

# DIAGNOSIS OF BIOMECHANICAL ERRORS USING REGRESSION ANALYSIS

Jackie L. Hudson  
Department of Health & Physical Education  
Rice University  
Houston, TX 77251

The development of skilled movement patterns depends in part on knowledge about errors in technique. For most performers this knowledge is understood at an intuitive level and acquired through the process of trial and error. Perhaps, the period of skill acquisition could be shortened if the learner had empirically derived information about errors in technique.

One approach to the diagnosis of errors is to examine intraindividual differences in successful and unsuccessful trials using biomechanical variables. Due to the abundance and interrelationship of biomechanical variables, a multivariate statistical method, such as regression analysis, is appropriate. To test the applicability of regression analysis in the diagnosis of biomechanical errors, the basketball free throw was studied.

## PROCEDURES

### Subjects

The subjects in this study were 22 right-handed, college women from three mutually exclusive groups of basketball skill. The elite group consisted of six competitors on the United States team in the World University Games. Seven non-scholarship players on a varsity team comprised the good skill group. The nine members of the novice group were members of an instructional class.

### Selection of Variables

Several characteristics of skilled performance in free throw shooting have been discussed in the biomechanics literature. Categorically, the cited variables are separated into product elements (characteristics of the object) and process elements (characteristics of the subject). The most prevalent focus is on product elements. It is well documented that as skill in shooting free throws increases, so does accuracy. In terms of angle and velocity of projection, there are numerous qualitative suggestions which range from low to high angles of projection and correspondingly low to high velocities of projection (Bee, 1942; Bell, 1973; Bunn, 1964, 1972; Cooper & Siedentop, 1969; Ebert & Cheatum, 1972; Fish, 1929; Godleski, 1971; Lambert, 1932; Lawrence & Fox, 1954; Meanwell, 1924; Murphy, 1939; Ohlmeyer, 1959; Redin, 1970; Rush & Mifflin, 1976; Scott, 1963; Teague,

1962; Veeneker, 1937; Wooden, 1966). The quantitatively-based recommendations are to use an angle 2-3° above the minimum angle which results in a successful shot (Mortimer, 1951); an angle 4-8° above the minimum (Hay, 1985); the angle corresponding to an angle of entry of 45° (Mullaney, 1957); and the angle associated with the minimum velocity of projection (Brancazio, 1981).

With respect to process elements, there is common support for a vertical alignment of the trunk (Barnes, 1980; Hartley & Fulton, 1971; Kaberna, 1968; Schaafsma, 1971; Stutts, 1969; Wooden) and a high release point (Barnes, Fox, Scott, & Loffler, 1966; Brancazio; Cooper & Siedentop; Cousy & Power, 1970; Hudson, 1982; Mortimer; Mullaney; Rush & Miffilin; Schaafsma; Stutts; Tarkanian & Warren, 1981; Wooden; Yates & Holt, 1982). However, there is disagreement about keeping the center of gravity over the base of support (Barnes, 1980; Hudson, 1982) or moving the center of gravity forward during the shot (King & Toney, 1973).

Based on the review of literature, three product elements (accuracy, angle of projection, and velocity of projection) and three process elements (trunk inclination, height of release ratio, and center of gravity ratio) were selected for analysis.

#### Collection and Reduction of Data

The testing protocol for each subject consisted of: (a) a subject-controlled warm-up period, (b) an accuracy test of 20 free throw trials, (c) preparation for filming with the application of colored, cloth tape on bony landmarks, (d) additional warm-up time to adjust to the filming environment, and (e) three free throw trials which were filmed and noted as made or missed. As a precautionary measure, additional trials were recorded for some subjects.

Film records were obtained with a 16mm Cine-Kodak Special camera which was positioned on an extension of the free throw line 23 m from the right side of the subject. Camera speed was 64 frames per second and exposure time was 4 ms. A Vanguard Motion Analyzer was used to collect digitized coordinates from 17 segmental end points and 3 points on the periphery of the ball. Anthropometric data from Dempster (1955) and the digitized coordinates were supplied to a FORTRAN IV program to calculate the variables of interest.

The location of the center of the ball was computed by a method of triangulation using the peripheral coordinates. The horizontal and vertical components of ball velocity were found by using the displacement of the ball center, the elapsed time between frames, and the equations of motion. The resultant velocity of the ball was calculated from the component velocities. The angle of projection was the angle formed by the resultant velocity and the horizontal.

The trunk segment was represented by a straight line joining the midpoint of the shoulders and the midpoint of the hips. Trunk inclination was measured in degrees with vertical being zero, backward being negative, and forward being positive. The height of release ratio was computed by dividing the height of the ball center at release by the height of the shooter. The anterior-posterior base of support was

defined as the distance from the trailing ankle to the leading toe. The distance the frontal aspect of the center of gravity was in advance of the trailing ankle was divided by the length of the base of support to yield the center of gravity ratio.

#### Treatment of Data

For the statistical analysis the dependent variable was accuracy; successful free throws were designated by the score of one and unsuccessful free throws received the score of zero. The independent variables were the five biomechanical parameters associated with release: angle of projection, velocity of projection, trunk inclination, height of release ratio, and center of gravity ratio. To obtain the values for intraindividual variation in performance, the following procedure was used: for each subject and each variable the average score over all trials was calculated and the error score for each trial was computed by subtracting the average of all trials from the value on a given trial. As an example, if the trunk inclination of subject A were 0°, 2°, and 4°, respectively on three trials, the average score would be 2°. For trial 1 the error score would be -2°, for trial 2 it would be 0°, and for trial 3 it would be +2°.

Because the purpose of this analysis was to compare successful shots with unsuccessful shots, subjects whose filmed trials were all successful or all unsuccessful were eliminated. The resulting data set included 48 shots taken by 5 members of the novice group, 6 members of the good group, and 4 members of the elite group.

The regression procedure of the Statistical Package for the Social Sciences (Nie, Hull, Jenkins, Steinbrenner, & Bent, 1975) and the .05 level of significance were employed to determine if successful and unsuccessful shots could be distinguished on the basis of biomechanical error scores. Separate analyses were conducted for each skill group as well as for the groups combined.

## RESULTS AND DISCUSSION

### Group Characteristics

The absolute scores of each skill group on the biomechanical variables are given in Table 1. There was a significant difference among skill groups in free throw shooting accuracy. In addition there was a significant reduction in accuracy by members of the good and novice groups when the accouterments of cinematography were added. (For further discussion on this point, see Hudson, Lee, & Disch, 1985.) Another significant difference among skill groups was found with the height of release ratio; shots taken by members of the elite group were released 27 cm higher than those taken by members of the novice group. The difference among skill groups in the center of gravity ratio was significant; members of the elite and good groups were well-balanced compared to the novice group which was less stable. One probable cause for the forward center of gravity in the novice group was the forward lean of the trunk. However, there was no significant difference among groups in trunk inclination. Neither were there differences among groups in the angle and velocity of projection. To summarize, skilled performers were characterized by a high point of release, a well-balanced weight distribution, and minimal trunk inclination.

TABLE 1. MEANS AND STANDARD DEVIATIONS OF BIOMECHANICAL VARIABLES

Variables	Basketball Skill Group		
	Elite	Good	Novice
Accuracy on 20-shot test (%)*	74.4 ± 7.9	68.6 ± 13.9	46.9 ± 13.3
Accuracy on filmed shots (%)	64.6 ± 13.1	42.9 ± 24.1**	22.9 ± 22.0**
Angle of projection (deg)	52.7 ± 5.3	52.5 ± 7.3	52.9 ± 5.2
Velocity of projection (m·s <sup>-1</sup> )	7.10 ± 0.50	7.03 ± 0.55	7.04 ± 0.58
Trunk inclination (deg)	2.3 ± 1.5	2.9 ± 1.8	6.7 ± 6.7
Height of release ratio*	1.30 ± 0.04	1.25 ± 0.05	1.23 ± 0.06
Center of gravity ratio*	0.44 ± 0.09	0.51 ± 0.07	0.65 ± 0.19

\* Difference among groups significant at the .05 level.

\*\* Difference between non-filmed and filmed trials significant at the .05 level.

#### Error Analysis

When the error scores of the novice group were analyzed with stepwise regression procedures, a linear solution was generated which had a multiple correlation significantly greater than zero. This equation to predict the success of individual shots accounted for 53% of the variation in accuracy and included four variables: height of release ratio, trunk inclination, center of gravity ratio, and velocity of projection. The order of inclusion and unstandardized and standardized (beta weight) regression coefficients for the selected variables are given in Table 2.

Successful shots were characterized by a greater height of release, a more forward trunk orientation, a more forward position of the center of gravity, and a greater velocity of projection. It appears that a primary reason for missed shots is the inadequate generation of projection velocity which results from incomplete

TABLE 2. REGRESSION RESULTS\* FOR NOVICE GROUP

Step Number	Variable Entered	Unstandardized Regression Coefficients	Standardized Regression Coefficients
1	Height of Release Ratio	11.206	0.555
2	Trunk Inclination	0.174	0.424
3	Center of Gravity Ratio	5.360	0.308
4	Velocity of Projection	0.097	0.284
	Constant	0.382	

\* R<sup>2</sup> = 0.535; F(4, 12) = 3.450, p < .05.

segmental movements. An aggressive treatment for the unsuccessful novice performer would be to increase projection velocity by increasing the trunk inclination, center of gravity ratio, and height of release ratio. However, if the trunk inclination and center of gravity ratio are increased dramatically, the values of these process elements become further separated from the model of the skilled performer. Considering that in the regression analysis the highest beta weight was for the height of release ratio, a more conservative treatment would be to encourage an increase in the height of release. By increasing the height of release (without increasing the angle of projection), the performer gains the dual advantage of having a longer distance through which to build up projection velocity and of needing less projection velocity. For the novice player who increases the height of release and still does not have sufficient projection velocity, small adjustments can be made in forward transfer of weight and forward lean of the trunk.

In analyzing the error scores of the good group, the best combination of independent variables could only account for 35% of the variation in accuracy. Although this solution was not significant, there was a tendency for missed shots to have a higher point of release, a greater angle of projection, and a lesser velocity of projection than successful shots. An obvious correction would be to recommend a lower height of release and a lower angle of projection. However, this interpretation may be in error. Compared to successful shots, the height of release ratio in unsuccessful shots was more similar to the ratio used by the elite performers; thus, suggesting a lower release could inhibit skill acquisition. Also, the higher release was related to a greater angle of projection, which results in a larger margin for error as the ball enters the goal. In exchange for the increased margin for error, it is necessary for these shooters to use a slightly greater velocity of projection. Apparently these good shooters did not increase projection velocity enough to take advantage of the more skillful height of release and angle of projection. Accordingly, experimentation might focus on making small adjustments in projection velocity.

For the elite group there were no trends to separate the successful from unsuccessful shots. Instead, it appears that these players were using individual strategies of adjustment. However, the lack of significance could also be attributed to the small number of shots which were analyzed.

After combining the skill groups, there were no trends for error diagnosis. Thus, there may be different types of biomechanical error at each level of skill. Although there seem to be some common errors among players at the lower level of skill, it may be necessary for individual regression equations to be developed for each player at the higher levels of skill.

#### Utility of Regression Analysis

In evaluating the usefulness of this regression model to diagnose errors in basketball shooting, there are several factors to be considered. The selection of accuracy as the dependent variable has advantages and disadvantages. Because this method of judging success or failure is the same method that is used in competition, there is good construct validity. Also, the status of success or failure can be noted easily and accurately at the time of data collection. However, the simple designation of a shot by success or failure obscures the fact that some failures are very close to being successes and some successes can result from inaccurate shots which take lucky bounces. A related problem is that using a dichotomous dependent

variable limits the amount of variability which can be accounted for by the independent variables. A more satisfactory accounting of error variance might result from using an interval-level criterion variable (e. g., velocity of projection). Although there exist many other independent variables which could be used to diagnose errors in shooting, the set of variables employed in this study can be useful to the coach or teacher because they are based on position and, therefore, can be acquired without sophisticated equipment.

From the results of this study it appears that regression analysis is a suitable tool to aid in the diagnosis of biomechanical errors. In conducting future analyses of this nature, it is important to consider that robust results are dependent on a large trials-per-variable ratio and that the best multivariate predictors are not necessarily the best bivariate predictors.

To generalize the use of regression analysis of basketball shooting to other sport skills, there are two situations in which to employ this tool. First, for performers who are trying to improve skill, regression analysis can identify crucial variables for concentrated attention. Because it is probable that learners do not manifest improvements in all aspects of a skill at the same rate, regression analysis can help to identify those aspects of skill which are less mature than the others. Second, for players who are trying to maintain a level of skill, attending to an isolated parameter rather than to the whole performance can be detrimental. However, in the event that a slump is encountered, regression analysis could be a useful tool to identify a flaw which is responsible for the slump.

In conclusion, the use of regression analysis to diagnose errors should be applied differently for performers of varying abilities. For novice performers, about three trials per subject are needed, and many subjects can be combined in the same analysis. For good players, about five to ten trials per subject are recommended, fewer subjects can be combined in the same analysis, and a more sensitive dependent variable may be required. For elite competitors, perhaps 20-25 trials per subject are needed, subjects should be analyzed individually, and a more sensitive dependent variable should be used.

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