted R square	Std. error of the estimate	R Square change	Change statistics			
							F change	df1	df2	Sig. F change
dimension0	1	.655[a]	.429	.383	4.53232	.429	9.498	3	38	.000

Note. a. predictors: (Constant), MDLT, JLWL, SIR.

Table 3. Regression coefficients[a]

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.	95.0% confidence interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	92.628	21.848		4.240	.000	48.399	136.857
	SIR	-.297	.450	-.087	-.661	.513	-1.207	.613
	JLWL	.244	.205	.159	1.192	.241	-.170	.659
	MDLT	.409	.101	.546	4.050	.000	.204	.613

Note. a. dependent variable: PV, MDLT, JLWL, SIR.

Discussion and conclusions

The pitcher has an essential role in the baseball team, and PV is one of the most important tools for the assessment of a successful pitcher (Werner, et al., 2008). Sixty-five to eighty-five percent of a winning team's success derives from effective pitching (Reiff, 1971).

A higher PV means that the batter does not have enough time to decide whether to swing or not. However, the level of PV in China is lower than that in Japan, Korea, or US. Therefore, we are seeking to find some effective training methods to improve Chinese pitchers' PV. There are many different training methods for PV development that have a certain effect, but it is hard to say which one is more effective. Thus, as can be seen in the results, 15 variables were chosen and analyzed using a test, survey, and statistical software. PV performance was moderately and highly related to the participants' max distance long toss, and moderately correlated with 30-second lunge lift and shoulder internal rotation. Max distance long toss is a good way to improve PV and improve strength of pitching because it can integrate the lower extremities, pelvis, trunk, arm, and hand to throw the baseball (Anz, et al., 2010; Fleisig, Hsu, Fortenbaugh, Cordover, & Press, 2013; Stodden, Fleisig, McLean, Lyman, & Andrews, 2001).

Long-toss baseball throwing may improve the PF of healthy pitchers providing greater arm strength, arm flexibility, arm speed, and ultimately pitch speed (Fleisig, Bolt, Fortenbaugh, Wilk, & Andrews, 2011). However, throwing max distance means a long toss and that method is somewhat controversial in professional baseball. Lots of professional teams have limited their pitchers to throwing a maximum distance of 120ft and insisted they only throw the straight baseball not arched as you want.

According to the theory of physics, velocity (v) = distance (d)/time (t). Velocity cannot be defined completely as a uniform motion because the baseball does not travel in a straight line but in an arc one. There are some differences between MDLT and the pitching mechanics of high ball velocity, such as elbow flexion and shoulder external rotation are greater for the max distance long toss in cooked position. At the time of ball release, both the forward trunk tilt and front knee flexion are smaller for the max distance long toss. The pelvis, upper trunk rotational velocities, elbow extension velocity, peak elbow varus torque, and peak shoulder internal rotation torque are all greater than in the fastball pitch. But there is a similarity in ball velocity. Thus, these throws may be beneficial in pitcher training (Fleisig, et al., 1996).

It is very important for PV that the proper and efficient coordination strength exists among the upper limbs, the core, and the lower limb (Clements, Ginn, & Henley, 2001). Jump lunge with a light load is a good way to improve the pitchers' kinetic chain that is most important to PV (Escamilla, Fleisig, Barrentine, Andrews, & Moorman, 2002).

Leg power and strength are also very important for pitchers because the force of throwing is generated from the ground. It has been proven to have a positive correlation with pitching and throwing. Many PF coaches from Major League Baseball think that lower extremity exercise is the most important exercise for baseball players (Spaniol, 2009).

Stride knee extension is also essential to pitchers who want to pitch high velocity during the ball release (Matsuo, et al., 2001). Another study showed stride ground reaction forces were strongly correlated with pitching velocity (McNally, Borstad, Oñate, & Chaudhari, 2015). The movement of JLWL is similar to the stride of the pitching movement. Thus, JLWL is also a good one of the specific strength training methods.

Upper extremity, including shoulder adduction, elbow extension, and wrist extension, can significantly predict PV and it can also contribute 51% to PV (Toyoshima, Hoshikawa, Miyashita, & Oguri, 1974). Shoulder external and internal rotations are both contributors to increasing ball velocity. A study showed that high-velocity pitchers had significantly greater shoulder external rotation during the arm-cocking phase compared to low-velocity pitchers (Matsuo, et al., 2001). Shoulder external rotation may cause stretch-shortening cycles (SSC) in shoulder muscles during pitching and throwing (Feltner, 1989).

Shoulder internal rotation (SIR) is one of the ballistic resistance trainings for PV improvement. Kibler (1994) contends scapula plays a vital role in maintaining the kinetic chain during overarm motion because about 54% of the total force is generated in the arm. McEvoy and Newton (1998) claimed that ballistic resistance training can significantly increase performance in baseball pitching. Baseball throwing speed is highly related to elbow extensor and SIR strength (Clements, et al., 2001). Nevertheless, the movement of quick shoulder internal rotation with an elastic band is similar to pitching, and it can improve shoulder's strength avoiding shoulder injury. Because pitchers lost pitching strength and suffered from pain after training sessions and games, it was more essential to improve shoulder and elbow strength than strength of other body parts (Yanagisawa, et al., 2003). A study (Huang, Wei, Jung-Chi, Hsu, & Chang, 2005) revealed that internal rotators' (IR) strength was greater than strength of external rotators (ER) in pitchers, and there was a 70% strength loss in IR when the pitchers were assessed in endurance. Adolescent and pre-pubescent baseball pitchers had relatively weaker shoulder ERs in muscle endurance. SIR with an elastic band can simulate the movement of both the IR and ER in the shoulder and enhance IR and ER strength.

Studies on resistance training including free weight (Popescue, 1975), elastic bands (Escamilla, et al., 2010), medicine balls (Newton & McEvoy, 1994), and isokinetic machines (Wooden, et al., 1992) have shown more positive improvements in throwing and pitching velocity. However, a study (Rodgers & Whipple, 1990) has shown the use of heavy loads cannot increase PV in the neuromuscular system.

PV in elite pitchers with both the pelvis (662 ±148°/s) and upper torso (1180 ± 294°/s) is associated with increased pelvis and upper torso velocities (Fleisig, et al., 1996). Pitchers who had greater lateral trunk flexion at maximum external rotation had higher ball velocity (Oyama, et al., 2013). Improved trunk strength will likely generate higher trunk velocity (Ishida & Hirano, 2004).

Medicine ball (MB) training can improve upper torso velocity better than other methods such as seated band rotation, lying cross-over, and twister (Stodden, Campbell, & Moyer, 2008). MB training as both ballistic and plyometric can improve baseball players to generate powerful, sequential, and rotational actions (Newton & McEvoy, 1994). It is proved that the medicine ball test is valid and reliable for evaluating core power (Stockbrugger & Haennel, 2001) because forces and energy from the hips will be transferred through the torso to the upper extremity when the pitcher pitches the baseball or MB (Raeder, Fernandez-Fernandez, & Ferrauti, 2015). MB training closely simulates the sequential stretch-shortening cycle of energy transfer, and it has been shown to help improve pitch velocity in baseball games (Raeder et al., 2015).

Moderate relationships were observed between PV and rotational MB throw velocity ($r=0.62$, $p=.02$) (Taniyama, Matsuno, Yoshida, Pyle, & Nyland, 2021). MB is a good training method for baseball pitchers, but the medicine ball showed no significant increase in PV but a significant increase in strength because it did not improve the neuromuscular qualities of force output and rate of force development (RFD) (Newton & McEvoy, 1994). Similarly, the correlation between medicine ball side throw and PV is very low ($r=-.106$). Therefore, pitchers should focus on core force output and RFD.

As revealed in the results, the PV formula was built by regression analysis. Thus, we got the statistical model for PV. The formula ($a= 92.628+.409b$) can be used to compute the PV. Descriptive statistics of PV and of the selected variables, as well as their correlations, are summarized. A follow-up regression analysis found that, together, MDLT, JLWL, and SIR explained 42.9% of PV variance.

In conclusion, PV was moderately related to pitchers' MDLT and somewhat correlated with JLWL and SIR. Therefore, to improve PV, the focus of the training should be on improving the pitchers' arm strength, lower body power, upper body fast strength, and core RFD.

Limitation

There are some limitations in that the sample size of pitchers was relatively small, so it is hard to generalize which PF methods of the PV development are better. In future research, we will be looking for PV training methods applied to different level athletes and female pitchers, and analyze the relationship between PV and PF or specific fitness on the basis of different country's pitchers.

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