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The relationship between basketball shooting kinematics, distance and playing position

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Three-dimensional cinematography (100 Hz) was used to establish the relationship between distance and the kinematics of shooting with respect to playing position in basketball. Fifteen subjects, divided into guards, forwards and centres (all n = 5), performed jump shots from each of three distances: 2.74, 4.57 and 6.40 m from the basket. Increases in mean release speed were found as shooting distance increased for all groups. This was due to increased angular velocities of both shoulder flexion and elbow extension and an increased speed of the centre of mass in the direction of the basket. Release angles for the two shorter distances (52-55°) tended to provide the advantage of a steep angle of entry into the basket, whereas those at the longest distance (48-50°) were closer to those requiring the minimum possible release speed. All groups exhibited an earlier timing of release as shooting distance increased, which gave rise to an earlier rotation of the shoulder axis. The more consistent changes in kinematic patterns with changes in shooting distance exhibited by guards as compared to centres would suggest that such adjustments are easier to make for those players who regularly shoot from long range.

Keywords: Basketball shooting, biomechanics, shooting kinematics.

Introduction

Evolution of the rules and tactics of the game of basketball has resulted in three basic playing positions: centre, forward and guard. Players in all three positions are expected to contribute to a team’s scoring. Centres tend to be the tallest players (Mansfield, 1995), normally playing close to the basket in order to utilize their height to the greatest benefits of the team (area A, Fig. 1), whereas the shortest players (guards) tend to originate attacking patterns, a role which requires them to dribble the ball up the court (Krause, 1991). This in turn causes them to stay further from the basket (area B, Fig. 1). Forwards tend to be of medium stature, their role incorporating aspects of those of both centres and guards. They are expected to help guards in setting up attacking patterns and centres in defending opponents close to the basket, and also to contest rebounds from missed shots, playing on both the left and right hand sides of the court between the zone and the side lines (Coleman, 1975). This is indicated by area in C Fig. 1. As players tend to play in specific areas of the court, it might be expected that shots attempted would tend to come from the area(s) in which the shooter plays. Notational analysis of shooting distances for 200 English National League matches played between 1984 and 1990 (Miller and Bartlett, 1994) revealed this to be the case. These data revealed that at least 80% of field goals were attempted from the following ranges: centres, 0-3.7 m; forwards, 3.0-6.4 m; guards, 5.5-7.3 m. These figures do not include free throws which, using the same data, accounted for 26% of all attempts.

Points are scored by shooting the ball through a horizontally elevated hoop. At release, the ball becomes a projectile and, as such, is subject to the laws governing projectile motion. The principal factors determining range (and therefore outcome) are release speed, release angle and release height (Fig. 2). Despite the large diameter of the ball, air resistance has comparatively little effect on range, as ball speed through the
air is low, the latter being the more important factor in determining drag forces (Hay, 1994).

To have the best chance of passing through the hoop, the ball should approach it vertically, allowing the greatest margin for error in all directions. In practical terms, this is impossible, as it would require (ignoring the effects of air resistance) a point of release directly underneath or above the basket. For any given release angle, release speed increases quadratically with distance from the basket, requiring the application of greater impulse during the release phase of the shot. For any shooting distance, however, there is a release angle for which the required release speed is a minimum, given by 45° + \( \frac{1}{2} \) angle of incline to basket (Brancazio, 1984; see Fig. 3).

The angle of release at any distance is positively related to the angle of entry of the ball into the basket. There is thus a trade-off between the respective advantages to be gained from an increased margin for error when the ball passes through the basket, resulting from large release angles, in which the ball enters the basket more steeply, and those from an increased margin for error in release speed and angle for values of the latter which require close to the minimum release speed (Brancazio, 1981). Based upon the allowable margin for error, Hay (1994) determined optimal release angles for a 4.57 m shot to be in the range 52–55°.

Maugh (1981) addressed the theoretical effects of changes in release height on success, reporting that an increase in this variable of 0.61 m (to 2.74 m) resulted in an 18% increase in the (sagittal plane) arc through which the ball could travel and still pass through the basket. Maugh did not make clear whether further increases in release height would be associated with increased chances of success, possibly because a release height of greater than 2.74 m may be outside the capabilities of all but the tallest players.

The basketball literature generally advocates similar shooting mechanics (e.g. Krause, 1991; Wissel, 1994), and does not differentiate between playing position. Players who play close to the basket, where the required release speed is comparatively small, are taught to shoot in the same manner as those playing further from the basket, where the required release speed is greater. It is therefore possible that those players who shoot almost exclusively from long or short distances have adapted their techniques to take account of this, and that those who regularly shoot from a range of distances will demonstrate a more consistent pattern.
of change in kinematic variables with changes in distance. We therefore wished to determine whether any justification exists for using different principles when teaching basketball shooting at different distances from the basket, and to facilitate the further understanding of the shooting process.

The objectives of the study were to establish the relationships between release speed, release angle and release height with shooting distance as exhibited by players in each of the major positions (guard, forward and centre), and to identify the changes in technique used to achieve the required release parameter values with changes in shooting distance.

Methods

Subjects

The 15 male subjects were active basketball players, all of whom had been a member of a college team or played at a standard deemed to be of a similar or higher standard. They were assigned to one of three groups (guards, n = 5; forwards, n = 5; centres, n = 5). The group into which a subject was placed was dependent upon the position normally played during competition. All of the subjects were right-handed. The mean (± s.d.) age of the subjects was: guards, 24.8 ± 4.2 years; forwards, 24.4 ± 1.5 years; centres, 21.8 ± 1.79 years. Their mean height was: guards, 171 ± 6 cm; forwards, 186 ± 3 cm; centres, 190 ± 2 cm.

Procedures

Filming took place indoors on a regulation basketball court, and was conducted in accordance with the guidelines of the British Association of Sports Sciences (Biomechanics Section) (Bartlett, 1992). Two tripod-mounted, phase-locked Photosonics 1PL motor-driven, pin-registration cameras were placed approximately 10 m from the performance volume such that their optical axes were approximately horizontal, forming an angle of approximately 90° with each other, and 45° with the horizontal-plane axes of the calibration frame, in order to maximize the accuracy of three-dimensional reconstructions. The nominal filming rate was 100 Hz (later found to be 99 Hz from the timing marks recorded on the film), and the cameras were loaded with Kodak 7251 Daylight or 7250 Tungsten film. As natural light was the method of illumination used throughout, when tungsten film was used a Hunter 85A filter was attached to the lens, allowing the use of artificial-light balanced colour film with daylight illumination. Schneider Kreuznach Varigon 18–90 mm zoom lenses were adjusted such that the images of the performers were maximized within the viewfinder. A metal calibration frame, built in the Craft, Design and Technology Department at Crewe + Alsager Faculty, and two separate vertical calibration poles formed a volume which was sufficiently large to contain the shooter and initial part of the ball trajectory post-release. The maximum volume calibrated was approximately 7.0 x 3.5 x 1.5 m. The frame was erected such that its orthogonal axes were parallel and at right angles to the backboard. After completion of a 10 min warm-up, the subjects were required to score an uncontested basket from each of three distances (2.74, 4.57 and 6.40 m) marked on a line adjoining the two baskets, and were instructed to shoot as they would during a game. Shooting distances were established using a previously described pen and paper analysis carried out by one of the authors between 1984 and 1990 (Miller and Bartlett, 1994).

The shooting distances selected for this study were such that both short- and long-distance shots were included, and two of the three groups (guards and centres) would be shooting from one unfamiliar distance. Also, the intermediate distance (4.57 m) is one from which all players, regardless of position, should have considerable experience, being the same distance as the free throw.

The ball position prior to each shot was not standardized, as such a position could have been contrary to a subject’s natural technique. As the position in which players receive the ball during a game prior to shooting varies, the use of a standard starting position was considered to be experimenter biasing. The subjects wore only a pair of shorts and appropriate footwear such that none of the body landmarks to be digitized was obstructed.

The cameras were started approximately 2 s prior to the beginning of each shot to ensure that they reached full running speed, and were thus phase-locked for the whole shooting process. Event synchronization was achieved by a manually activated switch prior to release. This placed a mark on the film in both cameras at identical times, thus ensuring that frames could be matched for subsequent analysis. The cameras were not switched off until the ball passed through the hoop to ensure a recording of a sufficient portion of the performance to permit analysis of release parameters. Trials were repeated until an attempt was successful. As the subjects were instructed to aim the ball directly into the hoop, a successful shot was defined as one which did not touch either the hoop or the backboard. It was thus certain that such shots had been released with appropriate parameters, as it is possible for the ball to make contact one or more times with the backboard and/or hoop prior to passing through the latter, which would indicate an error in release parameters.
Once a successful shot was achieved, the procedure was repeated for each subject in the group. When all subjects had been successful from the first shooting distance, a practice period of approximately 5 min was allowed, during which calibration of the volume encompassing the second shooting distance was completed. This procedure was repeated until successful shots had been achieved by all subjects from all three shooting distances.

Analysis of raw data

Developed films were projected onto a TDS HR48 digitizing tablet (x,y resolutions, 0.025 mm; active area, 1.20 x 0.90 m) which was interfaced to an Acorn Archimedes 440 microcomputer. From the size of the projected images, the minimum digitizer resolution was calculated to be $8 \times 10^{-4}$ m. Three-dimensional world coordinates were obtained from the digitized sequences using a direct linear transformation (DLT) algorithm correcting for linear lens distortion (Abdel-Aziz and Karara, 1971), which also included the first term from the equation for symmetrical lens distortion (Karara and Abdel-Aziz, 1974). Reconstruction accuracy was assessed automatically by the software by comparing the reconstructed object space coordinates of eight test points in the calibration frame with their true coordinates. Sequences were recalibrated if the mean reconstruction error exceeded $1.5 \times 10^{-2}$ m and/or the maximum single-point error exceeded $3 \times 10^{-2}$ m. Two control points were also digitized for each frame to compensate for any movement of the projected film. A standard 14-segment, 18-point model of the human performer based on the data of Dempster (1955), which had been corrected for tissue fluid loss, was used to represent the human performer. Limitations to the extrapolation of Dempster’s cadaver data to the general population have been highlighted (e.g. Bartlett, 1992), and are acknowledged.

The following points were digitized: vertex of head; 7th cervical vertebra; right and left glenohumeral, elbow, wrist, 3rd metacarpophalangeal, hip, knee and ankle joints; distal end of right and left feet. The following segments were defined (defining anatomical landmarks in parentheses): head/neck (vertex of head, 7th cervical vertebra); trunk (right/left glenohumeral joint, right/left hip joint); right/left upper arm (glenohumeral joint, elbow joint); right/left forearm (elbow joint, wrist joint); right/left hand (wrist joint, 3rd metacarpophalangeal joint); right/left thigh (hip joint, knee joint); right/left calf (knee joint, ankle joint); right/left foot (ankle joint, distal end of foot). Definitions of the measured joint angles are as follows (see also Fig. 4):

- **Shoulder**: the three-dimensional included angle formed by a line joining the centres of the shoulder joints and the appropriate elbow joint.
- **Elbow**: the three-dimensional included angle formed by a line joining the wrist, elbow and shoulder joint centres.
- **Knee**: the three-dimensional included angle formed by a line joining the hip, knee and ankle joint centres.
- **Ankle**: the three-dimensional included angle formed by a line joining the knee and ankle joint centres, and the distal end of the foot.
- **Trunk to horizontal**: the two-dimensional included angle formed by the projection, onto the x,z (sagittal) plane, of the line joining the mid-points of those lines joining the right and left shoulder, and right and left hip joints, and the forward horizontal.
- **Shoulder axis rotation**: the smaller of the two angles formed by the projection, onto the x,y (horizontal) plane, of a line joining the two shoulder joints and the direction of the velocity vector of the ball at release.

The wrist joint was ignored in the current study, as the data of Feinstein et al. (1955) and Christensen (1959) suggest that the innervation ratios of the wrist flexor muscles are sufficiently small to render them suitable to contribute only to the fine control (i.e. accuracy) aspect of the movement under investigation, and not to changes in force production, the latter of which was the focus of the study. The data of Scolnick (1967) suggest that the kinematics of the wrist joint would be similar irrespective of shooting distance, especially for successful shots where the selection of release parame-
Basketball shooting kinematics and playing position

ters is appropriate. In a study of the arm action of expert shooters, Scolnick found no significant differences for wrist joint angular displacements and velocities at release, and total displacement from the start of the shot to release, at shooting distances of 2.74, 4.57 and 6.40 m.

After calculation of mass centre coordinates and joint angles, the data were smoothed and velocities computed using generalized cross-validatory quintic splines implemented for the Archimedes by Bartlett and Bowen (1993) and based on a program by Woltring (1986).

Forty-five sequences were analysed, consisting of one successful shot by each subject at each distance. Analysis concentrated on the time from the first perceptible ball movement until 10 frames after ball release. Within this period, each frame of the film was analysed. Typical stick figure sequences are shown in Figs 5 and 6. Two times of interest for each sequence were defined as key events and were identified directly from the recorded film:

1. Take-off: the first perceptible frame in which foot-ground contact was broken.
2. Ball release: the first perceptible frame in which hand-ball contact was broken.

Take-off was selected as a key event as much of what follows during the shooting process is dependent upon the take-off parameters. Ball release was selected as a key event as release parameters are the result of body segment positions and resultant velocities at that time (Elliott, 1992). Release parameters also determine whether or not a shot will be successful, this being the most important factor of the skill.

Statistical methods

Although the size of each group was only five, which might be considered small and is often thought to necessitate the use of non-parametric statistics, there is no clearly agreed distinction between a large and a small sample. Furthermore, it has been proposed that if samples are random and of equal size, as was the case here, small sample sizes have little effect on the relationships between variables (Boneau, 1960). The robust nature of ANOVA procedures allows the violation of assumptions regarding the data, especially that of normality – itself a direct consequence of random sampling (Howell, 1992) – while still retaining a more powerful and flexible statistical test (Popham, 1967; Popham and Sirotnik, 1973). A homogeneity of variance tests was applied to the data for each group for all comparisons made. As no significant differences were found, the assumption of ANOVA that variances are

Figure 5 Typical stick figure sequences for (a) short-, (b) medium- and (c) long-range shots.
homogeneous (Cohen and Holliday, 1982) was not violated.

As this study aimed to examine the effects of two independent variables (position played and shooting distance) on a number of dependent variables mentioned above, a two-factor (group x distance) ANOVA with repeated measures on the second factor was used.

Post-hoc Tukey tests were carried out where necessary to detect significant interaction effects.

The alpha (significance) level was adjusted using the Bonferroni technique (Thomas and Nelson, 1990). This proposes the reduction of the alpha level for each independent comparison (0.01) by dividing it by the number of comparisons, here \( n = 13 \) (Howell, 1992), i.e. \( \alpha = 0.0008 \). This also gave an upper limit on the familywise Type I error rate of 0.12, which would be reached only if the different variables compared were completely independent (Thomas and Nelson, 1990), and hence prevented an excessive loss of statistical power and a consequently high Type II error rate.

The reliability of the data was established by repeated digitizing of one sequence at the same sampling frequency with an intervening period of 48 h. The same sequence was digitized by a person with experience of digitizing sports movements but unconnected with this study for the purposes of assessing objectivity. A single-factor ANOVA was used to compare these sequences with the original for selected linear and angular displacements and velocities. As no significant differences \( (P < 0.01) \) were found, it was concluded that the digitized data were both reliable and objective. Data precision was established by calculating the mean standard error for selected variables, the results of which are shown in Table 1.

### Results

Release speeds and angles are shown in Table 2. The value for guards at 6.40 m \( (8.39 \pm 0.49 \text{ m s}^{-1}) \) was found to be significantly different \( (P < 0.01) \) from guards, forwards and centres for the 2.74 m shot, and guards and forwards for the 4.57 m distance. Release angles for all groups for 2.74 and 4.57 m shots lay between 52° and 55°. For long-range shots, however, all groups utilized lower \( (48-50°) \), but not significantly different, release angles. No other release speeds or angles were significantly different.

A similar relationship between shoulder and elbow angular velocities at release with respect to shooting distance was found for guards and forwards (Table 3). For both groups, this relationship was positive, while

**Figure 6** Typical stick figure sequences at \( t = 0 \) (0), take-off (1) and ball release (2) for (a) short-, (b) medium- and (c) long-range shots.

<table>
<thead>
<tr>
<th>Table 1 Mean standard errors for objectivity and reliability studies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objectivity</strong></td>
</tr>
<tr>
<td>Angular displacement (°)</td>
</tr>
<tr>
<td>Linear displacement (m)</td>
</tr>
<tr>
<td>Angular velocity (rad s(^{-1}))</td>
</tr>
<tr>
<td>Linear velocity (m s(^{-1}))</td>
</tr>
</tbody>
</table>
the maximum value for centres was at 4.57 m. Despite this trend, statistical contrasts across both groups and distances failed to yield any significant differences.

At the 2.74 m shooting distance, guards released the ball with a near-stationary centre of mass (0.02 ± 0.75 m s\(^{-1}\)), which was significantly different from all groups at 6.40 m, and from guards and forwards at 4.57 m (\(P < 0.01\); Table 4). The data from long-range shots showed a tendency for body movement at release to be in the sagittal plane in the direction of the basket, speeds ranging between 1.22 and 1.52 m s\(^{-1}\).

Trends in the change in release height (a principal factor in determining outcome; Fig. 2) with increasing distance were similar for guards and forwards (Table 5), for whom the lowest value was at the intermediate distance. For centres, an inverse relationship was evident. Despite being the group with the tallest mean height, the release height for centres at 6.40 m (2.23 ± 0.31 m) was smaller than that for guards (2.30 ± 0.10 m), who were, on average, the smallest group, and significantly different to that for forwards (2.52 ± 0.03 m; \(P < 0.01\)). An inverse trend was found for all groups between shooting distance and the time from take-off to release. The mean release time for centres at 6.40 m was actually prior to take-off.

Angular positions for upper body segments at release were largely similar across groups (Table 6). Trunk angle tended to remain constant at all distances, while a small inverse trend was detected for elbow angle. No significant differences were in evidence for any of these parameters. All groups increased their shoulder axis rotation at take-off (Table 7), the maximum value for which was 32 ± 9° (guards, 6.40 m). Values at release, however, tended to remain relatively constant for all
Table 6 Mean (± s.d.) trunk and upper limb joint angular displacements at release

<table>
<thead>
<tr>
<th>Variable</th>
<th>Shooting distance (m)</th>
<th>2.74</th>
<th>4.57</th>
<th>6.40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk to forward horizontal (°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guards</td>
<td></td>
<td>81 ± 6</td>
<td>82 ± 4</td>
<td>82 ± 5</td>
</tr>
<tr>
<td>Forwards</td>
<td></td>
<td>79 ± 3</td>
<td>80 ± 3</td>
<td>80 ± 4</td>
</tr>
<tr>
<td>Centres</td>
<td></td>
<td>82 ± 2</td>
<td>82 ± 2</td>
<td>77 ± 6</td>
</tr>
<tr>
<td>Shoulder (°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guards</td>
<td>133 ± 9</td>
<td>129 ± 10</td>
<td>124 ± 8</td>
<td></td>
</tr>
<tr>
<td>Forwards</td>
<td>133 ± 11</td>
<td>133 ± 11</td>
<td>131 ± 5</td>
<td></td>
</tr>
<tr>
<td>Centres</td>
<td>126 ± 9</td>
<td>121 ± 9</td>
<td>115 ± 22</td>
<td></td>
</tr>
<tr>
<td>Elbow (°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guards</td>
<td>142 ± 11</td>
<td>136 ± 13</td>
<td>135 ± 5</td>
<td></td>
</tr>
<tr>
<td>Forwards</td>
<td>144 ± 11</td>
<td>140 ± 13</td>
<td>143 ± 15</td>
<td></td>
</tr>
<tr>
<td>Centres</td>
<td>141 ± 19</td>
<td>135 ± 17</td>
<td>143 ± 14</td>
<td></td>
</tr>
</tbody>
</table>

*Three-dimensional trunk-to-upper arm angle.

Table 7 Mean (± s.d.) shoulder and hip axis rotations* at take-off and release

<table>
<thead>
<tr>
<th>Variable</th>
<th>Shooting distance (m)</th>
<th>2.74</th>
<th>4.57</th>
<th>6.40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder axis rotation at take-off (°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guards</td>
<td>9 ± 6</td>
<td>14 ± 3</td>
<td>15 ± 6</td>
<td></td>
</tr>
<tr>
<td>Forwards</td>
<td>20 ± 4</td>
<td>28 ± 5</td>
<td>32 ± 9</td>
<td></td>
</tr>
<tr>
<td>Centres</td>
<td>14 ± 18</td>
<td>19 ± 9</td>
<td>24 ± 3</td>
<td></td>
</tr>
<tr>
<td>Shoulder axis rotation at release (°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guards</td>
<td>16 ± 12</td>
<td>21 ± 10</td>
<td>18 ± 7</td>
<td></td>
</tr>
<tr>
<td>Forwards</td>
<td>23 ± 6</td>
<td>29 ± 8</td>
<td>34 ± 13</td>
<td></td>
</tr>
<tr>
<td>Centres</td>
<td>23 ± 14</td>
<td>21 ± 4</td>
<td>23 ± 3</td>
<td></td>
</tr>
</tbody>
</table>

*0° = parallel to backboard. Anti-clockwise rotations viewed from above are positive.

Discussion

Deterministic factors influencing outcome in the basketball jump shot are shown in Fig. 2. Release speeds were similar to previously reported data for similar shooting distances (e.g. Toyoshima et al., 1985; Elliott, 1992). The increases in ball release speed with shooting distance should approximate to the quadratic relationship which exists between these two variables, even taking into account the effects of changes in release height with distance. While this was the case for guards and centres, and was reflected for the former by the significant differences (P < 0.01) between short- and long-range speeds, values for forwards increased almost linearly.

It should be recognized that the horizontal ball displacement from the point of release to the moment its centre passes through the basket is unlikely to be equal to the nominal shooting distance. This is due to both horizontal centre of mass movement during the shooting process, and release of the ball somewhat in front of the feet. Neither variable was measured. However, Gia- nikellis (unpublished data) found values for the latter of between 0.16–0.18 m. It is possible that the difference between the true horizontal ball displacement and the nominal shooting distance is greater than this, especially at 4.57 and 6.40 m, where horizontal centre of mass movement tended increasingly to be in the direction of the basket.

Figure 2 shows that, apart from release speed, the only factors which influence outcome are release angle, release height and air resistance. While the contribution of air resistance is small, the drag force experienced by the ball is, for the current range of release speeds, a function of the square of the latter. This suggests that a greater than linear increase in release speed with shooting distance may be necessary. The almost linear increase in release speed with distance found for forwards may be explained in part by examining release angles. For 2.74 and 4.57 m shots, these lay in the 52–55° range, which allows the greatest margin for error (Hay, 1994), but decreased to 50° at 6.40 m. From Brancazio's (1984) equation, this was found to be closer to the angle requiring minimum release speed (i.e. providing maximum range). A similar pattern was found for both guards and centres, the smallest difference between the actual release angle and that providing maximum range being 0.7° (centres, 6.40 m). This would suggest that at short and medium range, shooters of all playing positions tend to utilize release angles which provide a steeper angle of entry into the basket and therefore a greater margin for error. For long-range shots, this benefit was outweighed by the need for release angles which require the lowest possible release speed. It was seen that the change in release angle demonstrated by guards tended to exhibit a pattern of consistent decrease, while that for forwards and centres tended only to decrease between 4.57 and 6.40 m. All release angles were greater than those reported for male
subjects by Elliott (1992): 45°, 47° and 44° for shots of 4.25, 5.25 and 6.25 m, respectively. This may be attributed, in part, to the greater stature of the subjects in Elliott's study.

Release speed is determined, to a large extent, by the angular velocities of the joints of the shooting arm and the linear velocity of the shoulder of the shooting arm at the moment of release. While no significant differences were found when taking all groups into account, the similar trends exhibited by guards and forwards for shoulder and elbow joint angular velocities may indicate a relationship between these parameters and shooting distance for these two groups. The different relationship between the same parameters for centres may, in part, be a function of their unfamiliarity with the 6.40 m distance.

The increased contribution for all groups of centre of mass speed at release to ball speed with shooting distance is in accord with previous research (Walters et al., 1990). It would seem that for the required increases in speed between medium- and long-range shots, centres tended to utilize increased centre of mass speed in the direction of the basket to a greater extent, while keeping the required increase to a minimum by releasing the ball at an angle which provided maximum range. A zero centre of mass speed at release would be optimal, as the target would appear stationary relative to the shooter. For non-zero values, the target would appear to be moving, and would thus require consideration in the selection of release parameters. Interestingly, centres exhibited the lowest mean take-off speed for both 4.57 and 6.40 m shots, yet also the highest values at release for all distances. It is possible that these are active strategies on behalf of all groups. Guards and forwards tended to use take-off speed in order to increase release height, while centres used it as an aid to the provision of release speed, at the expense of height. Calculations which revealed small (< 0.06 m) horizontal distances travelled after take-off strongly suggest that take-off speed is not used to reduce the distance to the basket, and thus supports the above suggestions for its use. Elliott (1992) reported a positive correlation between horizontal displacement of the hip joint and shooting distance for male subjects which, in conjunction with ball release occurring at greater than 88% of maximum jump height, would suggest a considerably greater utilization of take-off speed to reduce the distance of the shot.

Outcome is also directly affected by release height (Fig. 2). It may be expected that, being the tallest group, centres would display the greatest release height followed, in descending order, by forwards and guards. This was found not to be the case, with the subjects’ height accounting for a maximum of only 35% of the variance in release height. The comparatively low mean release heights of centres, especially at 4.57 and 6.40 m, were due partly to a lower vertical centre of mass displacement (jump height) between take-off and release. This was due in turn to an earlier (but non-significant) release with respect to take-off than either guards or forwards. Indeed, the negative value for centres at 6.40 m indicates release of the ball prior to leaving the ground, therefore negating their natural height advantage. The most likely reason for this is that centres elected to utilize the forward and upward momentum of the body to help in the provision of release speed, and felt more comfortable releasing the ball while maintaining ground contact, being unused to generating the appropriate release speeds. It is also possible that use of this technique allowed greater control of release parameters. The greater variability found in the time from release to the vertical peak of the centre of mass for short- and medium-range shots, where the required release speed is small or moderate, suggests that release with a stationary or downward moving centre of mass has little or no effect on accuracy. The inverse relationship found between variability in this parameter and shooting distance provides a further indication of an increased need to use body momentum in the direction of the basket as an aid to provision of release speed as shooting distance increases.

The finding of forward lean of the trunk by all groups at all distances is in accord with the data of Elliott (1992). The slightly smaller values reported by Elliott may be due, in part, to the analysis technique employed, in which only the joint centres of the preferred side of the body were digitized. The decrease in shoulder angle at release with increased distance suggests an increased utilization of the ‘push pattern’ of release reported for four female subjects by Walters et al. (1990), in which the path of the ball prior to release tends to be rectilinear as opposed to curvilinear, which, in turn, requires concurrent shoulder flexion and elbow extension.

Segmental configuration at release, principally of the trunk, upper arm and forearm segments, also influences release height (Fig. 2). Addition of the joint angles of the kinematic chain with respect to the ground revealed the mean forearm angle to be between 6° (centres, 4.57 m) and 41° (centres, 6.40 m) forward of vertical. As increases in shoulder angle will increase release height within normal ranges of movement, this is seen to be a further factor contributing to the comparatively low release height for centres. While much coaching literature has advocated the use of full elbow extension at release (e.g. Stimpson, 1986), this was not in evidence, supporting previous empirical findings (e.g. 128–137°; Miller and Bartlett, 1993).

Much previous research into basketball shooting has employed a single-camera lateral view, assuming the
skill to be two-dimensional in nature (e.g. Elliott and White, 1989). A previous three-dimensional study by Miller (1992), however, reported considerable horizontal plane rotation of the shoulder axis at both take-off and release. This facilitates the alignment of the elbow and wrist joints with the eyes (Hay, 1994). It can be seen that the amount of change in the shoulder axis angle between take-off and release tends to decrease with increased shooting distance. This tends to be due not to a decreased amount of rotation at release, but to an increased rotation at take-off. This suggests an earlier 'pre-set' of the shoulder axis prior to release (Ingram and Snowden, 1989), probably because release occurs sooner after take-off as shooting distance increases. Guards tended to exhibit the smallest change in the amount of rotation between 4.57 and 6.40 m. This, along with the findings discussed above, seems to support the theory that guards have developed shooting techniques which are more consistent with respect to changes in shooting distance. Such techniques were found to be exhibited to a lesser extent by forwards.

Conclusions

The increases in release speed found with shooting distance were due, for guards and forwards, to greater contributions from shoulder flexion and elbow extension, and an increased centre of mass speed in the direction of the basket at release for all groups. The almost linear increase in ball release speed exhibited by forwards as shooting distance increased was due to the use of a release angle at medium range which afforded a comparatively steep angle of entry, and one at long range which required close to the minimum release speed, thereby providing maximum range.

For guards and forwards, release height was at a minimum at 4.57 m, whereas for centres this value exhibited an inverse relationship with shooting distance. The latter was due both to a decrease in the time from take-off to release, and a combination of segmental positions which resulted in the forearm forming the greatest angle with the vertical at release. The earlier time of release gave rise to an earlier rotation of the shoulder axis, which facilitates accuracy by aligning the elbow and wrist joints with the eyes.

Guards tended to display more consistent changes in kinematic patterns with changes in shooting distance than centres. This would suggest that it is easier to adjust shooting kinematics with respect to distance when playing a position which necessitates the majority of shots being taken from long range. This is supported by Walters et al. (1990), who reported a more consistent scaling of variables with respect to long-range, as compared to medium-range, shooters.

The current findings may also support the notion of teaching all players to shoot from a range of distances, and to encourage all players, especially centres, to continue to practise shooting from such ranges. Further research is recommended in this area.

References


