A BIOMECHANICAL ANALYSIS BY SKILL LEVEL OF FREE THROW SHOOTING IN BASKETBALL

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Free throw shooting in basketball is a task which falls into two broad categories of sports skills. First, it is a task of accuracy. Second, it requires submaximal velocity for most populations of players. Because of the submaximal velocity demands, there are endless combinations of segmental contributions in conjunction with numerous projection angles and velocities which can result in shots which directly or indirectly fall through the basket. In addition to the segmental actions which contribute to shooting performance, there may be other actions which are extraneous to performance. These non-related characteristics can be termed style. Since the identification of characteristics which are consistently employed by skilled performers and conspicuously absent in poor performers may lead to improved teaching and coaching, this study was conducted to analyze selected biomechanical parameters of free throw shooting by players of varying skill.

REVIEW OF LITERATURE

Most discussions of the biomechanics of free throw shooting are based on qualitative observation or mathematical deduction rather than on experimental evidence. Categorically, the variables cited are product elements (characteristics of the object) and process elements (characteristics of the performer).

Subjective assessments of the product elements of angle and velocity of projection are abundant. There are numerous advocates of "high" angle of projection (Bee, 1942; Bell, 1973; Bunn, 1964; Bunn, 1972; Ebert, 1972; Fish, 1929; Meanwell, 1924; Murphy, 1939; Ohlmeyer, 1959; Rush, 1976; and Scott, 1963), several proponents of "medium" angle of projection (Cooper, 1969; Godleski, 1971; Lambert, 1932; Redin, 1970; Teague, 1962; and Wooden, 1966), and one author in favor of "low" angle of projection (Veeneker, 1937). The reasons given in support of a particular angle of projection are often spurious. Lawrence (1954) advocates the use of high arch since the ball must be dropping when it reaches the goal. Lambert (1932) rejects the use of high arch because too much arch causes the shooter to observe the flight of the ball rather than the basket.

A few authors have linked quantitative and qualitative suggestions for angle of projection. These include Sharman (1965), who recommends a medium arch of 35-45^{o}; Hay (1978), who advocates a low arch of 49-55^{o}; and Hartley (1971), who espouses a medium arch of 55-60^{o}. Barnes (1980) encourages an angle of projection of 45^{o} for all shooters.

Mathematical deduction has led Mortimer (1951) to recommend an angle of projection of 2-3^{o} above the minimum angle which results in a successful shot. Similar methods have been employed in an example by Hay (1978) to suggest that the angle of projection should be 4-8^{o} above minimum.

Once the angle of projection is established (for a given point of release), there is only one velocity of projection which will take the ball through the center of the goal. Though most authors employ angle selection as the primary focus, two writers suggest that velocity considerations should come first. In citing the unpublished work of Brancazio, Maugh (1981) states that shots should be projected with the least velocity which can be successful. Mullaney (1957) advances the theory that shots should approach the basket with minimum terminal velocity. Since he assumes a 45^{o} angle of entry corresponds to minimum terminal velocity, the desired angle of projection would be the one which results in an angle of entry of 45^{o}.

In the literature on process elements, stability is given much attention. Barnes (1980) and Hartley (1971) state that accuracy is dependent on good balance. In a dissenting opinion, Auerbach (1957) suggests that there should be little concern about balance. According to Barnes (1980), balance is achieved by keeping the center of gravity over the base of support. King (1973) recommends that in the course of a shot the weight should move forward to the balls of the feet.

Several authors discuss the variable of trunk inclination with respect to maintaining stability. Barnes (1980) advocates a vertical alignment of the head, back, and hips. Three writers (Schaafsma, 1971; Stutts, 1969; and Wooden, 1966) caution against leaning forward while shooting. Hartley (1971) cites forward and backward lean as being detrimental. In an analysis of jump shooting by four female varsity basketball players, Gorton (1978) found a backward angle of trunk inclination of 1^{o}. Beginning players have been observed by Kaberna (1968) to lunge their bodies in attempting to score.

In the opinion of Broer (1979), many girls and women lack the strength to perform a one-handed shot from the free throw line. For players with strength limitations, free throw shooting requires near maximum velocity production. Among the characteristics of high velocity throws given by Cooper (1982) are: 1) the center of gravity shifts back and is then displaced forward and 2) the upper body is flexed after having been extended.

There is unanimity among experts that a high point of release is desirable. Several writers (Barnes, 1966; Schaafsma, 1971; Stutts, 1969; and Wooden, 1966) favor a high release point because it is characteristic of good shooters. Other writers (Cooper, 1969; Cousy, 1970; Maugh, 1981; and Mortimer, 1951) prefer a high release because it decreases the distance to the goal, the minimum angle of projection, and the minimum velocity of projection and it increases the margin of error. Suggestions on how to achieve a high release include: 1) using more flexion at the shoulder (Rush, 1976), 2) employing greater extension at the elbow (Mullaney, 1957), and 3) releasing the ball as the arm segments complete the range of motion (Tarkanian, 1981).

Based on the review of literature, six variables were selected for analysis. These include three product elements: angle of projection, velocity of projection, and accuracy; and three process elements: trunk inclination, center of gravity ratio, and height of release ratio.

PROCEDURES

Three mutually exclusive groups of college women served as subjects for this study. The nine members of the high skill group were competitors on the United States team in the World University Games. Seven non-scholarship players on a varsity team comprised the moderate skill group. The low skill group consisted of nine members of an instructional class.

The testing protocol for each subject involved: 1) a subject-controlled warm-up period, 2) an accuracy test of 20 free throw trials, 3) marking of bony landmarks with colored, cloth tape, 4) additional warm-up time to adjust to the tape, and 5) three free throw trials which were recorded for analysis.

Film records were taken by a 16 mm Cine-Kodak Special camera which was located 23 m from the right side of the subject on an extension of the free throw line. Camera speed was 64 frames per second with an exposure time of 4 ms. Points on the periphery of the basketball and the end of segments were digitized with a Vanguard Motion Analyzer. These data and segmental data from Dempster (1955) were supplied to a FORTRAN program to obtain the appropriate mathematical results.

To analyze the projection characteristics of the basketball it was necessary to know the location of the ball center. A method of triangulation, using coordinate data from three points on the periphery of the ball, was employed to locate the center of the ball.

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.

Trunk inclination was measured in degrees with vertical being 0^{o} and a forward inclination being positive. The base of support was defined as the horizontal distance from the rear 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. The height of release ratio was computed by dividing the height of the ball center at release by the height of the shooter.

Analysis of variance techniques and the 0.05 level of significance were used to determine if the groups were similar in the parameters of execution.

RESULTS AND DISCUSSION

As expected, several subjects exhibited characteristics which were stylistic in nature. Members of each skill group held the ball behind the head at some time in the preparatory phase of the shot. One member of the high skill group used extreme hip and knee flexion in the preliminary portion of the shot. At 0.2 s before release her right thigh was inclined 8^{o} below horizontal.

The mean and standard error of estimate for each skill group for each of the six selected variables are presented in Table 1. The statistical treatment of data revealed that there was a significant difference in skill groups in free throw shooting accuracy. In addition, the mean accuracy score for each group was reduced when joint markings, lights, and camera noise were added.

The height of release ratio was found to be significantly different among groups. In absolute terms, the shots of the high skill group were released 27 cm higher than those of the low skill group. Subjects who were able to attain high release height ratios were observed to employ greater flexion at the shoulder than the poorer performers. Additional evidence in support of a high release height ratio comes from comparing the individual shots by members of the low skill group. Successful shots were released an average of 4 cm higher than those that were unsuccessful.

Another significant difference was found in the center of gravity ratio. Members of the high skill and moderate skill groups were quite stable with ratios of .48 and .49, respectively. The low skill group with an average score of .65 was less stable at the point of release. Indeed, one member of the low skill group had a center of gravity ratio greater than 1.0, signifying an unstable condition. Based on these data, it appears that skilled free throw shooters do not shift the center of gravity

TABLE 1 Mean ± Standard Error of Estimate for Selected Variables

Variable	High Skill	Moderate Skill	Low Skill
Accuracy* (percent)	78 ± 8	69 ± 15	47 ± 14
Height of Release* Ratio	1.31 ± .04	1.25 ± .05	1.22 ± .06
Center of Gravity* Ratio	.48 ± .09	.49 ± .07	.65 ± .20
Trunk Inclination (degrees)	3.0 ± 2.1	3.0 ± 1.7	6.7 ± 7.1
Angle of Projection (degrees)	52.4 ± 5.6	52.5 ± 4.9	52.9 ± 3.2
Velocity of Projection (meters x seconds^{-1})	7.22 ± .52	7.04 ± .30	7.05 ± .43

*Significant at the 0.05 level

forward at release as suggested by Tarkanian (1981). The reduced balance displayed by the low skill group may reflect a lack of strength as cited by Broer (1979).

The amount of trunk inclination was not significantly different among groups. A possible explanation of this non-significance is due to the extreme variability within the low skill group. The hypothesis that members of the low skill group were homogeneous in trunk inclination was tested by comparing within to between subject variability. A significant difference was found which indicated that the group was heterogeneous and that improvement in stability due to trunk inclination probably occurs within the beginning level of skill.

The univariate analyses of variance of angle of projection and velocity of projection revealed that neither was significant. Although the group means were similar, there was considerable variability within each group. For example, the mean angle of projection in the high skill group was 52^{o} and the range was 46^{o} to 60^{o}. It is probable that a univariate analysis was inappropriate since, in successful shots, angle and velocity of projection are interrelated and dependent on the height of release.

Multivariate analysis was done to compare these data with the theoretically advanced ideal parameters. The equations of Mortimer (1951) and the release point distance from the goal for each shooter were used to compute: 1) the minimum angle of success, 2) the angle of projection which resulted in a 45^{o} angle of entry (Mullaney, 1957), and 3) the angle of projection associated with the minimum velocity of projection (Maugh, 1981). The low and moderate skill groups shot 5^{o} above the minimum and the high skill group shot 8^{o} above the minimum angle of projection. Thus, all groups exceeded the $2\text{-}3^{o}$ suggestion of Mortimer and fell within the $4\text{-}8^{o}$ range of Hay (1978). The angle of projection advanced by Mullaney averaged 9^{o} above the minimum angle of projection. Only four shooters exceeded the Mullaney angle. The low and moderate skill groups were 3^{o} below and the high skill group was 2^{o} below the angle of Mullaney. Since the angle of projection reported by Maugh represents the minimum velocity of projection, shots with greater or lesser angles would both require more than minimum velocity. Therefore, the absolute value of deviation from the recommended angle of projection was analyzed. The low and moderate skill groups missed the angle of minimum velocity by 3^{o} and the high skill group missed by 4^{o}. Though the projection characteristics of the high skill group appear to be distinquished from the low and moderate skill groups, the variability within each group was high. Thus, further investigation in this area is needed.

CONCLUSIONS

1. Greater stability (i.e., balanced center of gravity and vertical trunk inclination) is related to higher skill.

2. A greater ratio of height of release to standing height is related to higher skill.

3. Angle and velocity of projection, taken independently, are not related to skill level.

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