

**A Comparison of Two Landing Styles in a Two-foot Vertical Jump**

**RUNNING HEAD: Differences between two takeoff styles**

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## **ABSTRACT**

In team sports, such as basketball and volleyball, the players use different takeoff styles to make the vertical jump. The two-foot vertical jump styles have been classified according to the landing style and identified as Hop style, when both feet touch the ground at the same time and Step-close style, when there is a slight delay between the first and second foot making contact with the ground. The aim of this research is to identify the differences between the two styles. Twenty-three subjects participated in the study, of whom 14 were volleyball players and 9 basketball players. The jumps were video recorded and synchronized with two force platforms at 250 Hz. Two temporal periods of the takeoff were defined according to the reduction or increase in the radial distance between the CG and the foot support ( $T.-RD_{CG}$  y  $T.+RD_{CG}$ , respectively). The findings produced no specific advantages when both styles were compared with respect to takeoff velocity and consequently to jump height, but takeoff time was significantly shorter ( $p < 0.001$ ) in the Hop style takeoff. However, this reduction was compensated for by the greater time employed in the last step of the approach run ( $p < 0.001$ ). When the Step-close style was used, the vertical velocity of CG at the beginning of the takeoff is significantly lower. Moreover, the mean vertical force developed during  $T.-RD_{CG}$  was reduced by  $-627.7 \pm 251.1$  N, so lessening impact on landing. Horizontal velocity at the end of the takeoff is less when the Step-close style is used ( $p < 0.005$ ), suggesting that this style is better for jumps where it is

necessary to move horizontally during the flight against an opponent

**Key Words:** Impulse, Force platforms, video analysis.

## **INTRODUCTION.**

In sports where the vertical jump is especially relevant to performance –as is the case with basketball or volleyball- different takeoff styles are usually observed in the jump. Generally, these jumps are used when making certain important technical actions such as the shot at the basket in basketball or the shot or block in volleyball, which require not only a elevated jump but also the correct direction of forces to be able to overcome the opposition of the opposing player. These jumps are usually made with both feet after a two-or three-step run-up. These types of jump vary according to the time that elapses between the contact of the feet with the ground during the landing phase prior to the take-off for the jump. This fact enables us to differentiate two styles that have given rise to some controversy about their relative efficiency (5). Specifically, Coutts (6) identifies the styles as hop style, when both feet touch the ground at the same time, and step-close style, when the second, or trailing, foot takes longer to make contact with the ground. This paper aims to determine the differences between both styles using dynamometric and video recording techniques, and a methodology based on Dapena and Chung's theoretical interpretation of the high jump takeoff (8).

The two-foot support vertical jump has been studied from a biomechanical viewpoint on many occasions and with different purposes: to evaluate different ways of muscle participation (3, 15), to assess segmental participation (9,12,16), or to identify its determining efficiency factors (2, 13,

23). However, generally the jump is quantified based on the vertical component of the force from a stationary position, with or without a countermovement, or based on different heights, ignoring the effect on the takeoff phase produced by the run-up.

Takeoff analysis in vertical jumps with a run-up has focused on different goals: Dapena (7) and Dapena and Chung (8) connected it to the high jump, Saunders (20) assessed the effect of the run-up on takeoff effectiveness, and Vint and Hinrichs (22) conducted a comparative study of one-foot and two-foot takeoffs. Dapena and Chung (8) found differences between radial and vertical motions in the takeoff phase of the vertical jump, underlining the need to use a theoretical model in takeoffs with a run-up different from that used in vertical jumps made from a standstill or with a countermovement. Following this model for the Hop style, at the end of the approach run, the foot is placed in front of the CG, resisting the linear motion of the CG by flexing the takeoff leg. This action produces a radial distance reduction and the stretching of the muscles as the CG moves upwards (Figure1, b-c). The radial distance then increases, the leg muscle in the takeoff leg shortening while the CG continues rising (Figure1, c-e). The combined effect of fast horizontal velocity and the backward inclination of the body at the start of the takeoff facilitates reflex tension and other pre-tension mechanisms during the stretching of the muscles, which allows vertical force to increase as the muscles shorten (4, 15).

\*\*\*\*Figure 1 near here\*\*\*\*

Based on the vertical force recorded on a force platform and using a theoretical countermovement vertical jump model, Coutts (6) found significant differences between Hop style and Step-close style takeoffs. Among other divergences he argued that, in the Hop style, takeoff time is reduced while mean vertical force is significantly higher. These differences are caused by greater muscle pre-tension resulting from an increase in vertical velocity at the end of the run-up, as is the case with countermovement jumps from different heights (3, 15). Despite the differences described by Coutts (6) between the two takeoff styles, no statistically significant differences have been found in vertical velocity at the end of the takeoff and, consequently in the height of the jump.

Vint and Hinrichs (22), on comparing vertical jumps with one or two feet took into account the values of the horizontal force component, adapting the methodology proposed by Dapena and Chung (8) for the two-foot vertical jump. In addition to recording the vertical displacement of CG, they analysed the distance and radial velocity of CG, using the position of a vector that was defined from CG to the mid-point of both feet when they were firmly planted on the ground. Among other considerations in two-foot jumps, they found that when the minimum radial distance was reached, the vertical velocity of CG is positive, an important factor for performance of the vertical jump with a previous approach runs. Coutts (6) did not assess this aspect when he compared takeoffs made in the Hop style and Step-close style. In his model of jump he considered only the vertical displacement of CG based on the vertical

force component and theoretically estimating the vertical position of CG at the start of the takeoff. In this way, when minimum height is reached, the vertical velocity of CG is always zero.

Our practical interest lies in discovering which of the two styles might have more advantages when making the jump in sports where there is opposition such as basketball and volleyball, and where, in addition to the height reached by the CG, the time required for its execution and the spatial orientation of the corporal segments are factors that determine the performance of the takeoff (18). Moreover, taking into account the high number of jumps made in these sports, a second practical aspect is the prevention of injuries based on the analysis of the values reached in the vertical and horizontal force components pushing against the ground when taking off for both landing styles.

## **METHODS.**

### **Approach to the Problem**

This study was designed to check the effects of the two landing styles (hop style and step-close style) on the biomechanical factors that determine the efficiency of the takeoff in the two-foot vertical jump with a previous 3 step approach run, and with arm movement. The styles are defined according to the delay in landing of the second foot with respect to the first. Hop style is defined as a takeoff where both feet make contact with the ground simultaneously. After analyzing the results, the criterion used to identify hop style was that the delay in the arrival of the second foot was less than 0.009 s.

When both feet made contact with the ground at the same time, the first support was taken as being the foot that made the push off on the last step of the approach run. Step-close style was defined as a takeoff where there was a time lag between the landing of the first foot and the second foot, the criterion to identify step-close style being a lag time of between 0.079 and 0.131s.

The methodology proposed by Dapena and Chung (8) was adopted to evaluate the performance of the takeoff in the two-feet jumps. For the analysis of the radial movements ( $RD_{CG}$ ,  $RV_{CG}$ , distance and radial velocity, respectively), a position vector was defined from a rotation axis related to the support of the feet on the ground and the subject's CG. For the analysis of the vertical movements of the CG, the height of CG was recorded ( $Y_{CG}$ ), as well as the vertical and horizontal velocity components of the time the takeoff took ( $YV_{CG}$  and  $XV_{CG}$ , respectively).

Bearing in mind the importance of the time taken in executing this action in sports where there is opposition such as basketball or volleyball, the flight time of the last step of the approach run (T. Flight-last step) and the time the takeoff lasts (T. Take-off Phase) were recorded for both landing styles. Takeoff time has been divided into two periods according to greater or lesser radial distance (T.  $-RD_{CG}$  and T.  $+RD_{CG}$ , respectively). T.  $-RD_{CG}$  is timed from the instant when the first takeoff foot touches the ground ( $T_1$ ) to the instant in which the minimum radial distance is achieved ( $T_2$ ) and T.  $+RD_{CG}$ , from  $T_2$  to the instant in which the second foot loses contact with the ground ( $T_3$ ).

Finally, this study seeks to check the effect produced by the delay of the second foot on the vertical and horizontal impulse components that each foot exerts in the T. Take-off Phase. For that, the percentage of total impulse exercised by the trailing foot against the ground during takeoff was measured (Y Total Delay Foot (%) and X Total Delay Foot (%), for the vertical and horizontal component, respectively). Due to the delay of the trailing foot, it is expected that in the step-close style, the second foot exerts less impulse against the ground during the time that the radial distance is being reduced. According to Coutts' results (6) and the contributions of Andersen and Pandy (1) and Lees, Vanrenterghem and de Clercq (16) no differences should exist in the impulse components during the time the radial distance is increasing. To test this hypothesis the percentage of total impulse exercised by the trailing foot during the time the radial distance is reducing was measured (Y -RD<sub>CG</sub> Delay Foot and X-RD<sub>CG</sub> Delay Foot, for the vertical and horizontal components respectively) and that exercised during the time the radial distance is increasing (Y +RD<sub>CG</sub> Delay Foot and X +RD<sub>CG</sub> Delay Foot, for the vertical and horizontal components respectively)

### **Subjects**

Twenty-three male physical education undergraduates participated in the study. Ten of them were recruited among university league basketball players and the rest played university volleyball at national level (mean height:  $179 \pm 6.1$  cm.; mean mass:  $70.96 \pm 8.82$  kg). At the time of this study all of them were participating in competition. As a selection criterion, participants had to

have command of both styles, this being checked by analyzing time consistency over 15 consecutive jumps using both styles, recording takeoff times and the delay of the second foot with respect to the first (21). The study from which these data were collected received local ethics committee approval, and all participants gave their written consent

### **Procedures**

All the participants undertook a warm-up routine following the same protocol, doing general conditioning exercises to raise the body temperature as well as specific exercises for jumping. No stretching exercises were included because of their possible negative effect on the vertical jump (14, 19). After the warming-up period and applying the same protocol to all subjects, each participant jumped five times in line with the conditions described for the hop style. After a 10-minute break, they jumped five more times in the step-close style. In both situations, the participants were asked to try to achieve the greatest height of jump possible. This order was alternated for each subject. From the five jumps recorded for each takeoff style, one was selected for subsequent analysis taking into account the mean takeoff time. As the horizontal velocity of the approach run could influence takeoff, the participants were permitted to take three steps before starting the approach run, trying to reach the beginning of the takeoff phase at a horizontal velocity sufficient to enable them to give the maximum performance in the vertical jump.

To quantify force components, two force platforms were used (Dinascan – IBV – Instituto Biomecánico de Valencia, Valencia, Spain), one for each foot at 250 Hz. The jumps were filmed with a high-speed video camera (Redlake Motion Space 1000 S) with the same frequency as the platforms. For the synchronization of the two platforms and the video camera an electronic signal was used to activate the start (11). In each trial, the average horizontal and vertical force values from the two force platforms were calculated for a 0.08-second period after the subject lost contact with the platforms. These baseline values were then subtracted from all other force platform readings.

The velocity components and the positions adopted by the CG during the takeoff phase lasted were obtained by integrating the horizontal and vertical components of the force-time function obtained from *trapezoidal integration* of the horizontal and vertical components of the force-time function of the sum of the two platforms. The integration constants were drawn from images taken from the video camera. For a sequence of ten images, among which was the contact of the first foot with the force platform, manual digitalization of the 21 points that make up the 14-segment mechanical model of each participant was used (16). Quinting spline functions (24) were then applied to the coordinates of each point. To prevent the introduction of possible systematic errors the spline function was smoothed at zero value. For the calculation of the CG, position inertial parameters were used (segmental masses and c.m. locations) proposed by Zatsiorsky & Seluyanov (25) and adapted by Leva (17). The position of the CG at the instant the first foot made

contact on the force platform was considered the mean value of the CG positions of the two images among which contact was produced. For the computation of vertical and horizontal velocity components, the same procedure was used based on their respective derivatives corresponding to the times of the images among which contact occurred. For two-foot takeoffs, Vint and Hinrichs (22) locate the rotation axis at the mid point of the horizontal coordinates of the heels and the tips of both feet when fully planted on the ground. This would certainly be a good method when both feet are together on the ground at the same level but in our study it was observed that one foot was before other, so that using a fixed point as a rotation axis would cause an excessive error in the radial distance, especially at the beginning and at the end of the takeoff. Therefore, this research used as the rotation axis a point that shifts at constant velocity along the surface of the ground, from point A - determined by the mean horizontal coordinates of the center of both ankle joints and metatarsals of the first foot that lands, when this is firmly planted on the ground, and point B, which was determined by the mean horizontal coordinates of the mid-foot (metatarsus) of both feet when fully planted on the ground (Figure 2). The average velocity of the rotation axis displacement along the contact surface was calculated using the quotient between the distance between points A-B and takeoff time. Once radial distance was determined for each CG ( $RD_{CG}$ ) position, radial velocity ( $RV_{CG}$ ) was calculated by means of the derivative of the function with respect to time.

\*\*\*\* Figure 2\*\*\*\* near here

## **Statistical Analyses**

Data were statistically treated with the software Statgraphics 5.1 from Statistical Graphics Corporation (STCS, Inc. 2115 East Jefferson Street, Rockville, Maryland, 20852. USA). For each variable and experimental situation the mean and standard deviation were calculated, and to quantify the differences between the variables of both takeoff styles a repeated measures (multi-factorial ANOVA) was used.

In order to assess the reliability of tests, a simple ANOVA with repeated measures (five trials) was applied to both tests taking as the dependent variable the support time of the jump. There were no significant differences between trials, the intra-class correlation coefficients being 0.977 ( $p < 0.001$ ) for Step-close style jump and for Hop style jump the intra-class coefficients reach a value of 0.988 ( $p < 0.001$ )

## **RESULTS.**

Table 1 presents the mean, standard deviation and significance level of the flight times during the aerial phase of the last step of the approach run and the takeoff for both landing styles. The flight time of the last step of the approach run (T. Flight-last step) was significantly lower when the step-close style ( $p < 0.001$ ) was used while the takeoff time (T. Take-off Phase) was significantly lower with the hop style ( $p < 0.001$ ). No differences were found when the flight time of the last step (T. Flight-last step) and take off time (T. Take-off Phase) were added together. The time periods in which the takeoff

was divided show that the time during which the radial distance is reducing in the takeoff (T.  $-RD_{CG}$ ) is significantly lower with the hop style ( $p < 0.001$ ), while no statistically significant differences were found in the time when radial distance is increased in the takeoff (T.  $+RD_{CG}$ ). The data show that the time taken during the takeoff phase (T. Take-off Phase) is reduced in the hop style as a consequence of T.  $-RD_{CG}$ , while T.  $+RD_{CG}$  does not contribute to the reduction of takeoff time.

\*\*\*\*\*Table 1 near here\*\*\*\*\*

Table 2 presents the mean, standard deviation and significance level of CG values for Radial distance ( $RD_{CG}$ ), radial velocity ( $RV_{CG}$ ), height ( $Y_{CG}$ ), and vertical velocity ( $YV_{CG}$ ) of the CG for both landing styles. The data correspond to the start of the take-off phase when the first foot makes contact with the ground ( $T_1$ ), the instant of minimum radial distance ( $T_2$ ), and at the instant when the trailing foot loses contact with the ground ( $T_3$ ). Mean CG radial distance values ( $RD_{CG}$ ) only show statistically significant differences ( $p < 0.001$ ) at the instant the foot contacts the ground ( $T_1$ ), its mean value being greater with the step-close style. No statistically significant differences were found, either for the time in which minimum radial distance was reached ( $T_2$ ), or for the instant of the end of the takeoff phase ( $T_3$ ). On the other hand, CG radial velocity ( $RV_{CG}$ ) was greater in the hop style ( $p < 0.01$ ), while no significant differences were found in  $T_2$  and  $T_3$ .

The mean height of CG ( $Y_{CG}$ ) is similar in both styles for  $T_1$  and  $T_3$ . The  $Y_{CG}$

mean values at  $T_2$  are slightly higher when the takeoff is performed in the step-close style ( $p < 0.05$ ). The mean CG vertical velocity at  $T_1$  ( $YV_{CG}$ ) is higher when the takeoff is performed in the hop style ( $p < 0.001$ ), while no statistically significant differences are found in  $T_2$  and  $T_3$ . The absence of significant differences at the end of the takeoff ( $T_3$ ) indicates that the means of the height attained in the jump will be similar for both takeoff styles. Lastly, Table 2 sets out the mean, standard deviation and significance level of the mean CG horizontal velocity values ( $XV_{CG}$ ) for  $T_1$ ,  $T_2$  and  $T_3$ . For this variable, some differences are found between the means ( $p < 0.05$ ) only at the end of takeoff phase ( $T_3$ ), values being higher when the hop style is used. These data demonstrate that in the Step-close style takeoff, the reduction of horizontal velocity is greater than in the hop style.

\*\*\*\*Table 2 near here\*\*\*\*

Table 3 presents the mean, standard deviation and significance level of the horizontal and vertical components of impulse developed by the trailing foot in the takeoff for both landing styles, with the data expressed as a percentage of the impulse components developed by both feet. The data demonstrate that in the hop style, the horizontal and vertical impulse developed by the second foot during the takeoff phase (X Total Delay foot and Y Total Delay foot, respectively) is close to 50%, showing that both feet develop similar impulses. In step-close style, the impulse developed by the second, trailing foot is significantly reduced ( $p < 0.001$ ) for both components.

The analysis of the phases into which the takeoff has been divided indicates that in the hop style the mean values of the horizontal and vertical impulse component developed by the second foot during the time in which the radial distance is reducing ( $X -RD_{CG}$  Delay foot and  $Y -RD_{CG}$  Delay foot, respectively) are close to 50% ( $46.1 \pm 11.1$  and  $48.0 \pm 4.8$ , respectively). In the step-close style, the participation of the second, trailing, foot is very significantly reduced ( $p < 0.001$ ), behaving similarly to the way described for the time that the takeoff phase lasts (T. Take-off Phase). The horizontal and vertical impulse of the second foot during the time the radial distance is increasing ( $X +RD_{CG}$  Delay foot and  $Y +RD_{CG}$  Delay foot, respectively) is close to 50% for both landing styles. The results demonstrate that during the period in which the radial distance is increasing, the impulse is similar for both feet in both landing styles.

\*\*\*\*T able 3 near here\*\*\*\*

## DISCUSSION

In accordance with these results, the mean time of the takeoff phase is shorter when the hop style is used, this being in line with Coutts' data (6). This reduction may well be beneficial in certain sports with an opponent and when performance time is a relevant effectiveness factor, as argued by Gutiérrez et al. (10) for the volleyball spike, and by Rojas et al. (18) for basketball jumps shots. If the mean time values of the takeoff phase (Table 1) are considered, then only the period in which the radial distance of the CG ( $T. -RD_{CG}$ ) is

reducing contributes to the takeoff time being shorter in the hop style. This fact will be conditioned by the active participation of both feet during the greater part of the time in which the radial distance of the CG is reducing. In the step-close style, however, on average just one foot is used for approximately 56% of the time this period lasts.

The temporal benefits shown in the hop style are reduced when the flight time of the last step (T<sub>Flight-last step</sub>) is taken into account. The increase in flight time in the hop style is determined by the scissor movement of the legs that the player must make during the flight of the last step in order to arrive at takeoff with both feet simultaneously. This scissor movement of the legs during the last step causes the vertical velocity component ( $YV_{CG}$ ) at the start of the takeoff (T<sub>1</sub>) to be significantly greater in the hop style ( $p < 0.001$ ) as shown by the data in Table 2.

The results in Table 2 reveal no differences in CG vertical velocity at the end of the takeoff. Therefore, CG heights reached in both styles will be similar, thus confirming Coutts' results (6). He suggests there are no advantages in one style over the other with regard to vertical velocity at the end of the takeoff phase, although the step-close style would facilitate absorption of the impact force developed in the period during which the radial distance reduces or muscular stretching, which could be favorable to prevent injuries. Indeed, our findings confirm Coutts' contributions and suggestions (6). Thus, in the step-close style, the time of the period during which the radial distance of the CG is reducing increases by  $0.05 \pm 0.02$  s, and the mean vertical force is reduced by

-627.7  $\pm$  251.1 N. However, no differences were found for the horizontal component. These data show that greater absorption of the vertical impulse occurs and that the strain exerted by the muscles in eccentric activity is reduced.

The findings are confirmed on verifying that, in the step-close style, CG radial velocity ( $RV_{CG}$ ) at  $T_1$  (Table 3) is significantly lower ( $p < 0.01$ ), and mean acceleration in the period during which the radial distance is reducing drops by  $4.11 \pm 2.01 \text{ ms}^{-2}$ . The vertical component alone is accountable for such differences ( $p < 0.001$ ), no differences being found in the horizontal component, possibly because the participants were allowed to take three run-up strides before starting the approach run in both takeoff styles so that the final velocity at the end of the approach run was not too high.

The results indicate that, in the period during which the radial distance is reducing, stretching velocity, reflex tension, and certain muscle pre-tension mechanisms are lower in the step-close style and, consequently, the force applied in the period during which the radial distance increases is reduced, especially that exerted by the trailing leg, as suggested by Asmussen and Bonde-Peterson (3) when comparing jumps from different heights and with no countermovement. Yet, the lack of significance of vertical velocity ( $YV_{CG}$ ) at the instance of takeoff (Table 3) does not confirm this reduction in vertical force during the period during which the radial distance is reducing, this being in line with Coutts (6). However, he attributes this fact to the possible contribution of the horizontal force component. We failed to verify this in our

study and our data coincide with those of Andersen and Pandy (1). They argue that the use of the elastic energy built-in during the period of muscular stretching or lengthening leads to local or segmental effectiveness in the following phase of muscular shortening, even though its effect on the jump's overall effectiveness or total performance has not been confirmed. This is possibly caused by the influence of segment participation on the tension exerted by the muscles in the vertical jump (16).

The theoretical model proposed by Dapena & Chung (8) for the high jump, in comparison with the countermovement jump, explains its effectiveness on the possibility of finishing the approach run ( $T_1$ ) with the CG behind the takeoff foot and a CG vertical velocity close to 0. This allows the CG to move upwards as radial distance decreases, the minimum radial distance instant ( $T_2$ ) being reached with a relatively high positive vertical velocity ( $2.1 \pm 0.1$ , for jumps over 2 m). Similarly, Vint and Hinrichs (22) confirm this advantage when comparing jumps performed with one and two feet. The results of our study show CG radial distance ( $RD_{CG}$ ) at  $T_1$  to be significantly greater when using the step-close style ( $p < 0.001$ ), while CG height ( $Y_{CG}$ ) at the same instant is similar in both styles, confirming that the CG lags behind the first foot more when the step-close style is used, and that the vertical velocity ( $YV_{CG}$ ) will be lower at the beginning of the takeoff. These data indicate that there is a certain advantage in the step-close style in obtaining vertical velocity when the minimum radial distance is reached ( $T_2$ ). However, the results for this variable do not prove an advantage since no statistically significant differences were

found, despite the higher means of the step-close style.

The absence of a higher increase in vertical velocity at the instant of minimum radial distance ( $T_2$ ) when using the step-close style could be due to smaller muscle pre-tension caused by the lower radial velocity ( $RV_{CG}$ ) and vertical velocity ( $YV_{CG}$ ) at  $T_1$  ( $p < 0.01$  and  $p < 0.001$ , respectively). This fact may cause the mean vertical force to decrease in the period in which radial distance is increasing ( $-627.7 \pm 251.1$  N) in comparison with that developed in the hop style and especially due to the slight participation of the second supporting leg (Table 3). This explanation is supported by differences found in CG height values ( $Y_{CG}$ ) at the instant of minimum radial distance ( $p < 0.05$ ). Thus, the data show that in the step-close style the vertical downward displacement of the CG is increased by  $0.04 \pm 0.03$  m. over hop style. In their analysis of the two-foot jump using a takeoff similar to that of the step-close style, Vint and Hinrichs (22) obtain slightly higher values than those of this study for CG vertical velocity at the instant of minimum radial distance. This could be explained by the lower mean horizontal velocity obtained by our sample at the end of the approach run. By increasing run-up velocity and using the step-close style, the advantage of this style over hop style might be confirmed, but this would require further research.

#### **PRACTICAL APPLICATIONS.**

The height of the jump and the time taken in the execution of the technical skill considered as performance factors show no differences between the two

styles. Therefore, the choice of one or other style of jump should not be done with the aim of achieving the highest jump, but rather to jump differently in order to direct the forces and to adapt it better to the specific actions of the game. With the two-foot landing style (hop style) the time of executing the technical skill is reduced, as a consequence of the reduction of takeoff time, this benefit disappears when the flight time of the last step is taken into account.

The results indicate that a step-close style landing may be the most appropriate for takeoffs with an approach run in sports with opponents such as volleyball or basketball. This suggestion for orienting practice is in general concerned only with takeoffs with an approach run and based on the considerations below.

The benefits given by this alternative, step-close landing style are founded on the following aspects: a) There is a greater absorption of the vertical impulse, which may help to avoid injuries. With this situation, the lesser tension exercised by the musculature during the reduction of the radial distance of the CG, and particularly of the trailing foot, does not bring about the anticipated reduction of force exerted against the ground during the increase of the radial distance. b) At higher approach velocities the step-close style would have certain advantages over hop style, even though the vertical velocity of the CG before increase of the radial distance begins ( $T_2$ ) is similar for both styles. c) There is a greater reduction of the horizontal velocity component in the step-close style. This aspect could be positive in jumps made near the net in

volleyball or jump shots against an opponent in basketball, where excessive horizontal velocity at the end of the takeoff could result in fault in the game.

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## **FIGURE LEGENDS**

Figure1. Theoretical model of the vertical jump for hop style

Figure 2. Displacement of rotation axis (A-B) on the surface of the ground

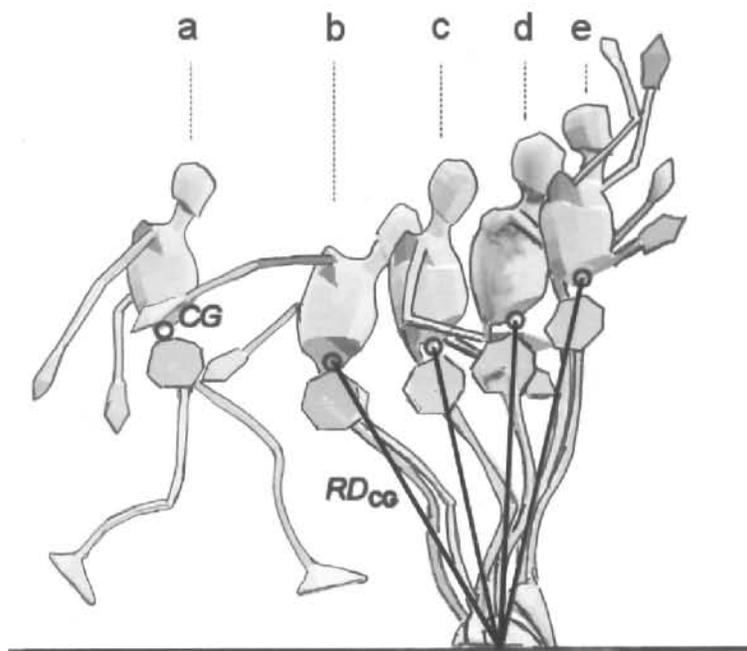


Figure1. Theoretical model of the vertical jump for hop style

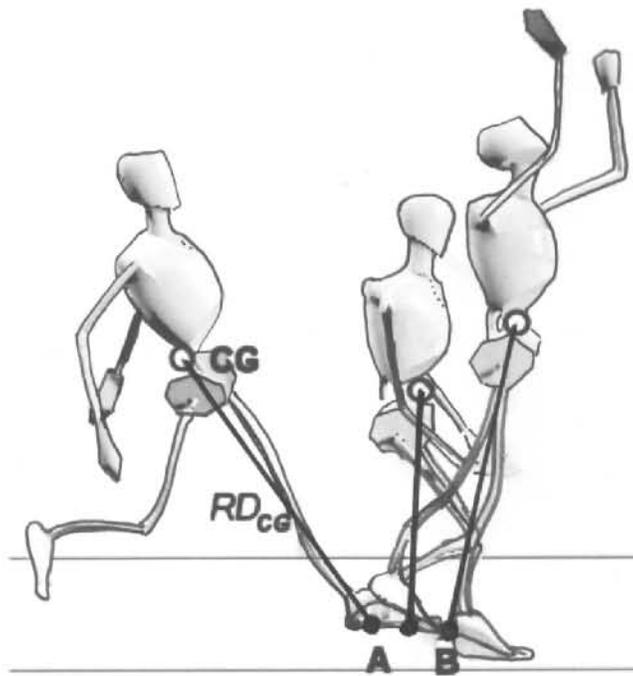


Figure 2. Displacement of rotation axis (A-B) on the surface of the ground.

Table 1. Means, standard deviation and significance level of flight time of the last step of the approach run (T. Flight-last step), (T. Take-off Phase) and their temporal components

	Hop style	Step-close	<i>P</i>
T. Flight-last step (s)	0.316 ± 0.051	0.221 ± 0.460	***
T. Take-off Phase (s)	0.303 ± 0.070	0.357 ± 0.049	***
T. -RD <sub>CG</sub> (s)	0.120 ± 0.031	0.170 ± 0.029	***
T. +RD <sub>CG</sub> (s)	0.182 ± 0.041	0.187 ± 0.027	

(Results are mean ± SD of twenty-three trials)      \*\*\* *p* < 0.001; \*\* *p* < 0.01; \* *p* < 0.05

Note. T. -RD<sub>CG</sub> corresponds to the time during which radial distance is reducing and T. +RD<sub>CG</sub> to the time during which radial distance is increasing

Table 2. Means, standard deviation and significance level for distance and CG radial and vertical velocities for times T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>,

	Final heel strike		<i>p</i>	Minimum radial distance		<i>P</i>	Takeoff		<i>p</i>
	T <sub>1</sub>			T <sub>2</sub>			T <sub>3</sub>		
	Hop style	Step-close		Hop style	Step-close		Hop style	Step-close	
RD <sub>CG</sub> (m)	0.95 ± 0.05	1.02 ± 0.05	***	0.77 ± 0.06	0.76 ± 0.06		1.19 ± 0.06	1.18 ± 0.05	
RV <sub>CG</sub> (ms <sup>-1</sup> )	-2.63 ± 0.28	-2.44 ± 0.23	**	0.00 ± 0.00	0.00 ± 0.00		3.51 ± 0.29	3.45 ± 0.28	
Y <sub>CG</sub> (m)	0.90 ± 0.05	0.91 ± 0.05		0.77 ± 0.05	0.75 ± 0.06	*	1.18 ± 0.06	1.17 ± 0.05	
YV <sub>CG</sub> (ms <sup>-1</sup> )	-2.08 ± 0.25	-1.50 ± 0.22	***	0.17 ± 0.13	0.22 ± 0.12		3.40 ± 0.29	3.38 ± 0.29	
XV <sub>CG</sub>	2.91 ± 0.42	3.11 ± 0.32		2.35 ± 0.40	2.40 ± 0.30		1.73 ± 0.38	1.53 ± 0.41	*

(Results are mean ± SD of twenty-three trials)      \*\*\* *p* < 0.001; \*\* *p* < 0.01; \* *p* < 0.05

Note. RD<sub>CG</sub> = radial distance, RV<sub>CG</sub> = radial velocity, Y<sub>CG</sub> = height of CG, YV<sub>CG</sub> = vertical velocity and XV<sub>CG</sub> = horizontal velocity).

Table 3. Means, standard deviation and significance level of the horizontal and vertical components of impulse developed by the trailing foot for both landing styles.

	Hop style	Step-close	<i>p</i>
X Total Delay Foot (%)	50.4 ± 11.1	39.2 ± 11.5	***
Y Total Delay Foot (%)	49.6 ± 2.7	40.2 ± 2.8	***
X -RD <sub>CG</sub> Delay Foot (%)	46.1 ± 11.1	18.0 ± 7.7	***
Y -RD <sub>CG</sub> Delay Foot (%)	48.0 ± 4.8	24.4 ± 5.1	***
X +RD <sub>CG</sub> Delay Foot (%)	50.9 ± 13.2	54.2 ± 12.1	
Y +RD <sub>CG</sub> Delay Foot (%)	50.5 ± 2.1	50.4 ± 2.9	

(Results are mean ± SD of twenty-three trials)      \*\*\* *p* < 0.001; \*\* *p* < 0.01; \* *p* < 0.05

Note. The data are given in percentages of the impulse components developed by both feet.