Prediction of Basketball Skill Using Biomechanical Variables

Jackie L. Hudson

Department of Health and Physical Education, Rice University, Houston, TX, 77251, USA

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Rice University

This study was designed to examine the use of selected biomechanical variables in the prediction of basketball skill. The subjects were college women in three mutually exclusive groups of basketball skill: an elite group of six competitors on the United States team in the World University Games, a good group of seven players on a varsity team, and a poor group of nine members of an instructional class. An accuracy test and digitized film records provided the data for 12 variables related to the process or product of free throw shooting. Discriminant analysis was employed to predict the categorical variable of skill. The most discrimination came from variables of accuracy, stability, and height of release rather than from variables of projection. Poor shooters were distinguished by instability; elite shooters were characterized by a high point of release and accuracy under pressure. Depending on the method of prediction, rates for correct classification of subjects ranged from 76-100%. Thus, it appears that discriminant analysis using biomechanical variables can be a successful tool in the prediction of basketball skill.

Key words: basketball, biomechanics, discriminant analysis, elite athletes, performance prediction.

At the highest levels of athletic competition, success can be dependent on the selection of the best performers. Traditionally, the selection of athletes has been based on objective indices of skill, as well as on subjective measures of performance such as reputation. One penalty for greater reliance on subjective rather than objective methods is that performers with high reputation and moderate ability may be chosen instead of players with moderate reputation and high ability. Thus, the identification of objective variables which predict performance should assist in the selection of the best performers.

Discriminant analysis is a promising technique for the identification of variables with predictive value for classifying performers. This technique has been employed with different categories of variables in a few sports to separate good from elite performers. Examples include wrestling skill predicted from psychological, physiological, and anthropometric variables (Naige, Morgan, Hellickson, Serfass, & Alexander, 1975; Silva, Shultz, Haslam, & Murray, 1981); distance running ability predicted from physiological and anthropometric variables (Pollack, Jackson, & Pate, 1980); and field hockey performance predicted from a skill test (Chapman, 1982). The success of prediction in these studies ranged from 58-80% when a single category of variable was employed and from 79-93% when two or three categories of variables were used.

Although excellent predictive results were obtained in the previously cited studies, the variables which were included are indirect or underlying indices of performance. That is to say, it is unlikely that the experimental test (e.g., repetitive barbell pressing) will occur in the actual sport contest. The predictive value has not been reported for categories of variables which are directly involved in the technique of sports performance. Therefore, this study was designed to examine the use of selected biomechanical variables in the prediction of basketball skill.

Method

Subjects

A total of 22 college women in three mutually exclusive groups of basketball skill gave informed consent to participate in this study. Data sets were obtained for an elite group of six competitors on the United States team in the World University Games, a good group of seven players on a varsity team, and a poor group of nine members of an instructional class.

Selection of Variables

The offensive and defensive skills used by a basketball player are dictated by the position being played. The free throw has become the one skill that all players commonly use. Several characteristics of skilled performance in free throw shooting have been discussed in the biomechanics literature. In terms of angle and velocity of projection the 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, 1978); the angle associated with the minimum velocity of projection...
(Brancazio, 1981); and the angle corresponding to an angle of entry of 45° (Mullaney, 1957). For a variety of reasons a high release point is favored by several writers (Barnes, Fox, Scott, & Loeffler, 1966; Brancazio; Cooper & Siedentop, 1969; Cousy & Power, 1970; Mortimer; Mullaney; Rush & Mifflin, 1976; Schaafsma, 1971; Stutts, 1969; Tarkanian & Warren, 1981; Wooden, 1966; Yates & Holt, 1982). With respect to variables of stability, there is agreement that trunk inclination should remain vertical (Barnes, Schaafsma; Stutts; Wooden) and disagreement about keeping the center of gravity over the base of support (Barnes, 1980) or moving the center of gravity forward during the shot (King & Toney, 1973).

Based on the review of literature, 12 variables were chosen for analysis. Five variables related to the product of shooting were included—angle of projection, velocity of projection, the difference between the angle of projection and the minimum angle of projection, the difference between the angle of projection and the Brancazio (1981) angle of projection, and the difference between the angle of projection and the Mullaney (1957) angle of projection. Five variables related to the process of shooting were analyzed—height of release ratio, absolute trunk angle, position of the center of gravity, absolute difference between the center of gravity and the midpoint of the base of support, and change in the center of gravity at release. Also, two variables related to the accuracy of shooting were added—percent accuracy in a nonfilmed free throw test and percent accuracy in filmed free throws.

Testing Protocol

For each subject the testing protocol 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 recorded for analysis. As a precautionary measure, additional trials were recorded for some subjects.

Collection and Reduction of Data

The free throw trials were filmed with a Cine-Kodak Special camera which was positioned 23 m from the subject on an extension of the free throw line. Clear images were obtained by using a camera speed of 60.8 ± 3.6 frames per second, a 90 degree shutter, an exposure time of 4.12 ± 0.22 ms, a 50 mm lens, 4×R reversal film, and 3000 W of additional lighting. Camera speed was verified with a sixty cycle clock placed near the subject. All trials for each subject were analyzed. Because of the collection of extra trials and the loss of information in other trials, complete data sets were available for 67 free throw trials. For each frame, digitized coordinates of 17 segmental end points and three points on the periphery of the ball were obtained with a Vanguard Motion Analyzer. The digitized coordinates and segmental data from Dempster (1955) were used with a FORTRAN IV program to calculate the variables of interest.

To determine the projection characteristics for each basketball shot, the location of the ball center 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 linear velocity of the ball was calculated from the component velocities. The angle of projection (theta) was the angle formed by the resultant velocity and the horizontal.

The location of the ball at release was used to calculate the hypothesized optimal projection angles for each shot. The method of Mortimer (1951) was employed to find the minimum angle of projection which would result in a clean shot. According to the recommendation of Brancazio (1981), the angle of projection associated with the minimum velocity of projection was computed. The angle of projection corresponding with an angle of entry of 45° was calculated with the Mullaney (1957) method. The real and hypothesized angles of projection were combined to create three variables for analysis: the difference between theta and the minimum angle of projection, the difference between theta and the Brancazio angle of projection, and the difference between theta and the Mullaney angle of projection.

The height of release ratio was computed by dividing the height of the ball center at release by the height of the shooter. 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. Because backward lean was considered as detrimental as forward lean, the absolute trunk angle at release was selected for the analysis.

The anterior-posterior base of support was defined as the horizontal distance from the trailing ankle to the leading toe. The location of the center of gravity of the body with respect to the base of support was considered to be the vertical projection of the center of gravity to the base of support. The distance the projected 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. Because the posterior ankle rather than heel was the point of demarka-
tion for the base of support, the center of gravity values are underestimated by about .06.

In addition to the center of gravity ratio, two other center of gravity variables were defined. Information about balance was included by finding the absolute difference between the center of gravity ratio (adjusted by .06) and the midpoint of the base of support (.50). To determine if there were a shift in the center of gravity during shooting, the center of gravity ratio immediately prior to release was subtracted from the center of gravity ratio immediately after release.

Treatment of Data

Discriminant analysis was employed to predict the categorical variable of basketball skill (1 = poor, 2 = good, 3 = elite) from 12 biomechanical variables which were part of the product or process of free throw shooting. Due to the interdependent relationship among many of the variables, each trial was treated independently. Thus, the 67 shots taken by 22 shooters represented six cases per variable and two subjects per variable.

It is acknowledged that the cases- and subjects-per-variable ratios are near the liberal end of acceptability. However, these ratios were used with the following justifications: (a) recently published biophysical studies have included as many variables as one less than the number of subjects (e.g., Silva et al., 1981); (b) in the statistical analysis, full rank of the dispersion and correlation matrices is retained unless there are fewer subjects than variables (Cooley & Lohnes, 1971); (c) because this study is an introductory, exploratory work and the included variables are supported in the literature, it is impossible to deselect the least significant variables without conducting the analysis; and (d) a conservative method of retaining variables was used to offset the searching of a liberal number of variables.

Because discriminant analysis with 12 variables has more than 4,000 possible solutions, it was necessary to develop a strategy for obtaining a single best solution. First, forward stepwise selection criteria were employed by adding at each step the variable with the largest F statistic computed from a one-way analysis of covariance where the covariates were the previously entered variables. Based on the suggestion of Costanza and Afifi (1979) to use a moderate significance level (.10 < p < .25) for including variables, iterations were continued until none of the remaining variables had an F statistic with significance of p < .10.

Next, the set of solutions generated by the stepwise analysis was examined to select the best solution. After eliminating the solutions which did not have a significant (p < .01) multivariate F ratio for the differences in group centroids, the best solution was deemed to be the one which used the minimum number of variables to provide the maximum number of correct classifications.

Four classification matrices were examined at each step in the analysis in order to assess the number of correct classifications. The first matrix was derived from traditional discriminant procedures. For each of the three skill groups, a classification function was computed with the raw data from all 67 shots serving as the basis. After each shot was evaluated by each of the three functions, the shot was assigned to the skill group corresponding to the highest value on the functions. Also, the probability for a given shot to belong to a given group was known. A shot was considered to be classified correctly if the predicted and actual category were the same.

The results of the first matrix were used to compile the second matrix. For each subject, the predicted classifications of all analyzed shots were combined such that the shooter was assigned to the skill category represented by the majority of shots. If a clear majority did not exist, probabilities of group membership were examined to establish the predicted category of skill. A shooter was considered to be classified correctly if the predicted and actual category were in agreement.

The third and fourth classification matrices were derived in a manner similar to the first and second matrices except that jackknifed rather than traditional discriminant procedures were followed. In the jackknifed procedure each case is classified by applying the classification functions computed from all the data except the case being classified (Lachenbruch & Mickey, 1968).

The statistical analysis was performed with the P7M program of BMDF (Dixon et al., 1981) and the DISCRIMINANT program of SPSS (Nie, Hull, Jenkins, Steinbrenner, & Bent, 1975). The BMDF program was used to: (a) calculate means and standard deviations for each variable, (b) determine if the groups were significantly different, (c) generate prediction equations for each group, and (d) classify each shot in the group with the highest probability. The SPSS program was employed to compute standardized discriminant weights.

Results and Discussion

The means and standard deviations for each of the 12 biomechanical variables are given in Table 1. All three groups were similar in angle of projection and velocity of projection. The elite group stood taller and used a greater height of release ratio, which reduced the distance these shots had to travel compared to the shots of the other groups. The average angle of projection for each group was in the 4°-8° above minimum range recommended by Hay (1978). The poor and good group means were close to the angle associated with the minimum velocity of projection which was
favored by Brancazio (1981). The elite group mean was close to the angle corresponding to an angle of entry of 45° which was suggested by Mullaney (1957). However, the variance in each group on the measures of angle of projection was high.

For most of the process variables the mean of the good group was between the means of the poor and elite groups, but closer to the elite group. The height of release ratio increased with the skill of the subjects. The poor group had a moderate angle of trunk inclination. After adjusting the mean center of gravity ratios for the systematic underestimation, the location of the center of gravity was at mid-stance in the elite group and progressively forward of mid-stance in the good and poor groups. In examining the absolute difference between the center of gravity ratio and the midpoint of the base of support, it appears that members of the elite and good groups were well balanced and members of the poor group were not well balanced. Each group exhibited a different style with respect to the change in the center of gravity ratio at release: the elite group showed no change, the good group moved slightly backward, and the poor group moved slightly forward.

The good group scored between the poor and elite groups but closer to the elite group on the 20-shot test of accuracy. However, when the stress of the biomechanical testing environment was added, the accuracy on filmed shots by members of the poor and good groups decreased by about 25%. Members of the elite group were influenced to a lesser extent by the testing environment.

Forward stepwise discriminant analysis was used with a set of 12 biomechanical variables to assess the predictability of membership in three basketball skill groups. The selected solution was significant at the .0001 level (\( \lambda = .327, F(10,120) = 9.00 \)). The two significant canonical functions accounted for 85.1 and 14.9% of the variance explained by the functions. Using traditional classification procedures, correct classifications were obtained for 54 of 67 (80.6%) shots and 19 of 22 (86.4%) shooters. Jackknifed classification yielded correct predictions on 51 of 67 (76.1%) shots and 18 of 22 (86.4%) shooters.

At higher levels of competition, a team selection situation would require discrimination between elite
Table 2
Classification Functions for Poor, Good, and Elite Basketball Groups

<table>
<thead>
<tr>
<th>Variables*</th>
<th>Poor</th>
<th>Good</th>
<th>Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy on 20-shot test (%)</td>
<td>0.195</td>
<td>0.399</td>
<td>0.407</td>
</tr>
<tr>
<td>Center of gravity ratio</td>
<td>121.713</td>
<td>128.222</td>
<td>98.817</td>
</tr>
<tr>
<td>COG ratio – midpoint of base</td>
<td>-95.639</td>
<td>-116.044</td>
<td>-84.855</td>
</tr>
<tr>
<td>Height of release ratio</td>
<td>416.293</td>
<td>416.849</td>
<td>439.550</td>
</tr>
<tr>
<td>Accuracy on filmed shots (%)</td>
<td>0.114</td>
<td>0.143</td>
<td>0.191</td>
</tr>
<tr>
<td>Constant</td>
<td>-291.613</td>
<td>-305.915</td>
<td>-326.275</td>
</tr>
</tbody>
</table>

*Variables are listed in order of stepwise inclusion.

and good, but not poor players. Thus, a discriminant analysis was performed to predict membership in good and elite skill groups. The original set of 12 variables was used with 38 shots taken by 13 good and elite players. A parsimonious solution was generated which had three predictor variables: accuracy on the 20-shot test, accuracy on filmed trials, and height of release ratio. The solution was significant at the .0001 level (λ = .437, F(3,34) = 14.59) and the canonical correlation was .750. Traditional methods yielded correct classifications for 34 of 38 (89.5%) shots and 12 of 13 (92.3%) shooters. Jackknifed classification correctly matched 33 of 38 (86.8%) shots and 11 of 13 (84.6%) shooters. A check on the strength of the classification functions was made by predicting the skill category of the 29 shots taken by poor group members. When both the traditional and jackknifed classification methods were employed, 28 of 29 (96.6%) of poor group shots were labeled as good rather than elite.

As with the three-group situation, another two-group discriminant analysis was conducted with 11 of the 12 original variables (excluding the 20-shot accuracy test). The resulting parsimonious solution contained two predictor variables (accuracy on filmed trials and height of release ratio) and was significant at the .0001 level (λ = .579, F(2,35) = 12.70). The canonical correlation was .649. Correct categories were predicted for 32 of 38 (84.2%) shots and 11 of 13 (84.6%) shooters and 31 of 38 (81.6%) shots and 11 of 13 (84.6%) shooters by the traditional and jackknifed classification methods, respectively. The strength of the classification function was verified as 28 of 29 (96.6%) poor shots were categorized as good instead of elite.

In both parsimonious two-group models, the height of release ratio was the only non-accuracy variable included. While parsimony may be statistically desirable, in this case it limits the diagnostic utility of the model (i.e., a good player striving to be elite might profit from having more information in the form of additional variables which have discriminatory power). Thus, both two-group analyses were expanded to include variables which were significant at the .15 level.

When the original set of 12 variables was searched, the expanded model contained five variables: height of release ratio, accuracy on the 20-shot test, absolute trunk angle at release, accuracy on filmed trials, and the change of the center of gravity ratio at release. This solution was significant at the .0001 level (λ = .356, F(5,32) = 11.56) and had a canonical correlation of .802. The classification functions for the good and elite skill groups are given in Table 3. Using the traditional classification method, 34 of 38 (89.4%) of shots and 13 of 13 shooters were correctly identified. Application of the jackknifed procedure yielded correct classifications for 33 of 38 (86.8%) shots and 12 of 13 (92.3%) shooters.

The criterion of permitting the inclusion of variables which are significant at the .15 level was used in a discriminant analysis of the two-group situation with 11 of 12 variables (excluding accuracy on the 20-shot test). An expanded model was generated which contained four variables: height of release ratio, accuracy on filmed trials, center of gravity ratio at release, and absolute trunk angle at release. This model was significant at the .0001 level (λ = .457, F(4,33) = 9.80) and had a canonical correlation of .737. The accuracy of classification was 34 of 38 (89.4%) shots and 12 of 13 (92.3%) shooters with the traditional method and 30

Table 3
Classification Functions for Good and Elite Basketball Groups

<table>
<thead>
<tr>
<th>Variables*</th>
<th>Basketball Skill Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>Height of release ratio</td>
<td>1176.452</td>
</tr>
<tr>
<td>Accuracy on 20-shot test (%)</td>
<td>2.936</td>
</tr>
<tr>
<td>Accuracy on filmed trials (%)</td>
<td>0.385</td>
</tr>
<tr>
<td>Trunk angle (deg)</td>
<td>-11.660</td>
</tr>
<tr>
<td>COG ratio – midpoint of base</td>
<td>507.681</td>
</tr>
<tr>
<td>Constant</td>
<td>-824.199</td>
</tr>
</tbody>
</table>

Note. Functions are based on the expanded model.
*Variables are listed in order of stepwise inclusion.
of 38 (78.9%) shots and 11 of 13 (84.6%) shooters with
the jackknifed procedure.

The relative importance of the predictor variables is
indicated by the absolute magnitudes of the standard-
ized discriminant function coefficients. Table 4 pre-
sents the standardized discriminant function coeffi-
cients for both of the three-group analyses and the two
expanded two-group analyses. From these coefficients
it can be seen that in both the two- and three-group
analyses, accuracy variables were weighted heavily. In
the three-group analyses, the center of gravity vari-
bles had high weightings, height of release had a low
weighting, and trunk angle had no weighting. The
coefficients in the two-group analyses were high for
height of release and moderate for center of gravity
and trunk angle. Interestingly, the five variables
which did not appear in any function were the vari-
bles related to angle and velocity of projection.

An examination of the raw data with the discrimi-
nant functions reveals that the poor shooters were
penalized by a center of gravity which was too far
forward as well as moving forward, a low release
height, and inaccuracy. Elite shooters were character-
ized by having a high release point, little trunk inclina-
tion, and accuracy in the stressful testing environ-
ment. To use this information in a coaching or teach-
ing situation, it appears that poor shooters could try to
improve stability (i.e., a center of gravity ratio which
remains in the mid-stance region) and good shooters
could concentrate on releasing higher while in an up-
right posture and practicing under pressure.

Regardless of the number of variables or method of
classification, two subjects were consistently misclassi-
ified. The member of the poor group who was msla-
beled held membership in the poor group on the basis
of enrollment in a beginning instructional class which
had no upper limit for skill of participants. The elite
group member who was misdiagnosed may have been
selected to the World University Games team for skills
other than shooting, or by virtue of reputation.

In this study all members of the poor group were
enrolled in the same instructional class and all subjects
in the good group were players on the same team. As a
result, there may have been common elements within
these experimental groups which may not be repre-
sentative of the populations at the poor and good skill
levels. For example, six of the seven good subjects had
a small amount of backward inclination of the trunk;
also, members of this group tended to shift the center
of gravity backward as the ball was released. In actual
(rather than absolute) trunk angle and change in cen-
ter of gravity ratio the mean of the good group was not
between the means of the elite and poor groups as
would be expected. Thus, for the good group, these
variables may be influenced by sample-specific charac-
teristics. However, these variables ranked as the least
important in the functions which contained them. If
there is a sample-specific influence, it remains to be
seen whether these variables would retain their theo-
retical importance as predictor variables or if their
coefficients would change. Replicating this study with
other samples from the populations could provide
insight into this problem.

Although one category of variable (i.e., biomechani-
cal) and one phase of basketball playing (i.e., free
throw shooting) were used to predict basketball skill
level, the success of prediction ranged from 76–100%.
One explanation for the high success of prediction is
that many of the players who have developed skill in
free throw shooting may have developed skill in other
aspects of basketball as well. Despite the obvious con-
tradiction exemplified by a few successful professional
basketball players who are poor free throw shooters,
discriminant analysis of free throw shooting using bio-
mechanical variables appears to have predictive value
as one aspect of the selection of basketball team mem-
bers.

In addition to using discriminant analysis with bio-
mechanical variables to identify skilled players, this
technique appears to have potential in the diagnosis of
errors which may limit performance. It remains to be
seen if a performer can improve skill level by correct-
ing errors which this discriminant analysis has identified as differentiating between skill levels.

Summary

Based on success rates of 76–100%, discriminant analysis using biomechanical variables appears to be a successful tool in the prediction of basketball skill, and, thereby, the selection of basketball team members.

For future team selections, population-specific equations could be developed or the functions derived in this study could be applied. Although a film analysis is required to obtain the necessary data for these functions, all the predictor variables are based on position and, therefore, could be acquired without sophisticated equipment.

The coach, teacher, or participant can gain insight about which variables are important in the acquisition of free throw shooting skill by examining the standardized discriminant function coefficients.

References


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Jackie L. Hudson is an assistant professor with the Department of Health and Physical Education, Rice University, Houston, TX 77251.

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