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Kinematic adjustments in the basketball jump shot against an opponent

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The aim of this study was to analyse the adjustments in technique made by a basketball player when shooting against an opponent. The subjects used consisted of 10 professional basketball players of the Spanish First Division League. Three-dimensional motion analysis based on video recordings (50 Hz) was used to obtain the kinematic characteristics of basketball jump shots with and without an opponent. It was found that when performing against an opponent the release angle of the ball increased, the flight time was reduced and postural adjustments as determined by the angles at the knee and shoulder increased, all significantly. There were several other non-significant differences that helped to interpret the changes in technique imposed by the presence of an opponent. It was suggested that when shooting with an opponent, players attempted to release the ball more quickly and from a greater height. This strategy will lessen the chance of the opponent intercepting the ball. It was concluded that the differences noted in the technical execution of the skill had implications for practice. It was suggested that training would benefit from practice with an opponent for at least some of the time to condition players to the demands which they were more likely to meet in the game situation.

1. Introduction

Shooting is the principal method used to score points in basketball and for this reason it is the most frequently used technical action (Hay 1994). The jump shot is distinguished as the most important of all the shooting actions (Hess 1980), and in the Spanish Basketball League it is the one most often used successfully, since 41% of all points are scored by using this technique (Asociación Clubs Baloncesto (ACB) 1997). Efficacy in shooting is identified with the ability to perform well in this sport and consequently it is extensively practised.

In basketball studies biomechanical research has focused on various aspects including basic shooting techniques (Brancazio 1981, Hay 1994), differences in play between the sexes (Elliott and White 1989) and the characteristics of players at different skill levels (Hudson 1985). Some of these studies have analysed the jump shot and the variables studied are mainly those that determine the flight characteristics of the ball. The principal factors determining the flight characteristics of the ball (and therefore outcome) are release speed, release angle and release height (Hay 1994).

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Some of these studies have also included analysis of the jump shot under different conditions, as the variability in the performance of the shot is determined by a number of factors (Sáenz and Ibáñez 1995) such as arm action (standard, hook and lay-up), previous technical action (dribble, reception fake), previous movement of the legs (stationary or running), final movement of the legs (with or without jump), body orientation, height and distance of the shot, and opposition. For example, Elliott and White (1989), Walters *et al*. (1990), Miller and Bartlett (1993) and Satern (1993) studied the effects of increased shooting distance in the jump shot, whilst Gabbard and Shea (1980) and Chase *et al*. (1994) analysed the effects of equipment modifications on children and jump shot performance.

Of these influencing factors, no research group has attempted to establish the effects of opposition on the movement characteristics of the jump shot. As the technical performance of the shot may be expected to change with the presence of opposition, then practising the jump shot skill without realistic opposition may be less beneficial to skill development and maintenance. Therefore, the aim of this study was to determine the influence of the presence of an opponent on jump shot technique. This aim was met by investigating the biomechanical characteristics of jump shot technique with and without an opponent.

2. Methods

2.1. *Subjects*

The subjects used were 10 male, active professional basketball players from the First Division of the Spanish Basketball League (ACB) who volunteered to take part. All were right-handed and specialists in mid- and long-distance shooting. The mean age was 23.36 ($\pm$2.87) years with a mean height of 1.95 ($\pm$0.09) m and a mean mass of 90.43 ($\pm$12.40) kg.

2.2. *Data collection*

The execution of the jump shot is subject to all types of stimuli, external contingencies and attentional mechanisms. For this reason, and in order to control these variables, it was necessary to analyse the action using a protocol similar to that encountered in competition, where the variables manipulated are controlled and those that influence it are kept constant. The manipulated variable was the presence or absence of opposition, while the controlled variables were the previous technical action (running and stop), body orientation and distance of the jump shot.

Two video cameras were used at 50 Hz to record the performance of the shots. The first was placed at a distance of 10 m from where the shot was to be made with an orientation of 45° to the direction of the shot, and the second was situated 11 m from the shot with an orientation of 45° to the direction of the shot and 90° to the orientation of the first camera. The cameras were started approximately 3 s prior to the beginning of each shot and were not switched off until the ball passed through the hoop to ensure the recording of a sufficient portion of the performance to permit analysis of release variables. After positioning the cameras, and before filming the shots, a reference object was filmed. The reference object was so oriented that the x-axis was in line with the direction of the shot, the z-axis was perpendicular and horizontal to the direction of the shot and the y-axis was perpendicular to the plane of the floor.

Once the warm-up was conducted, the subject completed the experimental protocol (figure 1). The starting position was in the central zone of the court

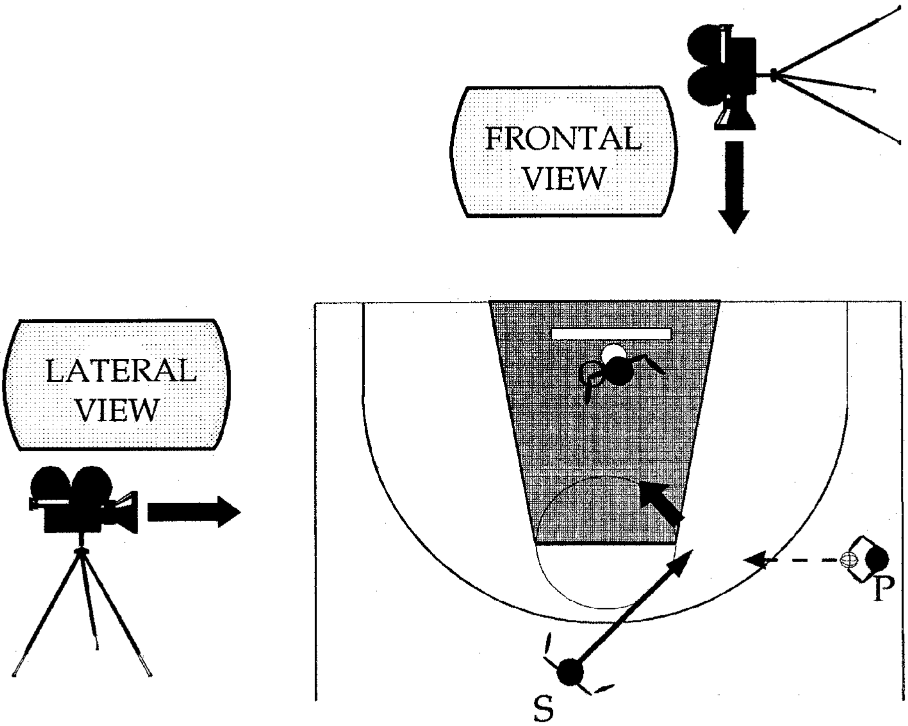

Figure 1. Experimental protocol.

(Position S of figure 1), and from that static position the player ran along a line as shown in figure 1. During his run, the player received a ball from player P at a point 2 m before reaching the shooting position. At the instant of receiving the ball, the player stopped and he finally made the shot. The opponent, situated in the horizontal projection of the hoop, O, remained in that position until the moment in which the ball left the passer's hands. The opponent, at that moment, at random, either remained in that position or moved to intercept the ball, sometimes succeeding in doing so. This protocol was continued until each player had performed 15 successful shots.

Eight shots by each player (four with and four without opposition) were selected for analysis, the criterion being those where the ball passed through the hoop without touching either it or the backboard.

2.3. *Data analysis*

The human model used for the analysis consisted of 14 segments plus an implement, in this case the ball, which was considered as a sphere. Twenty-three points, using the inertial parameters given by De Leva (1996), defined these segments. The co-ordinates of each point were obtained by digitizing the images of both cameras. The digitized data were smoothed, interpolated and synchronized to an equivalent sampling rate of 100 Hz, using a fifth order spline (Wood and Jennings 1979). The three-dimensional co-ordinates were obtained through the direct linear transformation (DLT) procedure (Abdel-Aziz and Karara 1971) and subsequently each of the biomechanical variables that defined the characteristics of the action were calculated.

2.4. *Selection of the variables*

The dependent variables were selected because they had been studied extensively in the literature and/or because basketball coaches focus on them in training sessions to improve the player's technique.

The variables were grouped according to Hudson (1985) who postulated two classes: (1) product variables, which determine the final result of the action and which here correspond to the angle, speed and height of the release of the ball and are based on the mechanical inter-relationships of projectile motion and are illustrated in figure 2, and (2) process variables, which are the most significant causes in determining the efficacy of the action during its execution. The process variables were classified into three groups and are described in tables 1, 2 and 3 and illustrated in figure 2. The temporal variables (table 1) were obtained from the key moments defined by the spatial positions adopted by the player and the ball during the course of the performance of the jump shot. The positional variables (table 2) were obtained from the spatial positions adopted, choosing the most significant positions in relation to the performance of the jump shot. The velocity variables (table 3) refer to the velocities developed during different phases of the shot.

2.5. *Statistical analysis*

As the aim of this study was to examine the effect of one independent variable (opposition) on the dependent variables mentioned above, a one-way analysis of variance was used. A value of $p < 0.05$ was used to indicate significance.

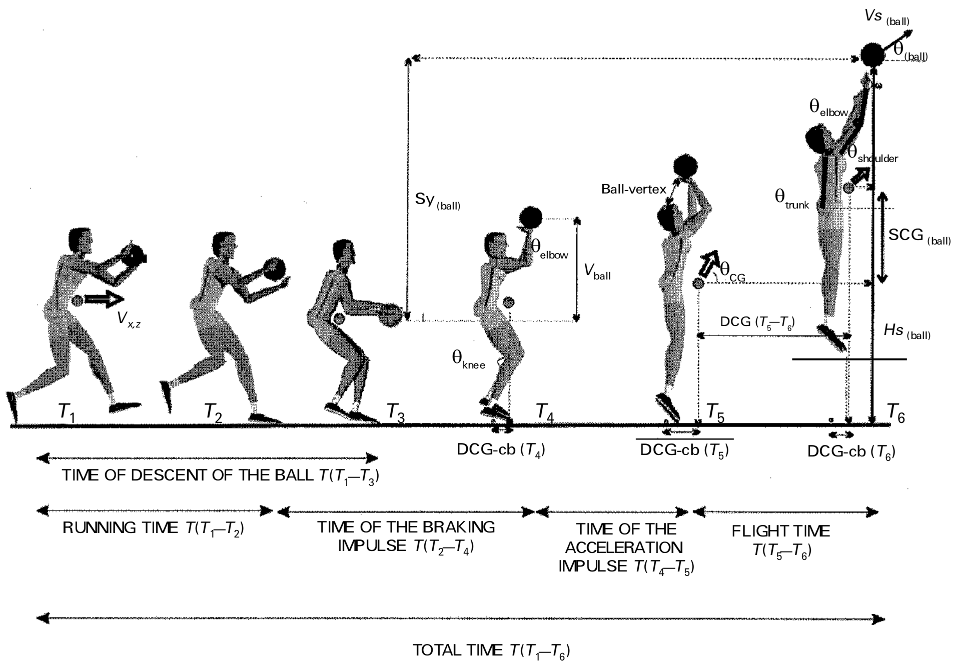

Figure 2. Biomechanical factors analysed.

Table 1. Temporal variables in the jump shot.

T_1	Moment of receiving the ball.
T_2	Moment when one or both feet made contact with the ground in order to jump.
T_3	Instant when the ball was at its lowest point.
T_4	Instant in which the centre of gravity (CG) of the player and the ball reached its lowest vertical point.
T_5	Instant in which the player took both feet off the ground.
T_6	Moment when the ball left the player's hands.

Table 2. Positional variables in the process of shooting.

DCG-cb. (T_4)	Distance between horizontal projection of CG and the centre of the support base and the lowest position of CG.
DCG-cb. (T_5)	Distance between horizontal projection of CG and the centre of the support base and take-off.
DCG-cb. (T_6)	Distance between horizontal projection of CG and the centre of the support base and ball release.
DCG ($T_5 - T_6$)	Distance between the horizontal projection of CG at take-off and ball release.
Ball-vertex (T_5)	Ball-vertex distance at take-off.
$Sy_{(ball)}$	Vertical displacement of the ball, from its lowest position to height of release.
θ_{knee} (T_4)	Knee angle at the beginning of the acceleration impulse phase, the three-dimensional included angle formed by a line joining the hip, knee and ankle joint centres.
θ_{elbow} (T_4)	Elbow angle at the lowest position of the CG, the three dimensional included angle formed by a line joining the wrist, elbow and shoulder joint centres.
θ_{CG} (T_5)	Take-off angle of CG, the two-dimensional included angle formed by the projection, onto the x,z (sagittal) plane, of the line joining the positions of the CG at take-off and one frame after take-off and the forward horizontal.
θ_{trunk} (T_6)	Trunk angle at ball release, the two-dimensional included angle formed by the projection, onto the x,y (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.
$\theta_{shoulder}$ (T_6)	Shoulder angle at ball release, the three-dimensional included angle formed by a line joining the centres of the right shoulder and elbow joints and the line joining the mid-points of those lines joining the right and left shoulder, and right and left hip joints.
θ_{elbow} (T_6)	Elbow angle at ball release.

Table 3. Velocity variables in the jump shot.

$V_{x,z}$ (T_1)	Horizontal velocity of the CG at the moment reception of the ball.
$V_{x,z}$ (T_5)	Horizontal velocity of the CG at the moment take-off.
$V_{x,z}$ (T_6)	Horizontal velocity of the CG at the moment ball release.
V_{ball} ($T_3 - T_4$)	Mean vertical velocity of the ball from its lowest vertical point (T_3) until the beginning of the acceleration phase (T_4).
ω_{wrist} (T_6)	Angular velocity of the wrist at ball release.

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 variations are homogeneous (Cohen and Holliday 1982) was not violated.

3. Results and discussion

3.1. *Product variables*

The release angle of the ball (θ_{ball}) increased significantly in the presence of an opponent (table 4) and this helped the player to avoid the possible interception of the ball by the opponent's hand. The mean release angle of the ball in this study was 45° in contrast to an angle of 48° found in the studies carried out by Mortimer (1951), Brancazio (1981), Hudson (1985), Satern (1988), Walters *et al.* (1990) and Miller and Bartlett (1996). This may be due to the greater height of the release of the ball caused by the greater height of the subjects in the present study, 1.95 m, against the mean of 1.83 m reported in the studies above. The distance of the ball from the basket in this study was similar to the distance in the studies referred to above, although the player's position on court was different.

The velocity of ball release (Vs_{ball}) was not significantly different between the opponent and non-opponent conditions. The mean value (6.33 m s^{-1}) was similar to data reported by Walters *et al.* (1990), where the jump shots taken from the free throw line were between 6.6 and 6.9 m s^{-1}, and by Miller and Bartlett (1993, 1996) who reported values of around 6.2 m s^{-1}, but it was lower than that reported in other studies where shots were taken from the same distance, such as Mortimer (1951) and Hudson (1985), who reported values of 9.95 and 7.13 m.s^{-1}, respectively.

The height the ball reached at release (Hs_{ball}) was higher when shooting against an opponent than without an opponent even though the height reached by the centre of gravity (CG) from the take-off position of the player to the release of the ball (SCG_{ball}) was lower, but neither of these were significantly different. The greater ball release height could be related to the greater release angle as several authors (Yates and Holt 1982, Toyoshima *et al.* 1985, Satern 1988, Miller and Bartlett 1996) have reported a close relation between these two variables, which reflects a more vertical orientation of the arm at release. The lower height reached by the CG may be related to the requirements of releasing the ball quickly with the presence of opposition.

3.2. *Process variables*

The temporal variables are shown in table 5. The significant reduction in flight time ($T_5 - T_6$) when there was an opponent suggests that the player is jumping more

Table 4. Results of product variables.

	Without opponent (N= 40)		With opponent (N= 40)			
	Mean	SD	Mean	SD	F	p
θ_{ball} (°)	44.7	2.3	47.0	1.7	4.592	0.036*
Vs_{ball} (m s^{-1})	6.30	0.57	6.36	0.50	0.194	0.666
Hs_{ball} (m)	2.85	0.16	2.88	0.16	0.559	0.4651
SCG_{ball} (m)	0.32	0.09	0.31	0.09	0.264	0.614

*$p < 0.05$.

rapidly and with less effort. Consequently, he will achieve a lower peak elevation of the CG. Although the latter variable was not significantly different between the two conditions (as noted above), the temporal data confirm the importance of this observation.

Given that the height of release of the ball was greater with opposition than when unopposed, the explanation may be that the player adopts changes in the position of his joints during shooting so that the height of the release of the ball is greater even though the jump elevation of the CG is lower in the presence of opposition. These postural adjustments are detailed as position variables (table 6) in which the angle at the knee at time T_4 and the angle at the shoulder at time T_6 were significantly different between the two conditions. These findings indicate that where players face an opponent they begin the propulsive phase of the jump shot with a larger angle of the knee (θ_{knee} (T_4)) giving them a more elevated position of the CG. In addition, at release the player increases shoulder flexion, ($\theta_{shoulder}$ (T_6)) and the angles of inclination of the trunk (θ_{trunk} (T_6)) and the elbow angle (θ_{elbow} (T_6)), although these two latter variables were not significantly different. It is probable that the sum of all the joint angles taken together would reveal significant differences between the two situations, since the tendency for each was for an increase when facing opposition.

Table 5. Results of process variables: temporal.

	Without opponent		With opponent			
	Mean	SD	Mean	SD	F	p
Running time, ($T_2 - T_2$) (s)	0.14	0.10	0.17	0.12	1.183	0.280
Time of descent of the ball, ($T_1 - T_3$) (s)	0.14	0.07	0.12	0.04	0.163	0.692
Time of braking impulse, ($T_2 - T_4$) (s)	0.30	0.09	0.30	0.08	0.048	0.828
Time of acceleration impulse, ($T_4 - T_5$) (s)	0.16	0.03	0.16	0.03	0.349	0.563
Flight time, ($T_5 - T_6$) (s)	0.26	0.04	0.24	0.03	3.984	0.04*
Total time, ($T_1 - T_6$) (s)	0.86	0.10	0.87	0.12	0.233	0.636

*$p < 0.05$.

Table 6. Results of process variables: positional.

	Without opponent		With opponent			
	Mean	SD	Mean	SD	F	p
θ_{CG} (T_5) (°)	77.86	6.54	77.17	5.80	0.227	0.640
DCG-cb.(T_4) (m)	0.16	0.07	0.15	0.07	0.416	0.528
DCG-cb.(T_5) (m)	0.14	0.05	0.13	0.05	0.997	0.332
DCG-cb.(T_6) (m)	0.07	0.04	0.08	0.04	1.438	0.235
DCG ($T_5 - T_6$) (m)	0.12	0.04	0.12	0.04	0.041	0.841
θ_{knee} (T_4) (°)	107.01	8.36	110.1	7.14	6.351	0.014*
θ_{elbow} (T_4) (°)	73.00	15.43	71.81	12.45	0.131	0.722
Ball-vertex (T_5) (m)	0.26	0.05	0.26	0.05	0.136	0.718
Sy_{ball} (m)	1.89	0.20	1.92	0.20	0.664	0.427
θ_{trunk} (T_6) (°)	82.68	2.87	85.26	2.64	0.782	0.389
$\theta_{shoulder}$ (T_6) (°)	136.95	3.92	138.79	2.64	2.494	0.032*
θ_{elbow} (T_6) (°)	123.81	9.89	126.42	10.54	0.064	0.803

*$p < 0.05$.

These results agree with the findings of authors such as Ryan and Holt (1989), White and Elliott (1989), Satern (1993) and Miller and Bartlett (1996) who reported that when the shooting distance was increased the joint angles of the propelling arm also increased at release. It is therefore suggested that the positions adopted by the upper arm segments at the end of the shot must be considered as relevant factors that are affected by the presence of opposition. These differences are illustrated in figure 3.

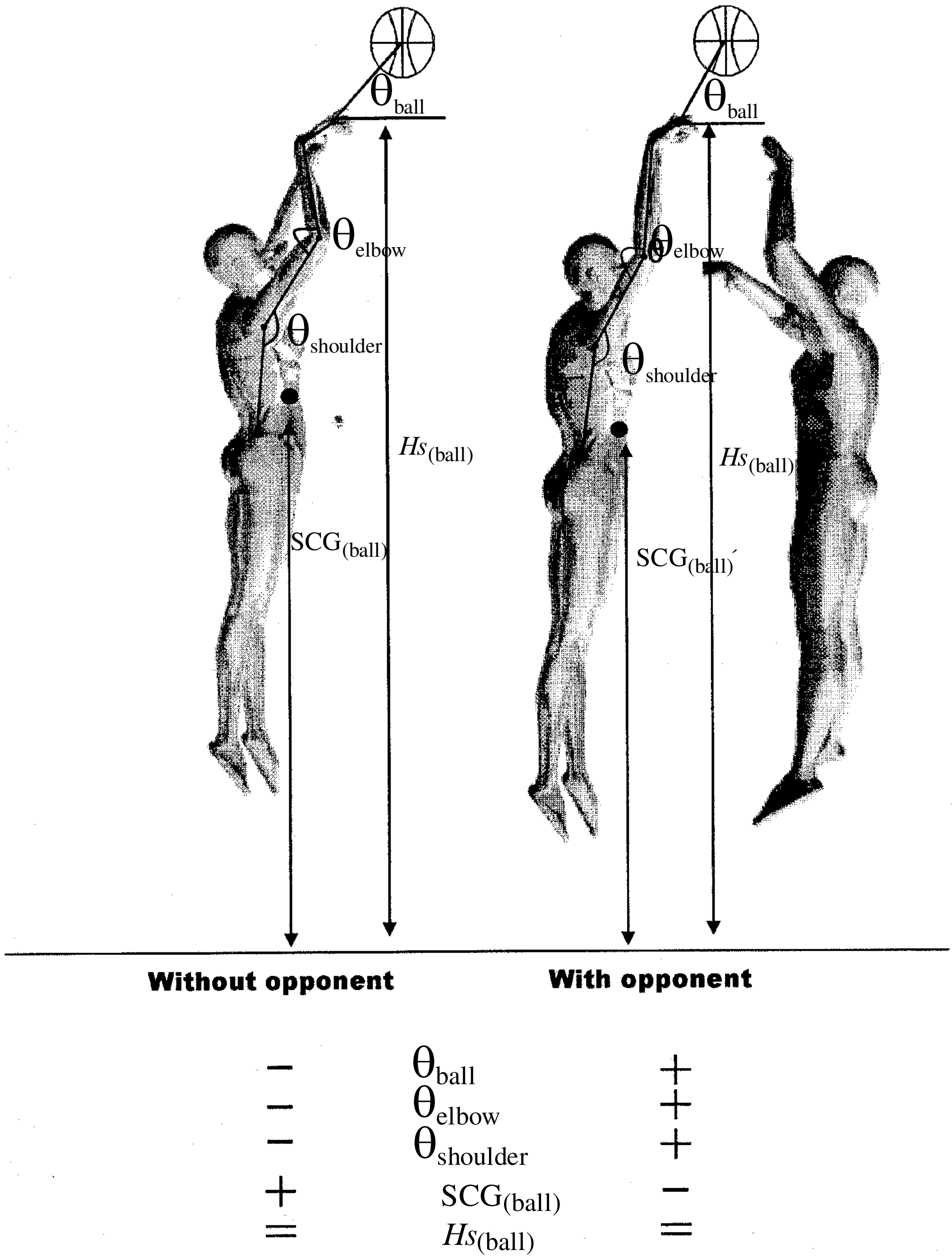

Figure 3. Differences between shots with and without opponent at the moment of ball release.

With regard to the velocity variables (table 7) there appears to be no difference in the horizontal velocity characteristics of the CG during the movement although there was a tendency for the CG to have a slightly greater horizontal velocity at the beginning of the movement (probably reflecting the urgency imposed by the presence of an opponent) and a lower horizontal velocity at release (reflecting the more upward projection angle as noted above in order to gain extra height). The vertical velocity of the ball from its lowest point until its release was significantly greater with an opponent, which confirms the earlier suggestion that when faced with opposition players move more rapidly in the initial phase of the shot. The wrist angular velocities were not significantly different between the two situations, but the lower value against opposition might reflect the emphasis placed on joint extension to gain height and in so doing also use this as a means to propel the ball.

4. Conclusions

In conclusion, it can be stated that players attempt to release the ball more quickly and from a greater height when confronted with an opponent. This strategy lessens the chance of the opponent intercepting the ball. Players realize this strategy by approaching more rapidly and positioning the body in a more upright position at the initiation of the upward movement of the ball. This manoeuvre gives players greater initial height but also a more stable base for generating a greater initial velocity of the ball. The greater initial knee position restricts the ability of the player to jump and therefore he performs a quicker but less powerful jump, while the more rapid upward movement of the ball helps to increase the joint angles at shoulder and elbow at release and this, combined with a more upright trunk, helps the ball to attain a greater height and a more vertical angle of projection. This interpretation is supported by significant differences and trends in the biomechanical data collected.

The differences in technical execution of the skill have implications for practice. Although the differences between the two situations are small, it is likely that they lead to significantly different demands on the neuromuscular co-ordination requirements for situations with and without opposition. This implies that training would benefit from practice with an opponent for at least some of the time to condition the players to the demands that they are more likely to meet in the game situation. It is unknown at this time what proportion of practice would best be done in this way, or the effects that variability of practice has on performance of the basketball jump shot.

Table 7. Results of process variables: velocity.

	Without opponent		With opponent			
	Mean	SD	Mean	SD	F	p
$V_{x,z}$ (T_1) (m s^{-1})	2.11	0.71	2.25	0.73	0.721	0.408
$V_{x,z}$ (T_5) (m s^{-1})	0.55	0.29	0.58	0.25	0.084	0.776
$V_{x,z}$ (T_6) (m s^{-1})	0.64	0.25	0.61	0.29	0.211	0.653
V_{ball} ($T_3 - T_4$) (m s^{-1})	4.07	0.90	4.45	0.91	6.483	0.021*
ω_{wrist} (T_6) (rad s^{-1})	26.22	8.19	24.03	5.10	1.864	0.176

*$p < 0.05$.

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