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CONTRIBUTION OF THE RUN-UP AND ARMS ACTION IN THE VERTICAL-JUMP TAKEOFF

CONTRIBUCIÓN DE LA CARRERA Y LA ACCIÓN DE BRAZOS EN LA BATIDA DEL SALTO VERTICAL

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ABSTRACT

The main objective of this study is to analyse the effect that the segmental contribution and the previous run-up exert on the biomechanics of the double-leg vertical jump. 16 athletes took part in this study with experience in the vertical jump. A force platform synchronized to a high-speed camera were used to gather kinematics and kinetics data. Two types of jumps were made: the drop jump (DJ), where the subjects drop from a height, and the hop-style jump (HSJ), where the subjects run before jumping. The HSJ resulted in a 14% increase in the height reached by the centre of mass (CM). The height of the CM in the takeoff contributes 24%, whereas the vertical velocity of the CM contributes 76% to the height of the jump. The HSJ allows a positive vertical velocity of the CM at the beginning of the impulse of acceleration.

KEYWORDS: Biomechanics, Vertical Jump, Takeoff, Force.

RESUMEN

Se ha evaluado el efecto de la contribución segmentaria y la carrera previa, sobre la biomecánica del salto vertical con doble apoyo. Han participado 16 deportistas con experiencia en el salto vertical. Se ha utilizado una plataforma de fuerza, sincronizada temporalmente a una cámara de alta velocidad. Se realizaron dos tipos de saltos: Drop Jump (DJ), donde los sujetos se dejaban caer desde una altura y Hop Style Jump (HSJ), donde los sujetos partían de una carrera previa. Cuando los saltos se realizan con el estilo HSJ, existe un incremento del 14% en la altura alcanzada por el centro de masas (CM). La altura del CM en el despegue contribuye un 24%, mientras que la velocidad vertical del CM contribuye un 76% a la altura de salto. El modelo de salto con carrera previa permite que la velocidad vertical del CM sea positiva antes de iniciarse el impulso de aceleración.

PALABRAS CLAVE: Biomecánica, Salto vertical, Batidas, Fuerza.

INTRODUCTION

One of the most common jumps in basketball or volleyball is made using both legs and preceded by a run (Voelzke, Stutzig, Thorhauer and Granacher, 2012). The efficiency of these double-leg jumps is related to the generation of vertical force and swift execution time (Hay, 1973, Kirby, Mc Bride, Haines, and Dayne, 2011). In sports, the greater the vertical force, the higher the jump, and the quicker execution, the more difficult it is for the opponent to block the action. Therefore, this type of activity requires the development of qualities that enable great vertical force to be generated in a brief time, this being known as “ballistic” or “explosive” movement. To evaluate such activities, several protocols are used, although the most widespread may be the Bosco test and, more specifically, the drop jump (DJ) (Bobbert, 1990; Villa and García-López, 2003). This test consists of dropping from a standard height, making contact with the floor, cushioning the landing, and without pausing before making the maximum vertical thrust. As in all the protocols used in the battery of Bosco tests, the jumps are made with restricted segmental movements (hands on the iliac crests and trunk erect) with the aim of focusing the action on the extensor muscles of the lower limbs.

Although the segmental restriction proposed in the DJ Bosco protocol enables an evaluation of the ballistic movement of focused stretching-contracting of the extensor musculature of the hip, knee, and ankle, prior studies question the ecological validity of this test. For example, Feltner, Bishop, and Perez (2004) have demonstrated that the action of the arms lengthens the time of applying vertical force, without altering the mean force during the impulse of acceleration in jumps with countermovement, in addition to altering the momentum exerted by the extensor musculature of the lower limbs. In this sense, Lees, Vanrenterghem, and Clercq (2004) have suggested changes in muscle participation when the vertical jump is made with the action of the arms. Also, Miura, Yamamoto, Tamaki and Zushi (2010) have demonstrated that, due to the different intensities reached in the stretching-contracting cycle for each type of jump, the height reached in single-leg jumps and prior run-up do not correlate with the height reached in double-leg jumps combined with countermovement (CMJ). The above considerations suggest that the tests that include segmental restrictions or modifications in the model of jumping are far from the principle of specificity.

The DJ Bosco protocol does not include the effect of the run-up, either, an aspect that has been studied by different authors (Dapena, 1980; Saunders, 1993; Dapena and Chung, 1988; Gutiérrez-Dávila, Campos and Navarro, 2009). Saunders (1993) observed that the jump height increases when the approach velocity reaches between 50% and 60% of the peak velocity but decreases when the speed is excessive. Sattler, Sekulic, Hadzic, Uljevic, and Dervisevic (2012) recently reported that the run-up boosts the jump height in high-level volleyball players by an average of 42% with respect to vertical jumps with countermovement. Dapena and Chung (1988) posit that the theoretic model used for the jumps with a run-up should be different from the model used for the vertical jumps with countermovement. This change in theoretic model, together with the increase in the segments comprising the kinetic chain could influence the benefits of the stretching-contracting cycle in vertical jumps when the Bosco protocol is used. Along these lines, findings by Anderson and Pandy (1993) as well as the results of Gutiérrez-Dávila et al. (2009) for vertical jumps with a run-up and arm action do not confirm that energy accumulated during muscle stretching in the stopping phase affects the overall efficiency or the height reached by the centre of mass (CM).

In this context, prior data lead us to question the ecological validity of the tests that include a segmental restriction in their protocol in order to evaluate jumping capacity, as in the DJ Bosco test. Thus, the present work has two aims: a) to evaluate the segmental contribution and run-up with respect to the factors of efficiency that determine the double-leg vertical jump, and b) to establish the possible relation between the data recorded in the Bosco test for the drop jump (DJ) and those for the vertical jump with a run-up and arm action, i.e. the hop-style jump (HSJ).

METHOD

A total of 16 male students in the Department of Physical Education and Sports of the University of Granada (Spain) participated (height= 1,80±0,06 m; mass=

73,2±7,6 Kg, body-mass IMC= 22,41±1,96 Kg/m^2). The selection criterion was regular participation in sports involving the vertical jump as a basic component. All participants were informed about the study and their consent was obtained following the guidelines of the Ethics Commission of the University of Granada.

A Dinascan/IBV force platform of 0,6 x 0,37 m, operating at 500 Hz, was used associated with a reference system in which the X axis corresponded to the direction of the run-up, the Z axis was the vertical, and the Y was perpendicular to the other two. The record of the force platform was synchronized to a Casio EX-FH20 video camera, which at 2100 Hz recorded the sagittal plane of the jumps made on the platform. The synchronization consisted of an electronic system that lit a led on starting the force recording.

After a normalized warm-up, using the same protocol for all subjects, consisting of 6 min of continuous progressive running, 2 min of stretching, and 2 min of several vertical jumps on the platform, they received instructions to perform the drop jump (DJ) and hop-style jump (HSJ).

For the DJ, the subjects started from a height of 0,17 m in an upright position with the hands on the iliac crests. From this position, they had to drop onto the force platform, cushion the fall and, without pausing, jump vertically as high as possible while maintaining the trunk erect and the hands on the hips. For the HSJ, the subjects had to make the highest possible jump beginning with a run-up on both legs before making contact with the force platform. The only restriction in the protocol was for both feet to reach the platform simultaneously. As in the methodology of Gutiérrez-Dávila et al. (2009), the lag of the second support foot being less than 0,009 s was taken as a criterion, discarding all the jump results for which the lag was greater. The height of 0,17 m for the DJ was chosen to achieve a vertical velocity of the CM similar to that recorded by the same authors for the HSJ. A session of 5 valid jumps was held for each modality analysing the jump for which the flight time was the median of the five jumps. The order of the jump styles for each session was changed for each subject.

Following the methodology of Gutiérrez-Dávila, Dapena, and Campos (2006), for each test the possible systematic error from the platform was determined by 20 successive records after the takeoff. The records related to the rectangular components of velocity and height of the CM at takeoff were determined from the respective components of reaction force from the force platform. For this, after subtracting the possible systematic error and weight of the subject from each force component, the vertical-acceleration components were calculated from the respective components of force and mass of the jumper.

The successive horizontal and vertical components of velocity of the CM, during the time that the jump lasted ($\boldsymbol{v}_{CM(X)}$, $\boldsymbol{v}_{CM(Z)}$, respectively), was determined by integration of the respective components for the functions of acceleration time. Finally, the successive horizontal and vertical positions of CM (X_{CM}, Y_{CM}, respectively), were determined by integration of the respective velocity-time functions. For the integration process, the trapezoidal method was used with a time increase of 0,002 s. The integration constants were calculated from the manual digitalization of the video images. Thus, to determine the CM at the instant of making contact with the platform (arrival), a mechanical model of 14 segments was used, whereby the segmental masses and the respective locations of their centres of mass were calculated from the values proposed by Zatsiorsky and Seluyanov (1983) and adapted by Leva (1996).

The instants of arrival and takeoff from the platform ($t_{(ARRIVAL)}$ y $t_{(TAKEOFF)}$, respectively), were determined from the vertical component of force, estimated at 0,001 s (half of the recorded interval), before the force reached a value greater or less than 2 N, for arrival and takeoff, respectively. The position and the components of the velocity of the CM in the instants of arrival and takeoff were determined from the vertical-force component, this being estimated at 0,001 s (half of the record interval), before the force takes a value higher or lower than 2 N, for arrival and takeoff, respectively. The position and the components of the CM velocity at arrival and takeoff were determined from the mean values in their respective time intervals. For the analysis of the CM movements, the methodology of Dapena and Chung (1988) and Vint and Hinrichs (1996) was adopted for the double-leg jumps. Thus, the distance and radial velocity of the CM (RD_{CM}, RV_{CM}, respectively) from a position vector of between the position of the CM of the subject and the rotation axis situated at the mid-point of the horizontal coordinates of the heels and the tips of the feet, when the feet are fully planted on the platform.

The stopping-impulse phase ($t_{(STOPPING)}$) was considered the period between $t_{(ARRIVAL)}$ and the instant at which the radial distance reaches its minimum ($RD_{CM\ (MINIMUM)}$). The acceleration-impulse phase ($t_{(ACCELERATION)}$), was defined as the period between $RD_{CM\ (MINIMUM)}$ and ($t_{(TAKEOFF)}$). Figure 1 presents the RD_{CM} in the three positions that define the phases in the two jumping models analysed.

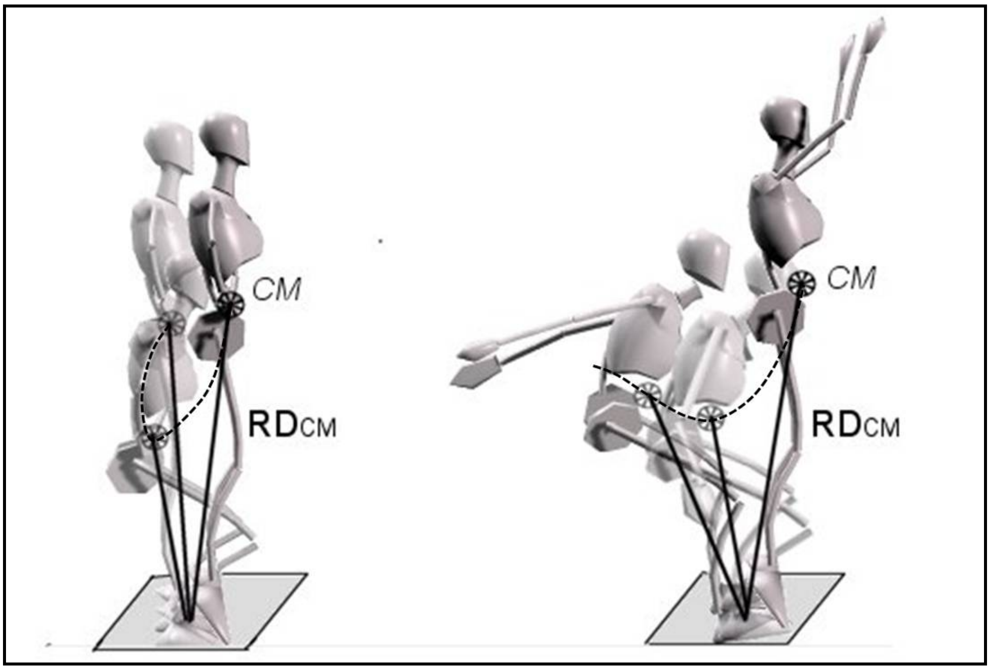

Figure 1. Graphic representation of the two jumping models as well as the radial distance in the initial position, minimum distance, and takeoff.

For the statistical treatment of the data, the software Statgraphics 5.1 (Statistical Graphics Corporation) was used, applying descriptive statistics and a repeated-measures analysis of variance (multifactorial ANOVA) for the two experimental situations (DJ and HSJ), as well as a simple regression analysis, using as dependent variables the height and velocity of the CM in the takeoff for the jumps made with the run-up and arm action ($H_{CM\ (TAKEOFF)}$ (HSJ) and $v_{CM(Z)\ (TAKEOFF)}$ (HSJ), respectively).

RESULTS

Table 1 presents the data for the central trend of the variables related to the segmental contribution in the vertical jump, as well as its inferential statistics, for the jumps made with the Bosco protocol (DJ) and those made with the run-up and arm action (HSJ). The results indicated that the CM height at the instant of takeoff ($H_{CM\ (TAKEOFF)}$) was significantly greater (p<0,01) when the jump was made with a run-up and arm action (1,16 vs. 1,21 m for DJ and HSJ, respectively).

The result was similar for vertical velocity at the instant of takeoff ($v_{CM(Z)\ (TAKEOFF)}$), although in this case the significance increased to p<0,001 (2,51 vs. 3,08 ms^{-1} for DJ and HSJ, respectively). The velocity of the CM at arrival ($v_{CM(Z)\ (ARRIVAL)}$) proved significantly greater when DJ was used (p<0,001). The radial velocity of CM at the instant of arrival ($v_{CM(RD)\ (ARRIVAL)}$) was significantly greater when the jump was made with the run-up and arm action (HSJ), due to the horizontal velocity of the CM due to the run-up. No differences were found between the means of the minimum radial distance ($RD_{CM\ (MINIMUM)}$), although clear differences arose (p<0,001) between the means of vertical velocity of the CM at that instant (0,00 vs. 0,23 ms^{-1} for DJ $v_{CM(Z)\ (MINIMUM\text{-}RD)}$ and HSJ $v_{CM(Z)\ (MINIMUM\text{-}RD)}$, respectively).

The temporal analysis presented in Table 1 indicates that the time used to stop the previous movement ($t_{(STOPPING)}$) was significantly greater (p<0,01) when the DJ protocol was used, i.e. when the movement of CM was vertical (0,238 vs. 0,167 s for DJ and HSJ, respectively), whereas no significant statistical differences were found for the time used in the vertical acceleration phase ($t_{(ACCELERATION)}$).

Table 1 also presents the force components of the mean net reaction during the periods of stopping and acceleration. When the run-up and arm action were used (HSJ), the horizontal component of mean force ($Fm_{(X)\ (STOPPING)}$ and $Fm_{(X)\ (ACCELERATION)}$) were significantly greater for the two phases analysed (p<0,001). With respect to the mean force of the vertical component during the stopping phase ($Fm_{(Z)\ (STOPPING)}$), certain differences arose in the means (p<0,05), while these differences increased by up to p<0,01 for the acceleration phase ($Fm_{(Z)\ (ACCELERATION)}$). It bears highlighting the excessive values of the standard deviations, with respect to the means, in the increases of the vertical force for the two jump styles (DJ and HSJ).

Table 1. Descriptive and inferential statistics of the variables related to the segmental contribution in the height of the vertical jump with countermovement.

Variables	DJ	HSJ	*DIF (HSJ-DJ)*	*F*
CM height at takeoff, $H_{CM(TAKEOFF)}$ (m)	1,16 ± 0,06	1,21 ± 0,07	0,05 ± 0,05	*14,13***
CM vertical velocity at takeoff, $v_{CM(Z)\ (TAKEOFF)}$ (ms^{-1})	2,51 ± 0,17	3,08 ± 0,29	0,59 ± 0,18	*139,5****
CM vertical velocity at arrival, $v_{CM(Z)\ (ARRIVAL)}$ (ms^{-1})	-2,00 ± 0,15	-1,57 ± 0,32	0,43 ± 0,34	*26,35****
CM radial velocity at arrival, $v_{CM\ (RD)\ (ARRIVAL)}$ (ms^{-1})	-2,07 ± 0,13	-2,81 ± 0,30	-0,74 ± 0,29	*99,29****
Minimum radial distance, $RD_{CM\ (MINIMUM)}$ (m)	0,77 ± 0,09	0,79 ± 0,10	0,00 ± 0,07	*0,71*
CM vertical velocity minimum radial distance, $v_{CM(Z)\ (MINIMUM\text{-}RD)}$ (ms)	0,00 ± 0,01	0,23 ± 0,07	0,24 ± 0,08	*129,38****
Stopping time, $t_{(STOPPING)}$ (s)	0,238 ± 0,072	0,167 ± 0,058	-0,055 ± 0,061	*12,56***
Acceleration time, $t_{(ACCELERATION)}$ (s)	0,227 ± 0,049	0,201 ± 0,040	-0,009 ± 0,049	3,17
Mean horizontal force of the stopping phase, $Fm_{(X)(STOPPING)}$ (N)	-89,2 ± 23,8	-386,8 ± 133,9	-277,9 ± 122,3	65,81***
Mean vertical force of the stopping phase, $Fm_{(Z)\ (STOPPING)}$ (N)	664,1 ± 251,9	882,1 ± 318,9	179,4 ± 269,9	5,98*
Mean horizontal force of the acceleration phase, $Fm_{(X)\ (ACCELERATION)}$ (N)	-84,4 ± 40,1	-399,3 ± 133,7	-306,3 ± 136,7	69,51***
Mean vertical force of the acceleration phase, $Fm_{(Z)\ (ACCELERATION)}$ (N)	861,6 ± 238,3	1019,1 ± 223,8	117,0 ± 208,4	9,15**

**** p < 0,001; ** p < 0,01; * p< 0,05*

Finally, in an effort to relate the jump height to arm action and the run-up (HSJ), and to the DJ jumping protocol (Bosco test), Figure 2 shows a positive correlation (r=0,69; p<0,01) between vertical height of the CM at the instant of takeoff for HSJ ($H_{CM\ (TAKEOFF)}$(HSJ)), and for the DJ protocol ($H_{CM\ (TAKEOFF)}$(CMJ)). When these same data are expressed in percentages of the height of the subjects, the correlation found cannot be considered statistically significant (r=0,25; p=0,35, see Figure 3). The correlation expressed in Figure 4 for the velocity of the CM in the takeoff ($v_{CM(Z)\ (TAKEOFF)}$) indicates a positive correlation between the vertical velocity of CM, when the jump is made with a run-up and arm action, HSJ ($v_{CM(Z)\ (TAKEOFF)}$), and the vertical velocity reached when the jump is made using the DJ protocol, ($v_{CM(Z)\ (TAKEOFF)}$ (r=0,72; $ES_{(est.)}$=0,18; p<0,01), with the regression equation where $v_{CM(z)\ (TAKEOFF)}$ (HSJ) = 1,1× $v_{CM(z)\ (TAKEOFF)}$ (DJ) + 0,34.

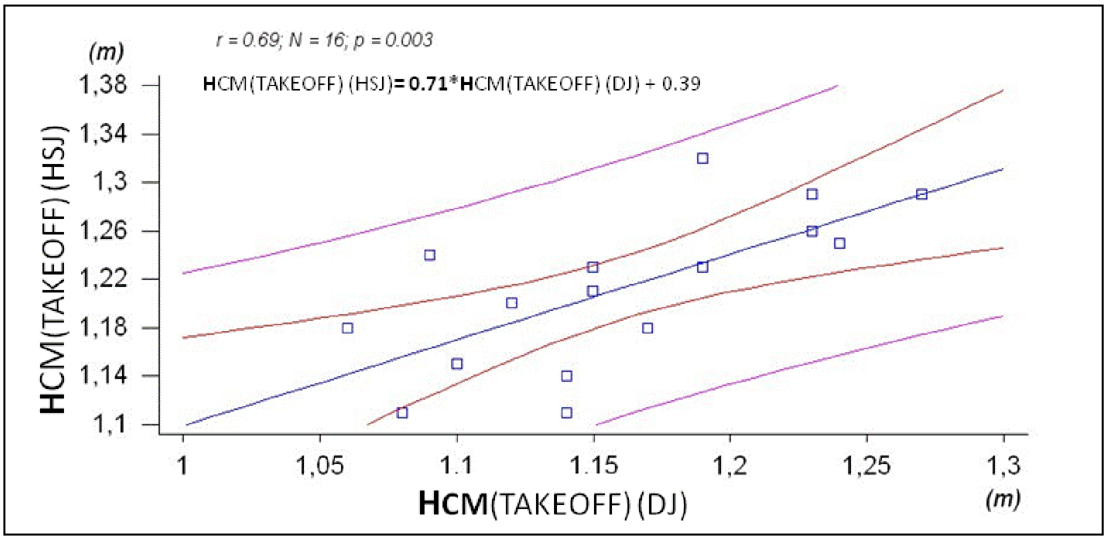

Figure 2. Relation between vertical height of the CM at the instant of takeoff for the jumps made with a run-up and arm action, HSJ ($H_{CM\ (TAKEOFF)}$) and for the Bosco protocol, DJ ($H_{CM\ (TAKEOFF)}$).

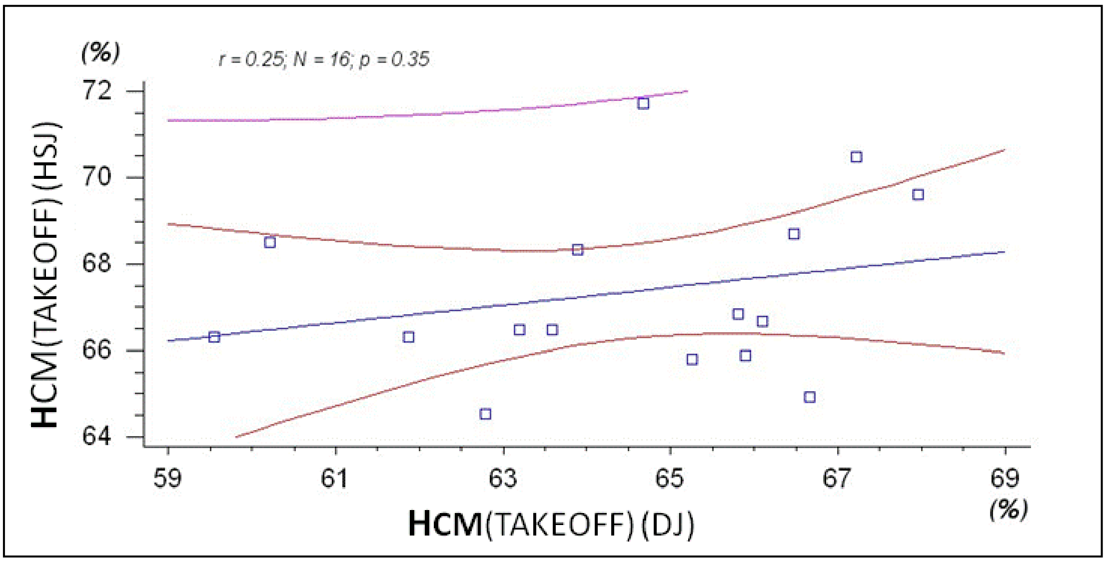

Figure 3. Relation between vertical height of the CM at the instant of takeoff for the jumps made with a run-up and arm action, HSJ ($H_{CM\ (TAKEOFF)}$) and using the Bosco protocol, DJ ($H_{CM(TAKEOFF)}$), expressed as a percentage of height.

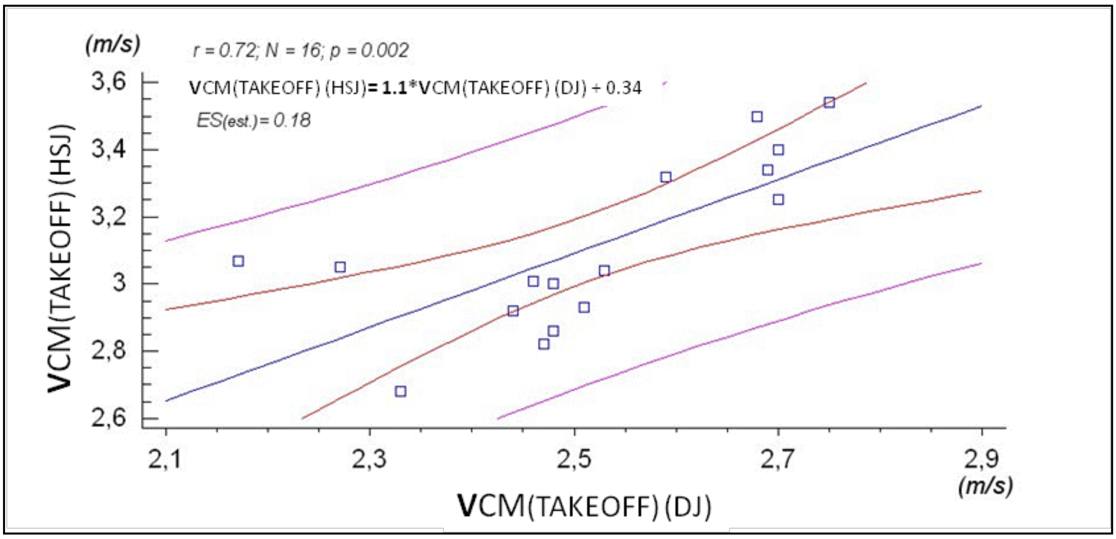

Figure 4. Relation between vertical velocity of the CM at the instant of takeoff for the jumps made with a run-up and arm action, HSJ ($\mathbf{v}_{\text{CM (TAKEOFF)}}$) and using the Bosco protocol, DJ ($\mathbf{v}_{\text{CM (TAKEOFF)}}$).

DISCUSSION

In consideration of the kinematic equations of freefall movement, the vertical components of velocity, at the instant of takeoff, represent a mean vertical displacement of the CM of 0,32 m for DJ and 0,48 m for HSJ, coinciding with the results of Sattler et al. (2012). This difference of 0,16 m, plus that produced by the height of the CM at the instant of takeoff (0,05 m, see Table 1), caused the jump height to be a mean of 0,21 m higher when the jump was made with a run-up and arm action (HSJ). Thus, for the average subject of this sample, the total height reached by the CM would be 1,69 m for the HSJ jump and 1,48 m for DJ, the former representing a 14% increase. According to the experimental data, the vertical velocity of the CM in the takeoff ($v_{\text{CM(Z) (TAKEOFF)}}$) contributes 76% to this increase, while the height of the CM in the takeoff ($H_{\text{CM (TAKEOFF)}}$) contributes 24%. Analysing the mean contribution of $v_{\text{CM(Z) (TAKEOFF)}}$ in the jump (an increase of 0,59±0,18 $\text{ms}^{-1}$for HSJ; see Table 1), we cannot state that this increase was due exclusively to greater vertical impulse during the acceleration phase. The data show that when the minimum radial distance was reached, i.e. before beginning the vertical acceleration phase, the vertical velocity of the CM was significantly greater ($p<0,000$) for HSJ, with a mean increase of 0,24 ms^{-1}; only the rest (0,35 ms^{-1}) was due to the increase in vertical impulse during the acceleration phase. These data coincide with those reported by Gutiérrez-Dávila et al. (2009) for jumps with a run-up and arm action.

Our results confirm the theories proposed by Dapena and Chung (1988) and Vint and Hinrichs (1996), who demonstrated that a jump model in which the CM lags with respect to the support leg at the end of the run-up and has a vertical velocity is close to zero, enables the CM to be shifted upwards while the radial distance is reduced, arriving at the beginning of the acceleration phase with a positive vertical velocity. This is not possible when the Bosco test is used, where the vertical velocity of the CM is always close to zero before beginning the acceleration phase. The jump models with a run-up are more effective the greater the horizontal velocity of the run-up (up to 60% of the maximum velocity) and the vertical velocity of the CM at arrival to the platform is closer to zero (Dapena and Chung, 1988; Saunders, 1993). According to the above, as a consequence of the protocol proposed for the HSJ jumps, the horizontal velocity of the run-up was relatively low (2,08±0,28 ms^{-1}) and the vertical velocity at arrival relatively high (1,57 ± 0,32 ms^{-1}), suggesting that a freer protocol for the HSJ jumps (Sattler et al., 2012) could raise the jump height even more, compared to those using the DJ Bosco protocol.

Given that, in the DJ jumps, the vertical velocity at the instant of the arrival was a mean of 0,43 ms^{-1} greater than for HSJ jumps, the impulse of vertical stopping would also have to be greater for DJ. In fact, this result was found due to the increased time and not to the vertical force, which is even greater for the HSJ jumps. On the contrary, the horizontal velocity that is reached in the arrival due to the run-up makes the horizontal stopping impulse also greater for the HSJ jumps, although in this case the greater impulse was due to the mean force applied during this phase. As indicated above, the vertical impulse during the acceleration phase also contributes to the faster vertical velocity in takeoff, which is achieved by the increased force, while the time is maintained with similar mean values in the two styles of jumps. Thus, the HSJ model of jumping would facilitate the reflex tension and other mechanisms of muscular pre-tension during the stopping phase, permitting an increase in vertical force during the acceleration phase (Cavagna, Dusman, and Margaria, 1968; Komi and Bosco, 1978).

The correlations explained in Figures 2 and 3 show that the relation between the CM height and the takeoff for DJ and HSJ jumps is due to the height of the subjects. When these variables are expressed as a percentage of subject height, we can regard them as independent of each other. However, the data show that when the vertical velocity of the CM increases under the conditions proposed in the Bosco test (DJ), it also increases when the jump is made with a run-up and arm action (HSJ). The high value of the correlation coefficient (r=0,72) and a relatively low standard error of estimation ($ES_{(est.)}$=0,18) permits us to predict with adequate confidence the dependence between the two variables. This relation can be explained by the large contribution of the lower members in the vertical movement of the CM (Luhtanen and Komi, 1978; Tidow, 1990; Tricoli, Lamas, Carnevale and Ugrinowitsch, 2005). However, we need to exercise caution in predicting the height reached by the CM based on the Bosco test, since it is necessary to consider that there are two different jump models, where the one used in the HSJ jump achieves a positive vertical velocity before beginning the vertical acceleration impulse and that the muscular contribution changes, becoming more intense, taking us away from the specificity of the movement.

CONCLUSIONS

Vertical jumps made with a run-up and arm action (HSJ) registered a 14% increase in the mean height reached by the CM with respect to the jumps made using the Bosco test protocol (DJ). The main increase resulted from the vertical velocity of the CM at the end of the jump ($v_{CM(Z)\ (TAKEOFF)}$), its contribution being 24%. From a mathematical perspective, this increase was determined by two factors: a) having attained a positive vertical velocity of the CM before starting the acceleration impulse ($v_{CM(z)\ (MINIMUM\text{-}RD)}$) as a result of the run-up and b) having produced greater vertical impulse during the acceleration phase, as a consequence of having increased the mean vertical force ($Fm_{(Z)\ (ACCELERATION)}$). The following expression summarizes this concept:

$$v_{CM\,(Z)(TAKEOFF)} = (v_{CM\,(Z)\,(MINIMUM-RD)}) + (\frac{\int F_{(Z)(ACCELERATION)}\,dt_{(ACCELERATION)}}{m})$$

With respect to the second aim proposed in this work, it was found that, when the vertical velocity of the CM increased in the Bosco test (DJ), it also increased when the jump was made with a run-up and arm action (HSJ). Although the statistics permit us to predict with sufficient confidence the dependence between the two variables, we should be cautious in using the Bosco test to predict the height reached by the CM, since, in addition to not considering the increased initial height, the two models involved have different mechanical explanations and the changes found in the vertical force suggest a different muscular contribution in the two jumping styles.

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