Journal of Strength and Conditioning Research, 2004, 18(1), 115–120

Physical Characteristics That Predict Functional Performance in Division I College Football Players

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Abstract. Davis, D.S., B. Barnette, J. Kiger, J. Mirasola, and S. Young. Physical characteristics that predict functional performance in Division I college football players. *J. Strength Cond. Res. 18(1):115–120. 2004.*—Strength and conditioning professionals who work with collegiate football players focus much of their time and effort on developing programs to enhance athletic performance. Although there has been much speculation, there is little scientific evidence to suggest which combination of physical characteristics best predicts athletic performance in this population. The purpose of this investigation was to examine the relationship among 6 physical characteristics and 3 functional measures in college football players. Data were gathered on 46 NCAA Division I college football players. The 3 response variables were 36.6-m sprint, 18.3-m shuttle run, and vertical jump. The 6 regressor variables were height, weight, percentage of body fat, hamstring length, bench press, and hang clean. A stepwise multiple regression analysis was performed to screen for variables that predict physical performance. Regression analysis revealed clear prediction models for the 36.6-m sprint and 18.3-m shuttle run. The results of this investigation will help strength and conditioning specialists better understand the variables that predict athletic performance in Division I college football players.

Key Words. functional tests, athletic performance, vertical jump, regression analysis, sprint

Introduction

Most National Collegiate Athletic Association (NCAA) Division I collegiate football programs place great importance on controlling player body weight, body composition, and increasing muscular strength and length (10, 21). They also devote considerable time to the measurement of athletic performance through functional testing of sprinting speed, agility, and vertical jump height (10, 21). Despite the emphasis placed on enhancing these physical characteristics and functional measures, only a few studies have attempted to investigate the relationship among physical characteristics and functional measures of athletic performance in Division I college football players (10, 21).

Activities that are commonly considered to be functional measures of athletic performance in college football players include the 36.6-m sprint, vertical jump, and 18.3-m shuttle run (5, 10, 21, 30). Performance on these functional tests has been shown to be correlated with playing ability (starter vs. nonstarter) and level of play (Division I, II, and III) in college football players (5, 10). As a result, prospective college and professional football players are commonly ranked by their performance on these functional tests (5, 10, 21).

Despite the great emphasis placed on strengthening in the athletic population, there is a lack of scientific evidence supporting a strong positive relationship between muscular force production and functional measures of athletic performance (1–4, 7, 9–11, 13, 24–26, 28, 29). Greenberger and Paterno (13) reported a modest correlation between quadriceps force, measured isokinetically at 240° per second, and a 1-legged hop test for distance. They reported correlation coefficients of 0.78 and 0.65 for the dominant and nondominant legs, respectively. Alexander (1) reported that a significant correlation existed between 100-m sprint times and the peak torque of the concentrically contracting knee extensors and the eccentrically contracting ankle plantar flexors in men. Anderson et al. (2) examined the relationships between isometric, isotonic, and isokinetic quadriceps and hamstring strength and 3 measures of athletic performance, measured by 36.6-m sprint time, vertical jump, and agility run time. They concluded that the best predictor of the 36.6-m sprint time was the right peak isokinetic concentric hamstring force at 60° per second; however, the coefficient of determination ($R^2 = 0.57$) was found to be low, suggesting that only 57% of the variability of 36.6-m sprint time is explained by hamstring force. The best predictor of agility run time was the left mean isokinetic eccentric hamstring force at 90° per second; again the coefficient of determination ($R^2 = 0.58$) was found to be low. Quadriceps and hamstring force did not correlate with vertical jump performance (2).

Several investigations have examined the relationship between muscle force and vertical jump height (2–4, 7, 9, 11, 12, 14, 16, 26, 29). Positive correlation between muscle force production and vertical jump height has been reported by several investigations (4, 7, 14, 16), whereas others have reported little or no relationship between lower-extremity muscular force production and vertical jump performance (3, 9, 29). The interaction of muscle force production and body weight seems to be the important variable when predicting vertical jump performance. Young and Bilby (28) found a positive correlation between muscle force production and vertical jump but only when maximum force was expressed relative to body weight. Blackburn and Morrissey (7) identified a difference in the relationship of open vs. closed kinetic chain force output and vertical jump performance. They concluded that closed kinetic chain force output of the knee extensors was positively correlated ($r = 0.72$) with vertical jump height, but open kinetic chain knee extension was not correlated ($r = 0.09$) with vertical jump performance (7). Dowling and Vamos (9) reported that the maximum peak jump force explained only 30% of the variability of vertical jump performance.

In addition to muscle force output, muscle length has long been thought to affect functional performance. However, only one study was found that examined the relationship between lower-extremity muscle flexibility and a functional measure of athletic performance (19). Lee and colleagues (19) examined the role of hip flexion range of motion in the prediction of vertical jump ability in male and female volleyball players. They reported that hip flexion range of motion was positively correlated with vertical jump ability in men; however, it was negatively correlated in women. In contrast, short-term muscle stretching has been shown to result in a decrease in vertical jump performance (8, 18). To date, no studies have examined the relationship between lower-extremity muscular flexibility and 36.6-m sprint and 18.3-m shuttle run time. Clearly, further research is needed to determine if lower-extremity muscle length influences functional performance.

In addition to muscle strength and length, anthropometric variables, such as body composition, height, and weight, have been thought to influence functional performance. Several studies have examined the relationship between anthropometric measures and functional tests of athletic performance. McLeod et al. (20) examined the relationship between body composition and vertical jump ability in high school athletes. They found that vertical jump height decreased sharply as percentage of body fat increased above 10% in men and 19% in women. Additionally, they found that vertical jump height showed a positive correlation with percentage of body fat up to 10% in men (20).

Misner et al. (22) examined body weight in relationship to vertical jump performance in female firefighter applicants. He concluded that body weight was not significantly correlated with vertical jump ability. Miller and colleagues examined the relationship between body weight, body composition, and player position and several response variables, including vertical jump, 36.6-m sprint, and 18.3-m shuttle run, in NCAA Division I football players. They found that percentage of body fat was inversely related to vertical jump performance. They also found that body composition was negatively correlated with 36.6-m sprint and 18.3-m shuttle run but only among linemen (21). Aragon-Vargas and Gross (3) examined the relationship between body weight and vertical jump performance in male college students. They found that body weight was negatively correlated with vertical jump performance. The authors were unable to find any studies that examined the relationship between player height and functional measures of athletic performance.

The importance of functional performance measures is tied to the idea that sprint time, shuttle run time, and vertical jump ability translate into on-the-field performance in college football players. Fry and Kraemer (10) examined the physical performance characteristics of college football players in all 3 NCAA divisions. They examined the correlation between 5 measures of physical performance and player position, playing ability, and caliber of play. Playing ability was categorized as starter vs. nonstarter, and caliber of play was categorized as Division I, II, and III. The 5 measures of physical performance included vertical jump, 36.6-m sprint, and 1 repetition maximum (1RM) strength testing for bench press, back squat, and power clean. Fry and Kraemer (10) concluded that power clean, bench press, 36.6-m sprint, and vertical jump were good discriminators between division of play and playing ability. Back squat was found to be a poor discriminator of playing ability and caliber of play. In addition to demonstrating the importance of functional performance measures in college football players, their investigation provided normative data for college football players by position, caliber of play, and playing ability (10).

Previous research in this area has advanced the knowledge of strength and conditioning; however, such research has failed to examine the relationship of multiple physical and anthropometric characteristics on measures of functional performance. The purpose of this study was to determine if height, weight, percentage of body fat, bench press, hang clean, and hamstring length are able to predict 36.6-m sprint time, 18.3-m shuttle run time, and vertical jump height in Division I college football players.

Methods

Experimental Approach to the Problem

To determine the predictive ability of anthropometric and physical characteristics on functional performance in college football players, data from 46 NCAA Division I college football players were retrospectively analyzed with multiple regression analysis. With cooperation from the West Virginia University athletic department and coaches, data from the 1999 summer conditioning session were obtained for analysis. Available data included player height, body weight, percentage of body fat, hamstring length, 36.6-m sprint time, 18.3-m shuttle run time, vertical jump height, and 1RM values for hang clean and bench press. Therefore, 3 dependent variables were identified: vertical jump, 36.6-m sprint, and 18.3-m shuttle run. The independent variables that were examined were height, weight, percentage of body fat, hamstring length, and the 2 strength measures. Before obtaining the data, the investigation was approved by the West Virginia University Institutional Review Board for Human Subjects.

Procedure

Height, weight, percentage of body fat, bench press, hang clean, hamstring length, 36.6-m sprint, 18.3-m shuttle run, and vertical jump were recorded for 46 college football players by the team's strength and conditioning coaches.

Subject height was measured in centimeters with a vertical wall ruler. Weight was measured in kilograms using a Toledo electric scale (Toledo Co., Toledo, OH). The scale was calibrated before data collection. Percentage of body fat was calculated using 3 sites (chest, quadriceps, and abdomen) and a Skindex System I caliper (Caldwell, Justiss and Co., Inc., Fayetteville, AR). The Jackson-Pollock formula was used to obtain an overall percentage of body fat value (15).

Bench press and hang clean values (Figure 1) were determined from a submaximal effort of 4–6 repetitions.

FIGURE 1. Hang clean lift.

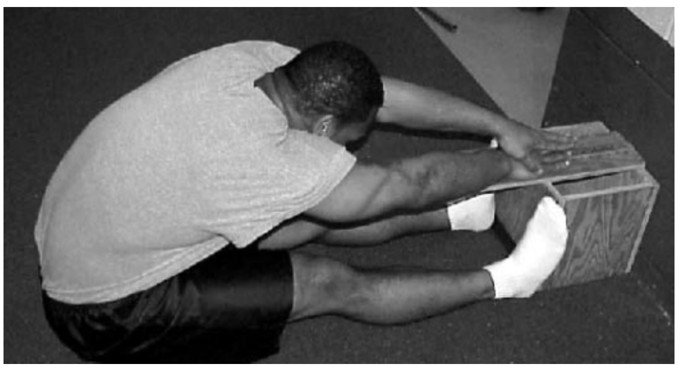

FIGURE 2. Sit and reach test for hamstring length.

The 3% rule was applied to the 4–6 repetition submaximal effort to calculate a theoretical 1RM.

Hamstring length was measured using a sit and reach test with the subject sitting on the floor with knees extended, feet together, and the plantar surface of the feet in contact with a vertical footplate (Figure 2). A horizontal ruler was attached to the footplate. The subjects were instructed to reach for their toes. Reaching their fingertips to the toes warranted a score of zero. If the subject could not reach the toes, a negative value was assigned corresponding to the distance between the fingertips and the toes. If the subject could reach farther than the toes, then a positive value was assigned corresponding to the distance between the fingertips and toes.

Functional tests included 36.6-m sprint, 18.3-m shuttle run, and vertical jump. Sprint times were measured by having the subject stand in a 3-point stance at the start of an artificial turf track. The examiner stood 36.6 m away from the subject with a handheld stopwatch. The subject's first movement from the 3-point stance triggered the examiner to start the clock. The moment any part of the player's body crossed the 36.6-m mark, the examiner stopped the clock, and the time was recorded. The subject performed the 36.6-m sprint 15 times during a 5-week period. Each subject completed 3 timed trials on the same

FIGURE 3. The 18.3-m shuttle run.

day of each week. The fastest and slowest times were eliminated, and the remaining 13 times were averaged.

To measure vertical jump, the subject's vertical reach was first established by having the subject stand facing a wall ruler. Each subject was instructed to extend both upper extremities as high as possible along the wall ruler, while the heels remained in contact with the floor. Standing reach was recorded at the subject's fingertips. The subject then stood with both feet comfortably together and, after a countermovement, jumped as high as possible. A measuring device known as the Vertec (Sports Imports, Columbus, OH) was used to gauge peak jump height (Figure 3). The test was repeated 2 more times. Vertical reach was subtracted from the best jump height, and the difference was used to represent vertical jump performance.

Shuttle run times were obtained by having the subject start in the middle of an 18.3-m marked area (Figure 4). The examiner faced the subject and started the clock once the subject initiated movement either to the right or left. The subject was required to touch the end line with the hand corresponding to the direction in which the initial movement occurred. After the subject touched the end line with the corresponding hand, the direction quickly changed as the subject was instructed to touch the other end line. The subject again changed direction for a final time before running to the start-finish line. This was performed 3 times, and the 2 best times were averaged and recorded.

Statistical Analyses

Data were analyzed using the JMP 4.04 statistical software package (JMP Software, Cary, NC). Means, ranges, and *SE*s were calculated for each variable. Variable screening was performed using stepwise multiple regression analysis for each of the 3 response variables, 36.6-m sprint, 18.3-m shuttle run, and vertical jump. For each response variable, 3 methods of variable selection were performed: forward selection, backward elimination, and mixed. In addition to using a variable screening approach, all 63 possible candidate models were compared using R^2, adjusted R^2, mean square error (MSE), Mallow's Cp, and PRESS statistic to determine the best model.

The candidate models were then subjected to tests for

FIGURE 4. Vertical jump test.

multicollinearity. The variance inflation factor, eigenvalues, and condition numbers were used to eliminate regressor variables, which were found to suffer from collinearity. The final candidate models were then subjected to model diagnostics, which screen for outliers and high-influence points. Model assumptions for multiple regression analysis were also evaluated. A Shapiro-Wilk test for normality supported the assumption of a normal distribution. Residuals were plotted against predicted values to ensure that a linear model was a good fit of the data. The prediction capability of each final model was validated using R^2_{Pred} as suggested by Myers (23).

RESULTS

Means, ranges, and *SE*s for each variable are listed in Table 1. The best model for each of the 3 response variables is listed with the respective R^2, MSE, Cp, PRESS statistic, and R^2_{Pred} in Table 2. With 36.6-m sprint as the response variable, a significant relationship was found to exist among 3 of the 6 variables (Table 3). Hang clean and bench press were negatively correlated with 36.6-m sprint times, whereas body weight was positively correlated. This suggests that as body weight increases, the sprint time increases, and as muscle force output increases, the sprint time decreases. The coefficient of determination (R^2) for this model was 0.85, suggesting that the model explains 85% of the variability of 36.6-m sprint time in college football players. The validity of the model, which determines the true ability of the chosen model to predict 36.6-m sprint time, was found to be 0.80 using R^2_{Pred} as the validation statistic.

With 18.3-m shuttle run as the response variable, 4 of the 6 variables were included in the model (Table 4). Body weight was positively correlated with shuttle run time, whereas bench press, sit and reach, and hang clean were negatively correlated. This indicates that as body weight increases, shuttle run time increases, and as muscle force output and muscle length increase, shuttle run time decreases. The coefficient of determination (R^2) was again found to be large at 0.81. The validity of the model as a predictor of shuttle run time was found to be $R^2_{Pred} = 0.73$. With vertical jump as the response variable, none of the 6 variables were found to be predictive.

Table 2. Selection criteria for each chosen regression model.*

	R^2	MSE	Cp	PRESS	R^2_{Pred}
18.3-m shuttle	0.81	0.0163	5.0	0.955	0.80
36.6-m sprint	0.85	0.018	4.0	0.935	0.73
Vertical jump	0.0000	—	—	—	—

* MSE = mean square error.

Table 3. Best model 36.6-m sprint.

	β-coefficients	*F* test	*p* value
Intercept	3.8		
Body weight	0.018	205.41	<0.0001
Bench press	−0.003	4.87	0.0329
Hang clean	−0.003	6.46	0.0148

Table 4. Best model 18.3-m shuttle run.

	β-coefficients	*F* test	*p* value
Intercept	4.006		
Body weight	0.0148	162.22	<0.0001
Bench press	−0.0046	16.66	0.0002
Sit and reach	−0.592	4.02	0.050
Hang clean	−0.0038	10.82	0.0019

DISCUSSION

Based on the review of existing literature, the authors were unable to find any studies that have attempted to

Table 1. Means, ranges, and *SEM*s for each variable.

	Height (m)	Body weight (kg)	Bench press (kg)	Sit and reach (m)	Hang clean (kg)	Percentage of body fat	36.6-m sprint (s)	Vertical jump (m)	18.3-m shuttle (s)
Mean (± *SD*)	1.87	103.58	171.35	0.116	131.93	10.91	4.72	.739	4.17
Range	1.68	73.2	111.4	−0.025	81.8	5.0	4.18	0.508	3.75
	1.98	150.9	238.6	0.267	188.6	20.7	5.66	1.00	4.81
SEM	0.01	3.17	3.89	0.010	3.67	0.60	0.05	0.017	0.04

investigate the relationship between this set of physical characteristics and functional measures of athletic performance in Division I college football players. For years, these variables have been used with minimal scientific evidence to support their contribution to predicting a player's functional ability. By determining the relationship between physical characteristics and measures of functional performance, one may be able to better predict which athletes will perform better in a given functional activity and which variables should be addressed in a rehabilitation or strength and conditioning program. Previous investigations have shown that functional measures of athletic performance, such as 36.6-m sprint and vertical jump, are valid predictors of on-the-field performance in college football players (5, 6, 10). There have been no investigations that have examined 18.3-m shuttle run to determine if it is a valid predictor of athletic performance in Division I college football players. This study suggests that bench press, hang clean, body weight, and hamstring length when used together are good predictors of speed and agility in Division I college football players. Of the 4 significant regressor variables, body weight demonstrated the strongest relationship to both 36.6-m sprint and 18.3-m shuttle run time. Intuitively, this was expected, since the heavier athlete would require more force to generate movement. This was most evident in the 18.3-m shuttle run, which requires 3 acceleration-deceleration movements.

Hang clean was found to be a good predictor of both the 36.6-m sprint and 18.3-m shuttle run. Since hang clean requires tremendous power output, it was not surprising to the authors that it had a strong relationship to 18.3-m shuttle run. This may be related to the rapid acceleration and deceleration that is required in both hang clean and 18.3-m shuttle run.

As with hang clean, bench press also showed a significant relationship to both 36.6-m sprint and 18.3-m shuttle run. It is not fully understood why such a relationship exists; however, it is hypothesized that it may be due to an increased ability to perform arm swing and aid in both direction change and force generation, which are required in the 18.3-m shuttle run.

The sit and reach test was negatively correlated to 18.3-m shuttle run. This suggests that as hamstring length increased, shuttle run time decreased. Although the sit and reach test was intended by the strength and conditioning coaches to be an indicator of hamstring flexibility, Kendall et al. (17) describe other factors that could influence the validity of the findings. Such factors include increased spinal flexion, altered length of the trunk musculature, and the relative length of the extremities and torso.

Interestingly, none of the regressor variables were found to be predictors of vertical jump. Intuitively, one might expect a strong positive relationship to exist between hang clean and vertical jump, since both activities require a similar explosive contraction of the back and lower-extremity extensors. However, the results of this investigation support the findings of Misner et al. (22), who concluded that leg press strength and mean peak muscle power did not correlate with vertical jump performance.

The results of this investigation are not consistent with the findings of the Miller et al. investigation. Miller and colleagues (21) found that body composition was a significant predictor of vertical jump performance, but the results of this investigation do not support their findings. Although body composition was initially found to be significantly related to 36.6-m sprint and 18.3-m shuttle run, it was found to suffer from severe collinearity with the remaining variables and was thus eliminated from our model. This may help to explain why body composition was not found to be a significant predictor of running speed and agility in players other than linemen in the Miller et al. investigation (21).

It is also important to examine the values for each parameter compared with normative data that have been collected at the high school and collegiate levels. When comparing the means and *SD*s of this investigation with the findings of Williford and colleagues (27), who identified normative values for elite high school football players, it is clear that there is a difference between high school and Division I college football players. When comparing vertical jump, 36.6-m sprint, height, weight, percentage of body fat, and bench press, the largest relative difference between the high school and the Division I college level was found to be percentage of body fat and vertical jump performance. The average player's body fat in this investigation was 2% lower than in elite high school players. The difference was even greater when comparing vertical jump performance. The mean was 17.1 cm greater for the Division I players reported in this investigation (27).

When comparing the findings of this investigation with those published by Fry and Kraemer (10), who identified normative values for all 3 NCAA college football divisions, we found that the mean values for this investigation were similar to the means they reported for Division I players. This comparison provides perspective to the level of performance of the players in this investigation compared with the average NCAA Division I player.

Since the data were collected retrospectively, the authors were limited to the variables that were measured. A prospective study is recommended to control the method of data collection, to control examiner reliability, and to consider other regressor variables that might help predict athletic performance in college football players. These may include quadriceps and hamstring torque and power, functional leg squat, subject age, and better measures of muscle length, including the quadriceps and hip flexors. In addition, the use of an electronic timing device in calculating 36.6-m sprint time is recommended to help decrease measurement error. As mentioned earlier, the authors have questioned the validity of the sit and reach test as purely a measure of hamstring length. Therefore, the authors recommend hamstring length be tested in the supine position as described by Kendall et al. (17).

PRACTICAL APPLICATIONS

The results of this investigation provide 2 valid prediction models that can be used to help NCAA Division I college football coaches better predict athletic performance. This investigation found a strong relationship between bench press, hang clean, and body weight with 2 of the 3 functional tests, 36.6-m sprint and 18.3-m shuttle run in Division I college football players. This study supports the long-standing contention that stronger and lighter athletes can run and cut faster than their weaker and heavier counterparts. The same assumption that stronger and lighter football players can jump higher is not supported by this investigation. This study offers strength and conditioning coaches in Division I college football programs a better understanding of which variables are key predictors of sprinting and cutting speed in this population. It also provides evidence that suggests height and body composition may not be as important as traditionally thought.

Although it is beyond the scope of this investigation to conclude that a training program aimed at improving bench press and hang clean strength and reducing weight will result in improved speed and agility, it would certainly suggest variables that should be considered for manipulation in a prospective training study. Since coaches value running speed and agility in Division I college football players, it would stand to reason that they should consider bench press and hang clean strength and body weight when making player selection.

It is important that theories of training and conditioning be carefully examined using the scientific method to substantiate or refute long-standing beliefs held by athletes, coaches, and professionals involved in strength and conditioning. Further research is needed to determine which additional variables should be included in the prediction models for 36.6-m sprint, 18.3-m shuttle run, and specifically vertical jump in this population.

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Acknowledgments

We thank coach Don Nehlen, Allen Johnson, Bernardo Amerson, and the West Virginia University strength and conditioning staff for their support of this project and their never-ending pursuit of athletic performance. We would also like to thank West Virginia University's athletic department for authorizing the release of information for research purposes. This study was approved by West Virginia University Institution Review Board for the Protection of Human Research Subjects.

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