Baseball performance via the lens of anthropometric testing, fitness metrics, and statistics: a longitudinal cross-sectional study

Zacharias Papadakis, PhD[a], Robert N. Padgett, MS[b], Andreas Stamatis, PhD[c] and Richard A. Karasch, MS[d]

[a]Human Performance Laboratory, Sport and Exercise Sciences, Barry University, Miami Shores, Florida
[b]Educational Psychology, Baylor University, Waco, Texas
[c]Sport and Wellness, State University of New York, Plattsburgh, New York
[d]Department of Athletics, Rice University, Houston, Texas

ABSTRACT

Background:
Anthropometric testing (AT) and fitness metrics (FM) are contributing factors for success in sports. Limited evidence exists regarding longitudinal baseball AT or FM roles on baseball performance statistics (PS). AT, FM, and PS associations were examined for 5 yr to create a performance model.

Methods:
Eighty collegiate Division I players participated in this study. Height, mass, and body fat percentage (BF%) were selected as AT variables of interest. Grip strength (GS), one repetition maximum squat (1RMSQ), and vertical-jump height were selected for FM. Batting average percentage (AVG), slugging percentage (SLG), on-base percentage (OBP) baseball statistics were selected as offensive PS. Earned run average (ERA), batting average against percentage (B/AVG), and strike-out per innings pitched for 9 innings (SO/IP)*9 were selected for defensive PS.

Results:
Offensive ($r=-0.15$, $P<0.005$; $r_s=-0.17$, $P<0.001$) and defensive ($r=-0.253$, $P<0.001$; $r_s=-0.314$, $P<0.001$) statistics correlated with BF%. Offensive ($r=0.26$, $P<0.001$; $r_s=0.43$, $P<0.001$) and defensive ($r=0.39$, $P<0.001$) statistics correlated with GS. Offensive ($r=0.26$, $P<0.001$; $r_s=0.43$, $P<0.001$) and defensive ($r=0.27$, $P<0.001$) statistics correlated with 1RMSQ. Offensive statistics AVG ($R^2=0.48$) and SLG ($R^2=0.46$) were explained by 1RMSQ. For defensive statistics, 1RMSQ was the best fit for (SO/IP)*9 ($R^2=0.43$) and B/AVG ($R^2=0.52$), and GS was the best fit for ERA ($R^2=0.39$). Squat and time interaction for B/AVG was significant ($P=0.04$).

Conclusions:
Baseball PS are associated with 1RMSQ and GS. Time moderates the effect of squat training on B/AVG. Pitchers need to include squats to lower their B/AVG. Coaches may focus on improving such FM variables and consider the time effect on selected FM that may affect PS.

Level of Evidence:
Level IV

Key Words
collegiate division I, vertical jump, grip strength, 1RM squat, strength and conditioning

INTRODUCTION

Baseball is perhaps the sport that is linked most intimately with performance statistics (PS).[1] Baseball PS play a key role by providing various types of performance feedback to the involved parties.[2] Youth players, coaches, parents, and strength and conditioning coaches (SCCs) constantly are searching for ways to improve physical and performance parameters and ultimately to improve players' baseball performance.[3] The role of the SCC, through proper physical fitness testing and training, is to develop, maintain, and enhance the physical development of players.[4–10] The results of such physical fitness testing programs can be predictors of successful baseball performance.[11]

Despite the popularity of baseball and the measures taken to maximize baseball development and performance, little is known regarding the impact of statistics that physical fitness testing has on baseball-specific performance on a longitudinal basis.[1] Increases in muscle size, strength, and power have been reported to be associated with improvements in baseball power numbers,[12,13] for example in hitting statistics, home runs are associated with lean body mass ($r=0.5$),[12] total bases with grip strength (GS) ($r=0.2$),[12] and slugging percentage with vertical jump peak and mean power ($r=0.5$).[13] Physical fitness metrics (FM) that examine strength, power, and agility have been presented as having low to moderate correlations with batting

and fielding performance,[8] such as batting associated with GS (r = 0.6), peak power (r = 0.5), squat (r = 0.4), bench press (r = 0.2), and agility (r = 0.8).[13,14]

Several studies have examined anthropometric and physiological characteristics of baseball performance and have highlighted the existence of a wide range of correlations between collegiate baseball performance and physical fitness.[3,15–18] These low to moderate correlations suggest that there may be no relationship between some of the parameters, which warrants further investigation. Regression modeling analysis often is used for exercise prescription in an effort to provide answers to such phenomena and make predictions of future patterns in performance.[19,20] It is not clear what impact selected FM, their results, and the subsequent training based on these results have on baseball performance. Moreover, no longitudinal study has examined selected FM parameters as predictors for baseball performance by using selected baseball statistics in a collegiate baseball team. Therefore, the purpose of this study was to examine the results of these three areas: how anthropometric testing (AT) and selected physical FM parameters are related to National Collegiate Athletic Association (NCAA) Division I (DI) baseball PS, which of the selected FM parameters across 5 yr of follow-up can predict baseball PS, and if the relationship between FM and PS changes from year to year.

Based on previous research about the practices of major league baseball SCCs,[9] the current authors selected a) body mass, body fat percentage, and body height as AT parameters; b) GS, one repetition maximum squat (1RMSQ), and vertical jump height (VJH) as FM parameters; c) batting average percentage (AVG), slugging percentage (SLG), on-base percentage (OBP) as offensive baseball PS; and d) earned run average (ERA), batting average against percentage (B/AVG), and strike-out per innings pitched for nine innings [(SO/IP)*9] as defensive baseball PS. The authors hypothesized that AT and FM parameters are positively related to collegiate DI baseball performance selected PS, focusing primarily on FM characteristics.[14,21] In addition, strength of lower limbs has been shown to be an important predictor of batting performance.[12,13] Consequently, the authors hypothesized that 1RMSQ would be a significant positive predictor of AVG, SLG, OBP, ERA, B/AVG, and (SO/IP)*9. Furthermore, since the authors were not aware of any other longitudinal studies that have investigated the relationship between FM and PS and their implication on batting, running, and fielding in baseball tasks, regardless of position and time,[3] they assumed that both GS and vertical jump height would be significant predictors of AVG, SLG, OBP, ERA, B/AVG, and (SO/IP)*9, and there would be no difference between the reported relationship of FM and PS throughout the years.

MATERIALS AND METHODS

Ethical Review and Study Design

The study was approved by the Ethics Committee of Rice University's institutional review board (IRB) for use of human subjects in research. Data were received in unidentified form from the coach, who collected these data as part of the training program, and the data were used for class-related practices. Therefore, the IRB did not assign a specific number for this study. All participants were NCAA DI baseball players that were followed for 5 yr. Fitness assessments were used to analyze body weight and height, body composition, GS, and lower-body strength and power. As part of their team requirements, players provided their consent for these assessments. Baseball statistics were recorded at the end of each season. Two anthropometric, one body composition, three physiological, and six baseball-specific skill variables in total were measured for a 5-yr period as part of the yearly strength and conditioning evaluation program. All testing sessions were supervised by certified SCCs. All testing was performed on a single day by the same coaching staff during afternoon hours in an air-conditioned facility during the off-season when no team practice was scheduled. Testing took place during the off-season, with the pretest performed in August and the posttest in November. During the playing season, the team followed a specific training program in order to maintain athletes' high fitness levels. In general, the in-season program, which followed NCAA regulations,[22] included two times per week on nongame days using total body lifts for the 60 scheduled games per year. All athletes were healthy during the testing period.

Participant Selection

Eighty collegiate baseball players, members of a DI team, were evaluated during the course of five separate seasons (2013 to 2018). The sample (n = 80) consisted of 42 pitchers, 12 catchers, 11 infielders, and 15 outfielders (Table 1). All performance assessments were part of the athletes' off-season and in-season regular strength and conditioning program. This program was periodized based on the baseball season with specific goals, but no disclosure of the detailed program was given, because the team was competing for the championship.

Data Collection

The order of the assessment was anthropometric, body composition, isometric strength measures, vertical jump, and 1RMSQ. Even though an optimal testing order has not been established, there is a consensus regarding an emphasis on fitness components in sequence that would allow for proper resting and would not stress the same muscle group or metabolic pathway.[23] Test-retest reliabilities for all assessments have been previously reported to be R > 0.90 for body composition,[24] GS,[25] vertical jump,[26] and 1RMSQ.[27,28] Baseball statistics were obtained from the team's NCAA official yearly statistics report for each individual player during the 5 yr of follow-up.

In order to establish the anthropometric and physiological variables' relationship to baseball PS, the authors assigned the anthropometric and physiological performance measures as independent variables and baseball PS as dependent variables. The authors normalized FM and PS to z scores, and any missing data were estimated from least squares prediction from non-missing variables. A multilevel linear regression model was used to evaluate the relative impact of FM on PS.

Anthropometry

Descriptive data were collected for all participants, including height, body mass, and body fat percent (Table 2). Participants' anthropometric measurements (height and body mass) were obtained using standard procedures as dictated by American College of Sports Medicine (ACSM).[23] Body

TABLE 1. Demographics of players by year and by position

Year	New[1]	Return[2]	NM[3]	Age (yr) Mean	SD	Height (cm) Mean	SD	BW (kg) Mean	SD
2013	32	-	65	20.1	1.2	183.0	6.0	89.3	7.7
2014	13	23	127	19.9	1.4	183.6	6.2	89.1	7.7
2015	11	19	97	19.5	1.4	185.3	5.1	90.2	7.5
2016	13	23	69	19.7	1.1	185.1	6.0	90.7	9.8
2017	11	31	56	20.0	1.1	184.6	6.2	9.1	9.6
Total	80		414						

Position	N	Age (yr) Mean	SD	Height (cm) Mean	SD	BW (kg) Mean	SD
C	12	19.7	1.3	179.8	3.6	87.3	7.9
IF	11	19.8	1.6	184.0	5.2	85.9	5.4
OF	15	20.0	1.2	181.9	6.0	89.2	9.2
LHP	6	19.8	1.2	189.6	7.3	96.1	10.5
RHP	36	19.7	1.3	186.6	5.0	91.5	7.6

[1]New players correspond to the number of players that were not previously assessed in prior years (total n = 80).
[2]Returning number of players indicates the number of players that were measured in the year of the row that had measurements from a previous year.
[3]Number of measurements (NM) obtained each year. Over the five years an individual player was assessed an average of 5.2 times (SD = 3.3; minimum = 1; median = 4; and maximum = 13).
BW, body weight; C, center field; cm, centimeter; IF, infield; kg, kilogram; LHP, left hand pitcher; NM, new measurement; OF, outfield; RHP, right hand pitcher; SD, standard deviation; yr, year.

mass was measured to the nearest 0.5 pound, and height was measured to the nearest 0.5 inch using a Detecto 439® (Detecto Scale Company, Webb City, Missouri). All body composition measurements were performed by the same SCC, who was not a certified anthropometrist but had more than 15 yr of experience on body composition measurements using the standardized procedures of four-site skinfold measurement as previously described.[23,29] Skinfold thickness was measured on the right side of the body with a Lange Skinfold Caliper® (Beta Technology Incorporated, Cambridge, Maryland USA). Measurements were taken as previously described.[23,29]

Isometric Handgrip Assessment
Isometric GS was assessed with a Jamar® Handgrip Dynamometer (Lafayette Instruments, Lafayette, Indiana). All measurements were assessed on both participants' dominant and nondominant hands, and the highest value was used for the statistical analysis. Isometric handgrip assessments were performed as previously described.[23,29]

Vertical Jump
Countermovement vertical jump was measured with a validated system, and peak power was calculated from Johnson and Bahamonde countermovement equation.[30] A

TABLE 2. Summary statistics of fitness and performance measures

Variable

Fitness metric	2013	2014	2015	2016	2017
Height (cm)	183.0 (6.0)	183.6 (6.2)	185.3 (5.1)	185.1 (6.0)	184.6 (6.2)
Body weight (kg)	89.34 (7.6)	89.14 (7.6)	90.1 (7.5)	90.7 (9.83)	90.1 (9.6)
Body fat (%)	12.1 (4.1)	12.2 (2.9)	12.2 (3.5)	12.7 (3.7)	12.5 (4.3)
Vertical jump Height (cm)	67.9 (6.2)	67.9 (3.8)	67.2 (11.3)	73.8 (7.7)	67.5 (17.5)
Vertical jump mean power (W)	2511 (1029.9)	2567 (392.0)	1768 (507.6)	2145 (712.7)	1870 (389.4)
Vertical jump peak power (W)	6290 (1538)	6451 (347)	6496 (1101)	7120 (620)	6472 (16131)
1RMSQ (kg)	145 (13.3)	145.6 (17.1)	141.6 (24.8)	151.2 (24.7)	141.0 (44.3)
Grip strength (kg)	65.2 (9.6)	63.6 (7.98)	62.13 (6.3)	64.5 (11.7)	55.7 (6.7)
Baseball performance					
AVG	0.26 (0.08)	0.24 (0.11)	0.19 (0.10)	0.19 (0.1)	0.19 (0.07)
SLG	0.32 (0.11)	0.29 (0.13)	0.24 (0.13)	0.26 (0.15)	0.26 (0.11)
OBP	0.35 (0.07)	0.36 (0.14)	0.29 (0.11)	0.27 (0.11)	0.27 (0.07)
ERA	1.96 (9.96)	7.22 (10.8)	11.11 (15.03)	24.19 (40.65)	25.77 (31.92)
B/AVG	0.25 (0.08)	0.24 (0.04)	0.27 (0.04)	0.31 (0.06)	0.3 (0.04)
(SO/IP)* 9	7.8 (2.18)	8.73 (2.33)	8.37 (2.34)	9.57 (2.51)	9.24 (2.1)

Note: reported values are the mean with standard deviations in parentheses.
1RMSQ, one repetition maximum squat; AVG, batting average percentage; B/AVG, batting average against percentage; cm, centimeter; ERA, earned run average; kg, kilogram; OBP, on-base percentage; SLG, slugging percentage; (SO/IP)*9 = strike-out per innings pitched for 9 innings; W, watts.

Just Jump Mat® (Probotics, Huntsville, Alabama) was used, which has been shown to be a valid and reliable method to measure vertical jump.[31] The best of three attempts with a 30-second rest between trials was recorded, and measurements followed standardized procedures.[30–32]

One Repetition Maximum Squat

During each testing session, participants performed a 1RMSQ strength test to measure lower-body strength as previously described.[27] Parallel squat was measured using an Olympic size bar and estimated 1-RM strength via a 3-RM test.[29] This test was the last in the sequence of the performed tests after the countermovement vertical jump.

Baseball Performance

Baseball performance was obtained from archived NCAA published statistics of regular seasons throughout the 5 years from 2013 to 2018. The authors selected the following variables of interest to characterize the fielding performance: a) AVG, (the number of hits divided by number of at-bats;[1] SLG (total bases from hits divided by number of at-bats;)[1] and OBP (hits plus walks plus hits divided by pitches)[1] were selected as offensive baseball fielding performance, and b) ERA (the number of earned runs yielded per nine innings),[1] AVG (the number of hits/[total batters faced-hit batters-walks-sacrifice hits allowed- sacrifice flies allowed]),[1] and innings (SO/IP)* 9[1] were selected as defensive baseball fielding performance.

Statistical Analysis

The sample size was determined by the athletes that were available to be followed for 5 yr from an individual NCAA DI baseball team; therefore, a sample size calculation was not performed. Missing data were imputed using least squares prediction from nonmissing variables.[33] All remaining analyses were conducted using R.[34] The Pearson and Spearman correlations were computed among the anthropometric, FM, and the baseball PS. Correlations were computed across all participants and time points to identify any trends in the data. The Spearman's rank correlation coefficient was used to identify relationships that may not be linear.

Each of the fitness metrics were used as predictors in a multilevel linear regression model. Because these data were collected on athletes for five years, multilevel modeling was used to account for the feature of these data that individual observations were nested within a particular athlete. This feature of these data needed to be accounted for in the analysis of the relationship between fitness metrics and baseball statistics because the underlying assumption of independence of observations from traditional regression analyses was violated.[35]

In this study, the multilevel linear regression models were specified with player-varying intercepts and slopes (i.e., random effects across players). This allowed each athlete to have a unique intercept and slope for the relationship between the FM and the baseball PS. These varying intercept and slope models were fit using the lme4 package.[36] Additionally, each model used the player position as a categorical (dummy coded) player-level predictor to account for difference among positions of athletes (see Appendix B

for more details, Supplemental Digital Content 2, http://links.lww.com/COP/A41). These player-level predictors controlled for any average differences in PS that were associated with the position that each player held (e.g., pitcher, catcher, outfielder). The right-handed pitcher group was used as the reference group because this group was largest (see Table A-1).

Models were compared within each baseball performance statistic (i.e., the dependent variable for each model), with regard to which fitness metric yielded the best fitting model of the observed data. This comparison was made using the Akaike's Information Criterion (AIC), model R^2, and parameter estimates. For the AIC, the model with the lowest value fit best. The model R^2 was computed as one minus the fraction of residual sum of squares for the estimated model to residual sum of squares for a null model (intercept only) model. For the parameter estimate, the authors compared the average slope between the fitness metric and the performance statistic to identify which had the largest predictive change on average. All the PS and fitness metric data were standardized to z-scores prior to model estimation. Additionally, the estimated standard deviation (SD) in the slope was compared. The SD of the slope was an estimate of how much the relationship between performance statistics and fitness metrics varied across players. The authors aimed to find a relationship that varied little across players. A low SD in the slope would be indicative that players would respond similarly to fitness training and that if coaches help train that relationship, they have more confidence that all their players would increase performance rather than a select few players.

RESULTS

The summary of observations from players by the year that they were tested and the player's position are reported in Table A1. The summary of each performance statistic and fitness metric are reported in Table 2. The correlations between performance statistics and fitness metrics are reported in Figure 1. The strongest of these relationships appear to be between 1RMSQ and SLG and between GS and ERA (see Table 3). Furthermore, see Appendix Table A2 for precise estimates of the strength of the relationships, Supplemental Digital Content 1, http://links.lww.com/COP/A40. The strength of the Spearman correlations is almost all stronger in magnitude (i.e., more extreme positive and negative correlations) for all performance and fitness metrics.

The results of the multilevel linear regression analyses are presented in Table 4 for offensive and defensive statistics. First, each row reported in Table 4 represents a separately estimated regression model (more results in the appendix A, Supplemental Digital Content 1, http://links.lww.com/COP/A40). These comparisons are made by the aid of the AIC and R^2 statistics reported.

The interaction of FM and time (FM x time) for defensive statistics (B/AVG) was significant. This indicates that as a player trains more over time, the negative effect of squats increases, and it means that time moderates the effect of squats on B/AVG to magnify the negative effect. Note that
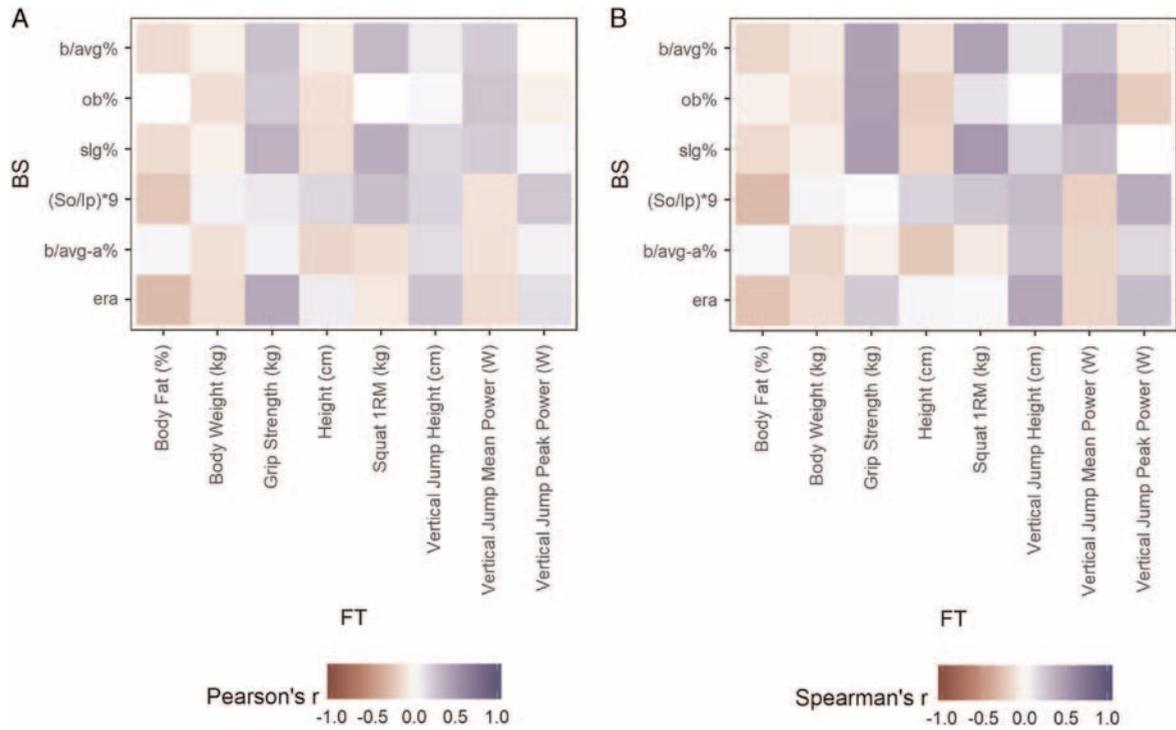
FIGURE 1. Heatmaps displaying the correlations among the fitness metrics and performance statistics, (A) heatmap displaying the Pearson's r and (B) heatmap displaying the Spearman's r.

the reported parameters are standardized in order to help with interpretation and comparison within groups of PS. The SD was estimated to be 0.27 which means that the slope varies an average of 0.27 SD across players.

Last, the multilevel regression model included a player-level predictor of position. The estimated parameters for differences in PS by player position were not statistically significant, indicating that player position did not

TABLE 3. Selected results of correlation analyses for Pearson and Spearman correlations for offensive and defensive statistics

Offensive performance statistics	Fitness metric	Pearson		Spearman	
		r	P	r	P
AVG	Squat 1RM (kg)	0.30	<0.001	0.43	<0.001
	Grip strength (kg)	0.26	<0.001	0.43	<0.001
OBP	Vertical jump mean power (W)	0.25	<0.001	0.41	<0.001
	Grip strength (kg)	0.23	<0.001	0.45	<0.001
SLG	1RMSQ (kg)	0.37	<0.001	0.49	<0.001
Defensive Performance Statistics					
(SO/IP)*9	Vertical jump peak power (W)	0.24	<0.001	0.37	<0.001
	1RMSQ (kg)	0.27	<0.001	0.24	<0.001
B/AVG	Height (cm)	−0.18	<0.001	−0.25	<0.001
	Vertical jump height (cm)	0.14	<0.005	0.26	<0.001
ERA	Vertical jump height (cm)	0.25	<0.001	0.41	<0.001
	Grip strength (kg)	0.39	<0.001	0.22	<0.001

Note: Pearson gives the strength of the linear relationship. Spearman gives the strength of the ranked relationship. The values in this table represent the strongest observed relationship for Pearson and Spearman coefficients separately.
1RMSQ; one repetition maximum squat; AVG, batting average percentage; B/AVG, batting average against percentage; cm, centimeter; ERA, earned run average; kg, kilogram; OBP, on-base percentage; SLG, slugging percentage; (SO/IP)*9, strike-out per innings pitched for 9 innings; W, watts.

TABLE 4. Selected results of best fitting multilevel regression models.

	Fitness metric	Term	Fixed effect	Random effect	R^2
Offensive performance statistics					
AVG	1RMSQ (kg)	FM	0.07 (0.06)	0.19	0.49
		FM×Time	0.01 (0.04)		
OBP	Vertical jump mean power (W)	FM	0.12 (0.08)	0.53	0.32
		FM×Time	−0.02 (0.05)		
SLG	1RMSQ (kg)	FM	0.11 (0.06)*	0.22	0.49
		FM×Time	−0.02 (0.04)		
Defensive Performance Statistics					
(SO/IP)*9	1RMSQ (kg)	FM	0.22 (0.09)*	0.51	0.45
		FM×Time	0.04 (0.04)		
B/AVG	1RMSQ (kg)	FM	−0.08 (0.15)	1.09	0.56
		FM×Time	−0.12 (0.04)*		
ERA	Grip strength (kg)	FM	0.30 (0.06)*	0.23	0.43
		FM×Time	−0.01 (0.04)		

Note. *$P < 0.05$. Models selected as best explanation of variability in performance statistics. All variables were standardized to ease comparison of effects between performance statistics. Fixed effect is the average expected change in performance for a one-unit change in the fitness metric (FM) and where the interaction (FM×time) represents the expected change in the relationship between FM and performance as the player trains for a year on this metric; standard error (SE). Random effect is reported as the standard deviation of fitness metric slope; and
AVG, batting average percentage; B/AVG, batting average against percentage; ERA, earned run average; FM x time, interaction; FM, fitness metric; kg, kilogram; OBP, on-base percentage; R^2, proportion of variance explained by model over the null (intercept only) model; SLG, slugging percentage; (SO/IP)*9, strike-out per innings pitched for 9 innings; W, watts.

contribute to substantial differences among players' PS. However, there does appear to be evidence that infielders were performing higher on average than right-handed pitchers on each performance statistic across all models that were tested (see Appendix Tables A6 and A7, Supplemental Digital Content 1, http://links.lww.com/COP/A40). Otherwise, the results were not significant.

DISCUSSION

This study examined mainly whether FM were positively correlated to selected DI baseball PS. In addition, the authors examined whether 1RMSQ can be a positive predictor of the selected PS.

Based on Cohen's classification for correlations,[37] the results of this study showed that offensive baseball PS, such as AVG, was moderately positively correlated with both GS and 1RMSQ strength; OBP was moderately positively correlated with the GS and mildly positively correlated with vertical jump mean power; and SLG was moderately positively correlated with 1RMSQ. On the other hand, defensive baseball PS, such as (SO/IP*9, was moderately positively correlated with vertical jump peak power and mildly positively correlated with 1RMSQ; B/AVG was mildly positively correlated with vertical jump height and mildly negatively correlated with height, and ERA was moderately positively correlated with both vertical jump height and GS. In regard to predicting offensive baseball PS from fitness metrics, AVG can be best predicted by 1RMSQ ($R^2 = 0.48$), OBP can be best predicted by vertical jump mean power ($R^2 = 0.31$), and SLG can be best predicted by 1RMSQ ($R^2 = 0.46$). Although defensive PS, such as (SO/IP)*9 and B/AVG, can be best predicted by 1RMSQ ($R^2 = 0.43$ and $R^2 = 0.52$, respectively), ERA can be best predicted by GS ($R^2 = 0.39$). Besides the squat, no other FM variable presented a time-moderating effect on B/AVG, highlighting that

training must be performed throughout the years and supporting the notion that lower-limb muscular power is related to in-season baseball performance statistics.[38]

Collectively, these findings revealed a consistent association between baseball field performance and 1RMSQ and GS. In regard to FM changes over the time, squat needs to be a critical component in the SCC programs, especially for improving B/AVG. Low B/AVG as associated with squat training means that pitchers need to incorporate this exercise in their training routine. This work validates previous work showing that lower-limb strength is related to SLG[14] and AVG.[39] Fielding performance in baseball is critical because this translates to having significant impact on winning or losing a game.[39] The findings of this longitudinal study inferred a link between physiological parameters and baseball performance.

Anthropometric and Baseball Performance Statistics

Results of this study showed that anthropometrics are correlated with PS. Body fat percentage was shown to have a negative correlation with SLG, meaning that the less body fat percentage the athletes have, the better their SLG is and vice versa. These findings were in agreement with Hoffman et al.[12] who indicated that lean body mass was significantly correlated with SLG ($r = 0.4$). Mangine et al.[40] found that fielding performance was correlated with body mass ($r = 0.364$), lean body mass ($r = 0.396$), and body fat percentage ($r = 0.028$). Even though they used different baseball statistics than this study to define the baseball fielding performance (i.e., the ultimate zone-rating extrapolation rates by runs saved or cost within a zone of responsibility in comparison with the league average for a position) and direct comparisons cannot be made, the authors believe that this showed a pattern. On the other hand, Basile et al.[11] did not find any significant relationship between lean body mass and body fat percentage with baseball performance. The

study by Hoffman *et al.*[12] stated that there were no anthropometric predictors of any of their dependent variables. Moreover, their study showed that anthropometric and performance variables are different between players of different experience levels.[12] This study followed a team of NCAA DI baseball players for 5 consecutive years, and the authors selected quite similar performance measures and baseball PS. The results, in general, are in agreement with Hoffman *et al.*;[12] anthropometric characteristics accounted for 12% to 43% of the variability on PS. Noteworthy enough, the majority of this study's anthropometric correlations were negatively related to baseball performance. This was probably because of the level of expertise of the study's sample (collegiate) compared with the Mangine *et al.*[40] sample (professional). For example, it is reported that that average body fat percentage on NCAA DI players ranges from 11% to 17%, but in Major League Baseball players, it ranges from 8.4% to 12.3%.[8] This study's body fat percentage was 12.3% ± 3.6%. It has been suggested that baseball performance should not be examined in a one-dimensional perspective, and it might be influenced by other factors, such as hand-eye coordination and psychological outlook.[11,12] Although the current authors cannot rule out such conclusions, it is likely that since this study's sample was a DI recruitment, these student-athletes were powerful, strong, and lean, with previous baseball experience and training at a high-level, which could explain the observed relationships.

Height was negatively correlated with defensive B/AVG fielding performance, meaning that taller pitchers were not as effective as the shorter ones on striking out the batters. According to the authors' knowledge, there is no previous study investigating the success rate of pitchers in regard to their height. A common baseball theory is that taller pitchers are more durable and naturally better than the shorter ones. The notion is that being taller standing on the plate is more intimidating, that the throw is done a greater downhill plane, and the release of the ball is closer to the plate.[41] Being taller and having longer arms and greater size in general would allow a pitcher to throw harder and faster balls because of greater leverage involved in the mechanics of pitching.[42] That could be the reason why recruiters seek the tallest and heaviest athletes. High stature gives an advantage in many sports, and although the height of the pitchers in this study was in agreement with the literature compared to other positions,[15] our data showed that high stature has a negative effect on pitchers' performance. Although Mangine *et al.*[40] reported similar correlations with height (r = –0.069), his sample was different than ours (i.e., professional vs. collegiate). Nevertheless, other data indicate that height is essentially irrelevant when a pitcher is good enough to become a professional as both short and tall pitchers can be effective on striking out the batters.[16,41,42]

Fitness Metrics and Baseball Performance Statistics

The results of this study indicated that 1RMSQ and jump test related values were the best predictors for (SO/IP)*9 and B/AVG in addition to grip strength, which was the best predictor for ERA. Vertical jump mean power was weakly correlated with SLG, and GS was moderately correlated with SLG. In contrast to what Basile *et al.*[11] reported, there was no significant relationship between squat press, vertical jump, bat velocity, and batted ball velocity, and these results are similar to those that have been reported in the literature.[12] Lower-body power (vertical jump peak and mean power) and GS were significantly positively correlated with baseball performance (home runs, total bases, and stolen bases) and more specifically with SLG (r = 0.4 and r = 0.2 for lower-body power and grip power, respectively).[12]

Offensive AVG and OBP were positively correlated with GS, and GS was positively correlated with only ERA from the defensive PS. Previous research has linked GS and offensive PS of batting performance.[43–45] This linkage may be caused by the upper-body strength that is required during batting.[44] Moreover, AVG and SLG have been positively correlated with GS, which further supports the role of upper-body strength during batting.[44] The sample of this study, a DI team, received full support from a group of SCCs throughout the year. The work of this group is to keep the team members conditioned and work on their deficiencies. As such, this cohort had their upper and lower bodies trained in a way that was efficient enough to lead to these FM and PS associations.

The results of this study indicated that 1RMSQ and jump test related values were the best predictors for AVG, OBP, and SLG. Although the study by Mangine *et al.*[40] indicated that vertical jump mean power was the single predictor of BS for all players (R^2 = 0.16), our study supports previous findings and showed that vertical jump mean power was among other predictors of BS (R^2 = 0.31). Baseball performance requires high levels of motor control and skill development, and our cohort, because of their prior and current training status, highlighted its importance as a contributing factor for baseball performance.[44] Mangine *et al.*[40] reported that fielding performance was correlated with vertical jump peak power (r = 0.397) and vertical jump mean power (r = 0.405). They used different baseball statistics than those that were used in our study to define the baseball fielding performance (the ultimate zone-rating extrapolation rates by runs saved or cost within a zone of responsibility in comparison with the league average for a position); therefore, any direct comparisons have to be made with caution.

The results of this study showed that OBP was positively related to vertical jump mean power, and all defensive PS were positively related to vertical jump peak power and vertical jump height. For this study, the authors used Jump Test™ (Just Jump Test, Huntsville, Alabama), which uses equations developed by Johnson and Bahamonde[30] that use the subject's height, mass, and vertical jump height in order to predict vertical jump power in watts. Nevertheless, when performing such a test, taller and heavier subjects will generate greater power outputs. Because of the increased dependency of this procedure on the anthropometric variables (especially in regard to the body weight) for the determination of anaerobic power for statistical analysis, the authors used z-scores; others have used relative values of power based on player's respective body weights.[30,32,46] Such scaling data manipulation techniques have been used in the literature for body weight relative values,[47] but it is difficult to draw results and make direct comparisons with other studies. Previous research in collegiate baseball did not find a significant relationship between power

and fielding performance.[13] However, since their methodology did not account for body mass relative changes on power, comparisons between individuals of varying size may be interpreted with caution.

Because of the longitudinal nature of the study, we examined the relationship between FM and PS during a 5-yr period. We found that significant changes were only for squat and defensive B/AVG. Spending time training on 1RMSQ seems to improve the B/AVG, and this can be useful and important advice for the SCC to practice. Hoffman et al.[12] assessed 343 professional players for 2 yr, and although authors did not examine differences across the years, they reported that lower-body power appeared to provide the greatest predictive power of baseball PS. This finding was also supported by the Hoffman et al.[28] study that found that there was a significant increase in squat strength in a 5-year period. Their study examined DIII football players, and ours studied DI baseball players. However, it highlighted the fact that strength improvements appear to occur throughout the career of the student-athletes.

Pitching and Baseball Performance Statistics

Pitching and batting performance are related to certain physical performance tests. For example, pitching can be predicted by age, BMI, standing long jump, 10-m sprint, and GS.[3] In this analysis, the authors did not include all previously mentioned variables to predict baseball performance, but they did include GS and 1RMSQ strength; these variables were the best predictors for offensive and defensive statistics. It seems that lower-body strength is important in batting performance and may be related to pitching and ball velocity, as others have shown.[3] Another study showed variability between position, but lower-body performance was one of the greatest predictors of defensive performance for all positions.[40] We found that offensive and defensive baseball performance can be predicted by 1RMSQ and GS, and there was not any statistically significant variability between positions. In more detail, the authors found that, on average, infielders were performing better than right-handed pitchers on each PS across all models tested. The GS reported values of this current research (i.e., 62.7 kg) are higher than previously reported values (i.e., 55.4 kg).[8] However, it has been stated that this difference may be caused by the type of handgrip dynamometer, for example Takei compared with Jamar.[8]

Modeling Baseball Performance Statistics

We followed a NCAA DI team for 5 yr, and using multilevel regression models that were separate for offensive and defensive statistics, we presented separate optimal estimated regression models. Based on that, we reported a range of 32% to 56% of the variance in baseball specific performance, such as AVG, OBP, SLG, (SO/IP)*9, B/AVG and ERA to be explained by squat, vertical jump and grip strength. We are not aware of any other similar longitudinal study except Hoffman et al.,[12] who followed 343 professional baseball athletes for 2 yr. Using regression analysis, it was revealed that performance measures could account for 25% to 31% of the variance in baseball-specific power performance, such as home runs, total bases, slugging percentage, and stolen bases. Anthropometric characteristics did not add any further

explanation to their model explaining the baseball-specific performance variables. From their selected performance variables, agility, speed, and lower-body power appeared to provide the greatest predictive power of baseball performance. Although this study followed a team of NCAA DI baseball players for 5 yr, and the authors selected quite similar performance measures and baseball PS, the results were in agreement with the study by Hoffman et al.[12] because anthropometric characteristics accounted for 12% to 43% of the variability on PS. On the other hand, FM accounted for 12% to 52% of the variability on PS.

Moreover, the reported parameters were standardized in order to help with interpretation and comparison within groups of PS. Because of this, the reported slope was interpreted similarly to a correlation coefficient. The FM slope estimates are essentially the average correlation between the fitness metric scores and baseball statistic scores across players. Furthermore, the SD of the average slope is quite important here, because the variability in the slope determines how consistent the interpretation of an increase in batting average is for higher squat rates across players. The SD was estimated to be 0.27 which means that the slope varies an average of 0.27 SD across players. Although the result in size of this SD was indicative that some players were estimated to have no relationship or slightly negative relationship between squats and batting average, some players were estimated to have very strong positive associations between squats and batting average. For example, if a player who had 1RMSQ (kg) of 145 kg increased his squat by 25 kg (one SD), this player would be expected to increase his batting average by 2% to 3%.

In addition, our multilevel regression model included a player-level predictor of position. The estimated parameters for difference in PS by player position was not statistically significant, indicating that player position did not contribute to substantial differences among players' PS. However, there does appear to be evidence that infielders were performing at a higher average than right-handed pitchers on each performance statistic across all models tested (see Appendix Tables A6 and A7, Supplemental Digital Content 1, http://links.lww.com/COP/A40). Otherwise, the results were not significant.

Limitations and Future Perspectives

Like any other ball-related game, expressing baseball sport performance in numbers is challenging. Nonetheless, since this study was able to elucidate correlations between the results of physical tests and performance, coaches may use physical testing more effectively. Proper technique and other factors, such as peripheral vision, in addition to physical fitness have significant effects on baseball performance.[48,49] The authors did not examine factors (i.e. aerobic capacity, running speed, upper-limb muscular power, or complex agility) other than the variables of interest. Future studies may examine the need for incorporating more physical factors and developing physical fitness tests that are specific to baseball. Moreover, since baseball players play in more than one position (e.g. catcher and outfield or outfield and infield), the potential of fitness variables to differentiate between positions and from season to season has not been investigated. Lastly, the possibility of using surveys to assess additional factors that cannot be measured using tradi-

tional testing methods must be evaluated for a more comprehensive baseball-related approach.[13]

CONCLUSIONS

Drawing from the philosophical approach of holism (i.e. the researcher tries to reflect the complex interplay of many variables) and not of reductionism (i.e. the researcher selects isolated factors), which is the most common practice,[50] the results of this study provide an alternative way of measuring athleticism in baseball. Since the impact of athleticism in baseball skill is difficult to quantify by specific testing, alternative procedures are important to emerge and capture such perspectives. For example, with baseball statistics, the authors were able to determine fielding percentage, and with FT they can determine the athleticism. What matters most is whether there is a practical way to assist coaches with using tests that are specific to the sport of baseball. For instance, SCCs may use these models to design safer and more effective individualized position training programs for collegiate baseball.

Furthermore, using the above prediction models, all other stakeholders, such as professional baseball scouts, parents, and athletes themselves, would be able to receive evaluation regarding players' potential for recruitment to play at the collegiate level by identifying strengths and weaknesses in relation to hitting, power, speed, base running, fielding, etc. The authors believe that the results of this study will be a valuable tool for those recruiting or scouting baseball players in an effort to further develop ways of early talent identification.

REFERENCES

1. Beneventano P, Berger PD, Weinberg BD. Predicting run production and run prevention in baseball: the impact of Sabermetrics. *Int J Bus Humanit Technol*. 2012; 2:67–75.
2. Bram AD, Feltz DL. Effects of batting performance feedback on motivational factors and batting performance in youth baseball. *Percept Mot Skills*. 1995; 81(3 Pt 2):1367–1378.
3. Nakata H, Nagami T, Higuchi T, *et al*. Relationship between performance variables and baseball ability in youth baseball players. *J Strength Cond Res*. 2013; 27:2887–2897.
4. Gearity B. Effective collegiate baseball strength coaching. *Strength Cond J*. 2009; 31:74–78.
5. DeRenne C, Szymanski DJ. Effects of baseball weighted implement training: a brief review. *Strength Cond J*. 2009; 31:30–37.
6. Simonson SR, Moffitt JT, Lawson J. What is the impact of NCAA Policy 11.7. 2.1. 1 Weight or Strength Coach (Football Bowl Subdivision) limits on strength and conditioning as a profession? *Strength Cond J*. 2014; 36:82–87.
7. National Collegiate Athletic Association. *NCAA Division I Manual*. Indianapolis, IN: National Collegiate Athletic Association; 2018.
8. Spaniol FJ. Baseball athletic test: a baseball-specific test battery. *Strength Cond J*. 2009; 31:26–29.
9. Ebben WP, Hintz MJ, Simenz CJ. Strength and conditioning practices of Major League Baseball strength and conditioning coaches. *J Strength Cond Res*. 2005; 19:538–546.
10. Magrini M, Dawes JJ, Spaniol FJ, *et al*. speed and agility training for baseball/softball. *Strength Cond J*. 2018; 40:68–74.
11. Basile R, Otto RM, Wygand JW. The relationship between physical and physiological performance measures and baseball performance measures: 1448Board# 211 May 30 9: 30 AM-11: 00 AM. *Med Science Sports Exerc*. 2007; 39:S214.
12. Hoffman J, Vazquez J, Pichardo N, *et al*. Anthropometric and performance comparisons in professional baseball players. *J Strength Cond Res*. 2009; 23:2173–2178.
13. Kohmura Y, Aoki K, Yoshigi H, *et al*. Development of a baseball-specific battery of tests and a testing protocol for college baseball players. *J Strength Cond Res*. 2008; 22:1051–1058.
14. Szymanski DJ, Beiser EJ, Bassett KE, *et al*. Relationships between sports performance variables and bat swing velocity of collegiate baseball players. *J Strength Cond Res*. 2011; 25:S122.
15. Carda RD, Looney MA. Differences in physical characteristics in collegiate baseball players. A descriptive position by position analysis. *J Sports Med Phys Fitness*. 1994; 34:370–376.
16. Coleman AE. Physiological characteristics of Major League Baseball players. *Phys Sportsmed*. 1982; 10:51–57.
17. Coleman AE, Lasky LM. Assessing running speed and body composition in professional baseball players. *J Strength Cond Res*. 1992; 6:207–213.
18. Gurry M, Pappas A, Michaels J, *et al*. A comprehensive preseason fitness evaluation for professional baseball players. *Phys Sportsmed*. 1985; 13:63–74.
19. Beaudoin D. Various applications to a more realistic baseball simulator. *J Quant Anal Sports*. 2013; 9:271–283.
20. Smith MR Modeling the performance of a baseball player's offensive production. 2006. All Theses and Dissertations. 362. Available at: http://scholarsarchive.byu.edu/etd/362. Accessed April 4, 2020.
21. Szymanski DJ, Szymanski JM, Schade RL, *et al*. The relation between anthropometric and physiological variables and bat velocity of high-school baseball players before and after 12 weeks of training. *J Strength Cond Res*. 2010; 24:2933–2943.
22. Papadakis Z, Stamatis A, Padgett RN, *et al*. NCAA in-season coaching time regulations negate strength and conditioning gains in women's Division-II basketball team. *Int J Sports Sci*. 2019; 9:92–99.
23. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*. Philadelphia: Lippincott Williams & Wilkins; 2018.
24. Jackson AS, Pollock ML. Practical assessment of body composition. *Phys Sportsmed*. 1985; 13:76–90.
25. Gerodimos V. Reliability of handgrip strength test in basketball players. *J Hum Kinet*. 2012; 31:25–36.
26. Slinde F, Suber C, Suber L, *et al*. Test-retest reliability of three different countermovement jumping tests. *J Strength Cond Res*. 2008; 22:640–644.
27. Hoffman J. Norms for Fitness. *Performance, and Health*. Champaign: Human Kinetics; 2006.
28. Hoffman JR, Ratamess NA, Kang J. Performance changes during a college playing career in NCAA division III football athletes. *J Strength Cond Res*. 2011; 25:2351–2357.
29. Beam WC, Adams GM. *Exercise Physiology Laboratory Manual*, 8th ed. New York, NY: McGraw-Hill; 2019.
30. Johnson DL, Bahamonde R. Power output estimate in university athletes. *J Strength Cond Res*. 1996; 10:161–166.
31. Nuzzo JL, Anning JH, Scharfenberg JM. The reliability of three devices used for measuring vertical jump height. *J Strength Cond Res*. 2011; 25:2580–2590.
32. Lara AJ, Abian J, Alegre LM, *et al*. Assessment of power output in jump tests for applicants to a sports sciences degree. *J Sports Med Phys Fitness*. 2006; 46:419–424.
33. Cox I, Gaudard M. *Discovering Partial Least Squares with JMP*. Cary: SAS Institute; 2013.
34. Team RC. *R Foundation for Statistical Computing*. Vienna, Austria: R: a language and environment for statistical computing; 2018:2013. 2014.
35. Raudenbush SW, Bryk AS Hierarchical linear models: applications and data analysis methods. Vol 1: Sage; 2002.
36. Bates D, Mächler M, Bolker B, *et al* Fitting linear mixed-effects models using lme4. arXiv preprint arXiv:1406.5823. 2014.
37. Cohen J. *Statistical power analysis for the behavioral sciences*. New York: Academic Press; 2013.

38. Watanabe Y, Yamada Y, Yoshida T, *et al*. Relationship between physical fitness at the end of preseason and the inseason game performance in Japanese female professional baseball players. *J Strength Cond Res*. 2019; 33:1580–1588.

39. Hakes JK, Sauer RD. *Effects and valuation of fielding in Major League Baseball: a play-by-play analysis*. Clemson, SC: Clemson University mimeo; 2005.

40. Mangine GT, Hoffman JR, Vazquez J, *et al*. Predictors of fielding performance in professional baseball players. *Int J Sports Physiol Perform*. 2013; 8:510–516.

41. Greenberg G Does a pitcher's height matter? Does a Pitcher's Height Matter? [The Baseball Research Journal]. 2010. Available at https://sabr.org/jounal/article/does-a-pitchers-height-matter/. Accessed December 10, 2020.

42. Coleman AE. Training the power pitcher. *Strength Cond J*. 2009; 31:48–58.

43. Spaniol F, Bonnette R, Melrose D, *et al*. Physiological predictors of bat speed and batted-ball velocity in NCAA Division I baseball players. *J Strength Cond Res*. 2006; 20:e25.

44. Fry A, Honnold D, Hudy A, *et al*. Relationships between muscular strength and batting performances in collegiate baseball athletes. *J Strength Cond Res*. 2011; 25:S19–S20.

45. Spaniol F, Melrose D, Bohling M, *et al*. Physiological characteristics of NCAA Division I baseball players. *J Strength Cond Res*. 2005; 19:e34.

46. Changela PK, Bhatt S. The correlational study of the Vertical Jump test and Wingate Cycle test as a method to assess Anaerobic Power in High School Basketball players. *Int J Sci Res*. 2012; 2:1–6.

47. Nevill AM, Bate S, Holder RL. Modeling physiological and anthropometric variables known to vary with body size and other confounding variables. *Am J Phys Anthropol*. 2005; (Suppl 41):141–153.

48. Meir R. Conditioning the visual system: a practical perspective on visual conditioning in rugby football. *Strength Cond J*. 2005; 24:86.

49. Stine CD, Arterburn MR, Stern NS. Vision and sports: a review of the literature. *J Am Optom Assoc*. 1982; 53:627.

50. Hickson M. The necessity of philosophy in the exercise sciences. *Philosophies*. 2019; 4:45.