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Independent Contributions of Upper Extremity Variables in Free Throw Shooting Accuracy from Multiple Positions: A Pilot Study in College Basketball Players

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Abstract

Physical factors play an important role in basketball free throw shooting success. This study aims to analyze the factors associated with success when shooting from different positions. Twenty-four college basketball players were assessed for upper extremity length, muscle strength, vertical jump height and reaction time, and hand reaction time. Five shooting positions (A–E) were located 4.54 m from the basket at angles of 45° around a semicircle. Shooting success was recorded as a percentage. The relationships between variables were analyzed with Pearson correlation analysis, and multiple linear regression analysis was performed to determine the contributions of the assessed physical factors to shooting success. The following factors contributed to the success rate: hand length, left palmar grip strength and left hand reaction time from A; left palmar grip strength, left shoulder extensor strength and vertical jump reaction time from B; left elbow extensor strength and left hand reaction time from C; right wrist extensor strength, body mass index, left shoulder external rotator strength, and left hand reaction time from D; and forearm length, left elbow extensor strength, and left wrist extensor strength from E position. Left elbow extensor strength, left hand reaction time, and vertical jump reaction time contributed to the total free throw success rate. These results of this pilot study demonstrated the important relationships between upper extremity extensor strength, grip strength, vertical jump reaction time, hand reaction time, and free throw success.

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INTRODUCTION

Free throw shooting (FTS) can be an essential element in winning a basketball match. A higher free throw percentage (FTP) and FTS success contribute to higher scores (Ángel Gómez et al., 2008).

Studies have confirmed that several physiological and environmental factors are associated

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with FTS performance and that performance declines in high-pressure conditions, including distraction by the audience, financial problems (Woolstenhulme et al., 2004), a high sound level, crowd noise and a lack of motivation (McGowan, 1987). The success of a free throw requires a perfect combination of a set of launching parameters - in particular, the height of the ball center from the ground at ball release and the velocity vector at ball release (Covaci et al., 2015). However, as yet there has been only limited analysis of the effects of physical factors on shooting success.

It has been shown that joint movements and compensatory variation of the shooting arm are associated with success in basketball free throw shots (Schmidt, 2012), and that muscle activation timing and mechanical efficiency are important indexes of skill (Fukushima et al., 2008). Most related studies have been limited to analyzing the factors contributing to FTP from the foul line. Throwing hand during an overarm or underarm throwing task plays important role in basketball. Relationship between reaction time and shot success has not been investigated previously in basketball players. Hand reaction time or vertical jump reaction time may affect free throw shooting skills in a basketball game. However, it is likely that athletes require different levels of the various physical qualities when shooting from different positions during a basketball game, and so analyzing physical parameters during shots taken from one position may not accurately represent shooting from other positions. This is the first study, which investigates the free throw success from different points of free-throw line. Therefore, our pilot study therefore aims to analyze the factors associated with shooting percentage from a range of different positions and to determine the contribution to FTP of various physical factors.

MATERIALS and METHODS

Subjects and recruitment

Twenty-four right-handed male college basketball players volunteered to participate in the study. All had played competitive organized basketball for at least three years. Players with a systemic disease, neurological problem, upper extremity inequality, or a history of upper extremity disorders were excluded. The mean age of the subjects was 21.8 ± 1.9 (range, 19–25) years. The players were informed about the procedures and provided written consent before study initiation. The principles outlined in the Declaration of Helsinki were followed in this study.

Procedures

Prior to assessment, demographic data was recorded for each player, including age, height, body weight, a detailed medical history, basketball playing time (years), and training time (hours per day). Assessments included upper extremity length measurements, hand and upper extremity muscle strength tests, a vertical jump test including height and reaction time, and a Nelson hand reaction test. These tests were administered in a random order, after the subject had warmed up for 5 minutes on an exercise cycle at a self-selected intensity. All subjects wore low-cut athletic court shoes. Each subject’s FTS performance from five shooting positions was recorded.

The experimental procedures for measuring each variable were as follows:

Upper extremity length. The vertical lengths of the dominant side upper extremity were measured with a universal tape, including the longest finger, hand, forearm, arm, and total upper extremity. The values were recorded in centimeters (Srivastava & Sahai, 2010).

Muscle strength. Three tests of hand strength (handgrip, palmar pinch, and tip pinch) were performed bilaterally with a hand dynamometer® (Jamar hydraulic hand dynamometer, Lafayette, LA, USA), following standardized positioning and instructions (Mathiowetz et al., 1984). A digital muscle dynamometer® (J-Tech Commander Power Track Dynamometer, USA) was used to measure the strength of flexor and extensor muscles of the hand, elbow, and shoulder, as well as shoulder internal and external rotator muscle strengths. Each muscle group was tested three times bilaterally by the same physiotherapist and a mean composite score calculated for each (Dollings et al., 2012).

Nelson hand reaction test. Reaction time, an indicator of motor quality, is defined as the elapsed time between muscular action and reaction (Ando et al., 2002). The subject sat on a chair with the forearm and hand resting on a table. The thumb and index finger tips were raised 8–10 cm above the table with the upper side of the thumb and index finger parallel to each other. The test supervisor held a scale with the lower end positioned between the thumb and index finger of the subject. The subject was asked to look directly at the central point of the scale and to catch the scale between thumb and finger when it was released. After the subject caught the scale, the figure level with the top edge of the thumb was read and recorded. This process was repeated 20 times in total and the best and worst five results were excluded (JK., 1979).

Vertical jump height. The subject was requested to stand in front of a wall and the maximum height he could reach was marked. The subject then jumped using both legs and touched the wall as high as possible. The distance between the first and second touch points was measured with a tape (Bosco et al., 1983). The score was recorded as the mean of three jumps.

Vertical jump reaction time. The subject was requested to stand in an erect position and then to jump as quickly as possible when the supervisor clapped. The supervisor recorded the time between the clap and the initiation of the jump, and the mean of three tests was recorded (Markovic et al., 2004).

Free-throw percentage. Participants performed ten free throw shots at a regular basket (height 3.04 m from the ground) with an official game ball from five predetermined positions. The shooting positions (A–E) were located in a predetermined angular relationship across of 4.54 m from the basket at the angles of 45 degrees from left to right relative to the basket (Figure 1). The score was calculated as the number of successful throws as a percentage of the number of free throws attempted. Total FTP was calculated as the mean FTP from these five positions (Englert et al., 2015).

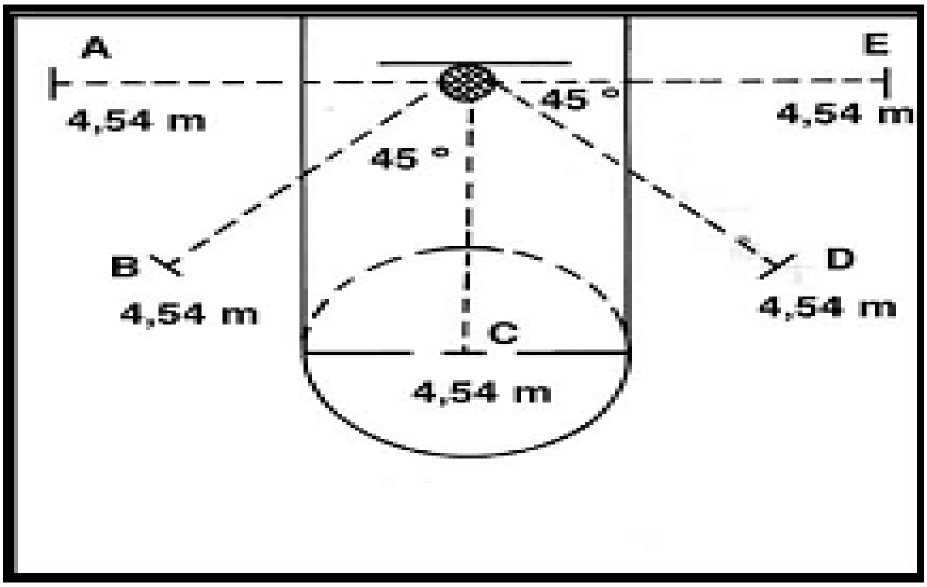

Figure 1: Shooting positions; A, B, C, D, E, were located at an angle of 45^0 to each other with a distance of 4.54 m from the basket

STATISTICAL ANALYSIS

Statistical analysis was performed using Statistical Package for Social Sciences (SPSS) for Windows version 15.0 (SPSS Inc.). Descriptive statistics calculated included frequency distributions, percentages, and means and standard deviations (mean ± SD), and the relationships between variables was analyzed using Pearson's correlation coefficients. A stepwise multiple linear regression analysis was performed in order to determine the contribution of independent variables to FTP. And the statistically significant contributions were expressed as percentage. The variables with a statistically significant univariate association with FTP (*p*<.05) were the independent variables entered into the analysis (shoulder, elbow, and hand muscle strengths, upper extremity length measurements, hand reaction time, vertical jump distance, and vertical jump reaction time).

RESULTS

Table 1: Baseline characteristics and mean values (±SD) of selected variables of the basketball players

Variable	Players (n=24) Mean ± SD	
Age (years)	21.83 ± 1.99	
Body height (cm)	181.63 ± 5.17	
Body mass (kg)	77.04 ± 7.45	
Body mass index (kg/m2)	23.39 ± 2.54	
Basketball history (years)	8.71 ± 3.98	
Training time per day (hours)	1.92 ± 0.72	
Vertical Length measurements (cm)		
Longest finger	8.90 ± 0.55	
Hand	29.17 ± 1.49	
Forearm	45.46 ± 3.08	
Arm	78.71 ± 4.83	
Total upper extremity	162.23 ± 8.72	
Vertical jump test		
Distance (cm)	49.15 ± 7.46	
Reaction time (s)	1.82 ± 2.57	
Free throw percentage (%)		
From A position	30.83 ± 24.30	
From B position	36.67 ± 20.99	
From C position	56.25 ± 23.18	
From D position	34.58 ± 12.85	
From E position	35.42 ± 21.67	
Total	38.67 ± 15.07	
	Right Side	**Left Side**
Muscle strength tests	**Mean ± SD**	**Mean ± SD**
Hand grip	37.83 ± 8.50	35.55 ± 7.68
Palmar grip	6.13 ± 1.35	5.43 ± 1.52
Pinch grip	3.47 ± 2.13	2.95 ± 1.67
Wrist flexor	155.79 ± 50.84	145.29 ± 40.24
Wrist extensor	171.67 ± 32.87	173.87 ± 40.69
Elbow flexor	294.67 ± 53.66	269.38 ± 50.11
Elbow extensor	226.63 ± 35.85	214.79 ± 29.99
Shoulder flexor	246.96 ± 38.94	238.63 ± 44.01
Shoulder extensor	219.75 ± 38.40	228.46 ± 34.47
Shoulder internal rotator	223.29 ± 50.66	221.96 ± 41.41
Shoulder external rotator	156.54 ± 42.39	147.08 ± 23.20
Hand reaction time (s)	8.87 ± 2.11	8.38 ± 2.31

SD, standard deviation

Table 1 shows the results of the assessments of the subjects.

Table 2: Pearson correlation coefficients (r) of the baseline characteristics and extremity length variables with free throw percentage from A, B, C, D, and E points and total free throw percentage

Variable	Age	Height	Body mass	BMI	Basketball history	Training time	Finger length	Hand length	Forearm length	Arm length	UE length
Position A	0.272	0.051	0.115	0.066	0.362	-0.195	0.396	0.439*	0.064	0.150	0.206
Position B	0.236	0.080	-0.280	-0.317	0.555*	0.096	-0.088	0.143	-0.090	-0.259	-0.156
Position C	0.306	0.097	0.145	0.085	0.369	-0.412*	0.155	0.207	0.275	0.056	0.173
Position D	-0.224	0.681**	-0.070	-0.464*	0.163	0.185	0.285	0.332	0.439*	0.261	0.375
Position E	0.143	0.170	-0.185	-0.282	0.241	-0.054	0.377	0.307	0.444*	0.361	0.433*
Tot. FTP	0.247	0.241	-0.052	-0.196	0.483*	-0.156	0.318	0.400	0.291	0.146	0.273

Tot. FTP, total free throw percentage; UE, upper extremity; tot. FTP; * p<0.05; ** p<0.001

Table 3: Pearson correlation coefficient (r) of the hand and wrist muscle strength test variables with free throw percentage from A, B, C, D, and E positions and total free throw percentage

Variable	Hand grip(R)	Hand grip(L)	Palmar grip(R)	Palmar grip(L)	Pinch grip(R)	Pinch grip(L)	Wrist flex(R)	Wrist flex(L)	Wrist ext (R)	Wrist ext (L)
Position A	0.165	0.033	-0.133	-0.425*	-0.100	-0.125	-0.045	-0.227	-0.044	-0.061
Position B	-0.105	-0.196	-0.385	-0.417*	-0.238	-0.189	-0.170	0.112	0.223	-0.047
Position C	0.194	0.162	0.132	0.180	0.238	-0.465*	0.136	0.263	0.253	0.203
Position D	0.421*	0.351	0.275	0.155	0.033	0.152	0.255	0.266	0.690**	0.409*
Position E	0.011	-0.201	-0.340	-0.356	0.252	0.101	-0.202	-0.091	-0.123	-0.573*
Tot. FTP	0.160	0.008	-0.154	-0.270	0.055	0.107	-0.031	0.057	0.240	-0.061

Tot. FTP, total free throw percentage; flex, flexion; ext, extension; R, right; L, left; * p<0.05; ** p<0.001

Table 4: Pearson correlation coefficient (r) of the elbow and shoulder muscle strength tests variables with free throw percentage from A, B, C, D, and E positions and total free throw percentage

Variable	Elbow flex(R)	Elbow flex(L)	Elbow ext(R)	Elbow ext(L)	Shoul. flex(R)	Shoul. flex(L)	Shoul. ext(R)	Shoul. ext(L)	Shoul. IR(R)	Shoul. IR(L)	Shoul. ER(R)	Shoul. ER(L)
Position A	0.288	0.335	-0.138	-0.186	0.294	0.413*	0.197	0.414*	-0.031	0.004	-0.044	-0.215
Position B	-0.209	0.024	-0.210	-0.110	-0.140	0.253	-0.207	0.564*	-0.059	0.138	0.037	0.140
Position C	-0.044	-0.129	-0.399	-0.752**	-0.115	0.052	-0.004	0.351	-0.178	-0.234	-0.557*	-0.201
Position D	0.026	0.410	0.092	0.084	0.300	0.396	-0.065	0.649**	0.349	0.343	0.001	0.483*
Position E	0.172	0.204	-0.306	-0.526*	-0.110	-0.133	-0.215	-0.080	-0.282	-0.348	-0.469*	-0.099
Tot. FTP	0.073	0.200	-0.298	-0.457*	0.045	0.253	-0.058	0.483*	-0.108	-0.081	-0.308	-0.041

Tot. FTP, total free throw percentage; shoul, shoulder; flex, flexion; ext, extension; R, right; L, left; IR, internal rotation; ER, external rotation; * p<0.05; ** p<0.001

Table 5: Pearson correlation coefficient (r) of the vertical jump distance, vertical jump reaction time and hand reaction time variables with free throw percentage from A, B, C, D, and E positions and total free throw percentage

Variable	Vertical jump Distance	Vertical jump RT	Hand RT (R)	Hand RT (L)
Position A	0.053	-0.280	-0.427*	-0.647**
Position B	0.117	-0.629**	0.016	-0.360
Position C	-0.167	-0.340	-0.204	-0.418*
Position D	0.264	-0.334	-0.332	-0.538*
Position E	-0.163	-0.473*	-0.232	0.157
Total FTP	-0.007	-0.561*	-0.332	-0.485

FTP, free throw percentage; RT, reaction time; R, right; L, left; * $p<0.05$; ** $p<0.001$

The Pearson's correlation analysis showed the following statistically significant correlations between the FTP for a given position and the assessed characteristics of the subjects (Tables 2–5): position A with hand length, left palmar grip strength, left shoulder flexor and extensor strength, and left and right hand reaction time; position B with playing time, left palmar grip strength, left shoulder extensor strength, and vertical jump reaction time; position C had with training time, left pinch grip strength, left elbow extensor strength, right shoulder external rotator strength, and left hand reaction time; position D with body height, body mass index, forearm length, total upper extremity length, right gross grip strength, right and left wrist extensor strength, left shoulder extensor and external rotator strength, and left hand reaction time; and position E with forearm length, total upper extremity length, left wrist extensor strength, left elbow extensor strength, right shoulder external rotator strength, and vertical jump reaction time. Total FTP correlated significantly with playing time, left elbow and shoulder extensor strength, vertical jump reaction time, and left hand reaction time.

The stepwise multiple regression analysis revealed the following significant predictors of FTP from each shot position (with the percentage): position A, hand length (80%), left palmar grip strength (74%), and left hand reaction time (41%); position B, left palmar grip strength (79%), left shoulder extensor strength (66%), and vertical jump reaction time (39%); position C, left hand reaction time (80%) and left elbow extensor strength (56%); position D, body mass index (63%), right wrist extensor strength (47%), left shoulder external rotator strength (85%), and left hand reaction time (79%); and position E, forearm length (75%), left elbow extensor strength (83%), and left wrist extensor strength. The significant independent predictors of total FTP were left elbow extensor strength (86%), left hand reaction time (72%), and vertical jump reaction time (31%).

DISCUSSION

Successful free throws can have a significant impact on a team's success (Gimenez & Janeira, 2003), accounting for 20%–25% of all points scored in a game and two-thirds of points scored by winning teams in the final minute (Kozar et al., 1994). In this pilot study, we analyzed the factors associated with shooting percentage from five different positions. Our results showed that, in general, upper extremity extensor muscle strength, grip strength, hand reaction time, and vertical jump reaction time contributed to free throw shooting success.

Free throw shooting ability is an important skill for basketball players (Hamilton & Reinschmidt, 1997) and can be a decisive factor in winning a game; 80% of games are won by the team with the higher FTP (Guerrero, 2007). Thus, specific training programs for improving shooting skill are important for improving game performance. Such programs require further analysis of the factors that affect shooting performance. In the present study, we included several possible factors related to the upper extremities and investigated the relationship between these factors and free throw success.

It has been suggested that certain anthropometric measurements are important for throwing activities in basketball. Previous studies have reported that arm length, hand length, and leg length our significantly related to players' performance (Okazaki et al., 2015; Ruhal, 1998). Koley et al. found a significant relationship between basketball shooting ability and weight, height, upper arm length, forearm length, hand length, hand breadth, and leg length (Koley et al., 2011). In a recent review, a player's standing height was reported to be a variable that influenced the optimal release height of the ball and thereby shooting performance (Okazaki et al., 2015). Similarly, greater hand length, forearm length, and body height have been found to be related to free throw success. In the present study, there was a significant relationship between hand length and FTP from position A, forearm length and FTP from positions D and E, height and FTP from position D, and BMI and FTP from position D. These contributed to the success rate of free throws from different positions by 60%–80%.

Handgrip strength has been proposed as an important factor for throws in various sports (Visnapuu & Jürimäe, 2007). Similarly, our results indicated that palmar, pinch, and handgrip strengths were related to FTP. Left palmar grip strength was an independent variable contributing to the free throw success rate from positions A (74%) and B (79%). Thus, incorporating grip strength training into a rehabilitation program may improve FTS.

Muscle strength is an important factor in sports that require specific physical qualities. Several studies have shown that strength training increases performance in reaction time and power (Ronnestad et al., 2008), speed (Roberts et al., 1982), coordination (Lephart et al., 1996), and endurance (Faigenbaum et al., 2001). In the present study we found that the strength of various wrist, elbow, and shoulder muscles affected the FTS performance. FTP from position A was related to left shoulder flexor and extensor muscle strength, from position B was related to left shoulder extensor muscle strength, from position C was related left elbow extensor and right shoulder external rotator muscle strength, from position D was related to both right and left wrist extensor muscle strengths, left shoulder extensor muscle strength, and left shoulder external rotator muscle strength, and from position E was related to left wrist and elbow extensor muscle strengths and right shoulder external rotator muscle strength. To summarize the relationship between upper extremity muscle strength and total FTP, we found a positive correlation between left elbow and shoulder extensor muscle strengths, and free throw success rate.

Previous studies have analyzed muscle activation patterns during free throws using electromyography (Escamilla & Andrews, 2009; Kibler, 1998; Miller & Bartlett, 1996). Pakosz et al. showed that m. biceps brachii of the left arm was activated first, and then m. triceps brachii activity of the left arm followed. The m. triceps brachii activated to straighten the arm for throwing the ball (Pakosz, 2011). It has been suggested that the earlier activation of the left arm may have two possible explanations: this arm provides a support function, and it is closer to the direction of movement during shooting, including lifting the ball over the head and straightening the arms. In the present study, it was found that strength in the following muscles contributed to the success rate: position B, the left shoulder extensor; position C, the left elbow extensor; position D, the right wrist extensor and left shoulder external rotator; position E, the left wrist and elbow extensor. In line with the electromyography studies, the results of the present study suggest that elbow extensor and shoulder external rotator of the left arm and the strength of both wrist extensors could play important roles in shooting performance.

Previous studies have shown that the players' reaction time can affect the result of a game, with the winners having shorter reaction times (Yüzüncü and Education, 2012). Reaction time is accepted as a good indicator of performance in reactive sports such as basketball. Basketball players have to respond appropriately and quickly during a game and they are required to throw the ball in the appropriate direction. Movements that require speed and dexterity, have been found to be related to players' reaction time. Basketball players have been shown to have faster visual reaction times than subjects in a non-athlete group (Ghuntla et al., 2012). In the present study, left hand reaction time was negatively correlated with FTP from positions A, C, and D and with total FTP, contributing to the success rate by 41%, 80%, 79%, and 72%, respectively. The quicker reaction time found in basketball players has been explained by Guizani et al. as due to better muscular co-ordination and performance in speed and accuracy tasks (Guizani et al., 2006). We therefore suggest considering reaction time training to improve free throw success in basketball training programs.

Vertical jumping is an important integral part of basketball play (Bosco et al., 1982). An absolute measure of jumping effectiveness is provided by the height of the jump. Improved jumping performance, through a combination of concentric contraction immediately following an eccentric stretch, produces more chemical energy available for the generation of power, which is considered to be a combination of strength and speed. A player's performance would be expected to be affected by the vertical jumping height he can achieve, as well as his reaction time (Manojlović & Erčulj, 2013; Okazaki et al., 2015). However, previous studies have reported that free throwing performance is not related to vertical jumping ability (Church, 2009; Woolstenhulme et al., 2004). Similarly, in this study no correlation was found between vertical jumping height and the success rate of free throwing. This finding indicated that jumping height, when shooting, does not affect shooting performance, or that there may be others factors relate to lower extremity conditions. However, vertical jump reaction time was correlated with the FTP from position B and E and with the total FTP. In addition, it contributed to the free throw success by a mean of 30%. Okazaki et al. reported in their review about the basketball jump shot that weaker players who are not able to generate sufficient force, and/or players with a shorter standing height and who have less potential for generating a high ball release height, must use a strategy of generating greater segmental velocities to perform a successful shot (Okazaki et al., 2015). We therefore suggest incorporating exercises that aim to improve hand and vertical reaction times, given their relationship with FTP in our study.

Our study had some limitations. This was a pilot study; our sample was small. It did not use dynamic electromyogram studies, which may have provided detailed information about the activation patterns of upper extremity muscles during free shooting. Furthermore, it did not include the basketball players' success rates during the season's games. Further studies are warranted to investigate the effects of these factors on the players' success rate during the season.

CONCLUSION

Improving performance in free throw is an important element of winning basketball games. Our study found that hand reaction time, vertical jump reaction time, upper extremity extensor strength, and grip strength contributed to the free throw success rate of college basketball players in this study. Athletic rehabilitation should include upper extremity extensor strengthening, grip strengthening, and reaction time training to improve free throw shooting accuracy. The results of our study suggest that future studies should investigate the changes in basketball players' free shooting success following training, which aimed to improve these variables.

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Conflict of interest statement

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